Gainful Utilization of Limestone (Kota stone) Waste as Pavement Material.

Ph.D. Thesis

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Gainful Utilization of Limestone (Kota stone) Waste as Pavement Material.

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by

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January 2019

DECLARATION

I, Pradeep Kumar Gautam, declare that this thesis titled, "Gainful Utilization of Limestone (Kota stone) waste as pavement material." and the work presented in it, are my own. I confirm that:

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- Where any part of this thesis has previously been submitted for a degree or any other qualification at this university or any other institution, this has been clearly stated.
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CERTIFICATE

This is to certify that the thesis report entitled "**Gainful Utilization of Limestone (Kota Stone) Waste as Pavement Material"** which is being submitted by **Pradeep Kumar Gautam, ID: 2014RCE9037,** for partial fulfillment of the degree of **Doctor of Philosophy** in Civil Engineering to the Malaviya National Institute of Technology Jaipur, has been carried out by him under my supervision and guidance. I consider it worthy of consideration for the award of the degree of Doctor of Philosophy of the institute.

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Pradeep Kumar Gautam.

ABSTRACT

Sustainability in pavement construction has become an emerging topic around the globe. This is because construction of roads requiresvast quantity of quality aggregates which are obtained via mining. This is a highly unsustainable process as extraction of these aggregates include activities like drilling, blasting, crushing and transportation, which causes air, water, and noise pollution. Also, unplanned disposal of mining waste leads to natural imbalance most prominent among which are migration of species, destruction of natural habitat of birds and animals, loss of land fertility, genesis of various respiratory diseases. Scientific interest in finding potential methods by which construction of roads and highways can be made environment-friendly whilst maintaining their structural integrity and reducing construction cost have increased in last decade. Studies have been conducted where use of locally produced quarry waste has been used successfully as construction and building material. These studies establish the fact that the majority of quarry waste generated has potential to be used as pavement material.

In the recent past, Kota Stone mining Waste has emerged as a severe threat to the biodiversity of Kota and Jhalawar district of Rajasthan. The genesis of this waste is in the form of boulders, stone chips and slurry, produced during activities like in situ mining, cutting and polishing. Piles of Kota stone waste stretching kilometres is a common site in the area of its origin. This has created a nuisance for residents, mine owners, workers, and nearby flora and fauna. Respiratory diseases like silicosis are common among residents mining sites. The unmanaged, unplanned dumping of slurry waste has polluted the localecosystem by intermixing with nearby soil and degrading the fertility of the agricultural land. To control the situation, government agencies have imposed tight environmental control policies over opening of new quarries and imposed fines on mine owners; thishave little to no effect on the situationas no solution has been suggested for already accumulatedmassivewaste in the area. The scarcity and restriction of dumping land have resulted in increasing hauling distance, adding to transportation cost and exacerbate pollution. This situation demands concrete steps to utilize the accumulated waste.

Previous studies available suggest mining and processing waste of stones such as marble, granitehavepotential to be used as construction and maintenance material.

In the present study, an attempt has been made to utilize the waste generated in various stageslike mining, cutting, and polishing in different layer of flexible pavement. For the present study, Kota stone slurry (KSS) and Kota stone aggregate (KSA) were evaluated on physical and chemical properties. Ten soil samples were evaluated prepared by replacing black cotton soil (BCS) with KSS between 2.5- 20%. KSA was evaluated as granular sub-base and bituminous course material. Six Granular Sub-base (GSB) mixes and fifteen hot mixes were examined. Kota stone aggregate were evaluated as non-bituminous (GSB) and bituminous material (Dense bituminous macadam, Bituminous concrete and Open-graded friction course) on the basis of mechanical and durability properties of mixes such as Marshall quotient, indirect tensile strength test, tensile strength ratio, resilient modulus , dynamic creep, Cantabro, aged Cantabro, permeability and drain down test. Kota stone slurry was found suitable as soil stabilizer when replaced in black cotton soil between 17.5-19%. Study also finds suitability of KSA (up to 25-50%) in hot mix asphalt.

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ABBREVIATIONS

BC	:	Bituminous Concrete
BCS	:	Black Cotton Soil
CBR	:	California Bearing Ratio
CA	:	Coarse Aggregates
CB	:	Clay Bricks
CS	:	Conventional Stones
C&D	:	Construction and Demolition Waste
CKD	:	Cement Kiln Dust
DBM	:	Dense Bituminous Macadam
HMA	:	Hot Mix Asphalt
ITS	:	Indirect Tensile Strength
IRC	:	Indian Road Congress
KSA	:	Kota Stone Aggregates
KSW	:	Kota Stone Mining And Cutting Waste
LL	:	Liquid Limit
LS	:	Limestone Aggregates
MDD	:	Maximum Dry Density
MD	:	Marble Dust
MORT&H	:	Ministry Of Road Transport and Highways
MQ	:	Marshal Quotient
NCAT	:	National Centre for Asphalt Technology
OGFC	:	Open Graded Friction Course
OMC	:	Optimum Moisture Content
PI	:	Plasticity Index
PL	:	Plastic Limit
RA	:	Recycled Aggregates
RAP	:	Recycle Asphalt Pavement
RCA	:	Recycled Concrete Aggregate

RHA	:	Rice husk ash
SEM	:	Scanning Electron Microscopy
UCS	:	Unconfined compressive strength
TSR	:	Tensile strength ratio
TI	:	Toughness index
VFB	:	Void filled with bitumen
VMA	:	Voids in mineral aggregates

CHAPTER-1

INTRODUCTION

India is one of the fastest growing economies in the world and has one of the largest road networks in the world (PRS India legislative research 2018). About 6604 km of national highways were constructed in the year 2016-17 alone, and as part of its infrastructure reforms, Government of India is aiming to construct around a total of 84,000 km of national highways around the country(Government of India 2018). Since natural aggregate contributes to more than 90% by weight of pavement, it is evident that excavation and consumption of natural stone like basalt, andesite, and limestone will increase exponentially. The present rate of mining and processing of these stone is already having a negative impact on environment, and the consistent rise in the demand of these natural aggregates make this situation more unsustainable. On one side, extraction of these natural resources is leading towards their rapid depletion, and on another side, an enormous quantity of these extracted materials are discarded as waste. Despite all these impacts, construction of highways can't be restricted as they play a significant role in the development of a nation. Therefore, it is vital to search for an alternative which can provide a sustainable aspect by reducing consumption of natural resources, easing landfill pressure whilst maintaining the structural integrity of pavement structure.

1.1. Geographical Setting of the Study Area

India has a vast reserve of dimensional limestone like granite, marble, quartzite, slate, limestone, etc. It ranks 3rd in world stone export, sharing about 12% of the global share market. Production wise, it ranks 1st in the production of raw siliceous product like granite and sandstone and 5th in raw calcareous product, i.e. marble and flaggy limestone. Globally it has emerged 9th largest exporter of finished stone products. Needless to say, that dimensional stones have become a significant economic commodity for India. It is estimated that India has about 27% of world's stone reserve (Trade Articles - Indian Stone Industry), out of which majority is found in the Rajasthan state of India.

Rajasthan is located in northwestern part of India, covering an area of about 3,42,249 square kilometers, thus making it area wise largest state of the country. The land is bounded between 23°03'-30°12' N and Longitude 69°29'-78°17'E, encompassing 33 districts. Geologically speaking, its rocks range from one of the oldest (more than 3500 million years) to recent, displaying diversity in mineral deposit (Mineral Report, Government of Rajasthan 2015). Every part of this state is enriched with a variety of metallic and non-metallic minerals. The state is immediately identified with inexhaustible reserves of various building and ornamental stones. It holds a monopoly on the production of wallosnite, emerald, jasper, semi-precious garnet and is a leading producer of various highly popular building materials like marble, granite, sandstone, Kotastone etc.(Report, Geological Survey of India 2011). Some of the significant sources of excellent quality limestone are mined from areas of Makrana, Rajnagar, Rikhabdev, Ajmer, Andhi, and Bhaislana areas. Morwar, in Rajmand district of Rajasthan,holds a Guinness world record for largest extraction of block slabs of white marble (300,000 metric tons per year). Makrana Marble which has been used in world-famous structures like Taj Mehal in Agra and Victoria Memorial in Kolkata has its origin in this state only. Granite, another excellent quality dimensional limestone stone, identified by its hard and durable surface accompanied by enthralling colours and texture, is used commercially in tiles, slabs and in monumental structures around the world. In Rajasthan, it is found in Ajmer, Alwar, Banswara, Barmer, Bhilwara, Chittaurgarh, Dungarpur, Jaipur, Jaisalmer, Jalor, Jhunjhunun, Jodhpur, Nagaur, Pali, Rajsamand, Sawai Madhopur, Sikar, Sirohi, Tonk and Udaipur districts. Because of its unique geology, Rajasthan is also the home to some exclusive building materials among which most famous is Kota Stone.

1.2. Kota Stone: Occurrence

Kota stone is dimensional limestone found in the upper Vindhya region of Kota and Jhalawar district of Rajasthan, India. Deposit of this stone is located in between latitudes N 24°32’ and N 24°48’ and longitudes E 75°50’ and E 76°05’, covering an area of about 150 square kilometres, with a cumulative reserve of approximately 100 million tons . It is quarried in Ramjang Mandi, Chechat, Suket, Manpura, Morak, Mur-ka-Khere in Kota district and near Aroutiya, Paroliya and Kishanpura in Jhalawar district of Rajasthan, India as shown in Figure 1.1. The quantitative distribution is summarized in Table 1.1. The viable limestone beds manageable to splitting are located at a depth range from 15.0 meters to 25.0 meters from the ground surface and form part of anticlinal- synclinal type of sedimentary laminated structures. This limestone reserve occurs in sacks which are separated from each other by clay partings. The thickness of laminations in each sacks increases with depth.

It is hard, durable, tough limestone with crushing strength of about 17.8 kg/mm^2 and compressive strength of 21.89 kg/cm^2 (Indian Mineral Yearbook Report, 2013). It is a fine-grained variety of dimensional stone having natural split, non-slip surface, and amorphous texture, because of which many a time known as splittable or flaggy limestone (Kumar & Lakhani 2017). It is available in shades of yellow, green and blue. These properties make it fit for commercial purposes, and has been used for decorative purposes in public and domestic buildings for tiling and flooring purposes (Sharma et al. 2007).With time, the popularity of this stone has increased around the world and has been preferred over other famous and expansive dimensional stone like granite and marble. Last few decades have seen a surge in mining and processing of this stone. The production has increased at an exponential rate from 10MT in the year 1996-1997 to 55MT in the year 2011-2012. Export of this stone increased from 100,000 units in January 2014 to 400,000 unit with United Kingdom, France, United State, Canada and Italy being top five importers sharing 31.8%, 10.8%, 8.6%, 8% and 5.8% of total export respectively (Export analysis and trends of Kota stone | Zauba).

Table 1.1: Area Wise Kota Stone Reserve

S. No.	Area	Mineable reserve (million tons)
1.	Atraliya Deposit	5
2.	Chechat	30
3.	Suket (Atraliya, located on Shravada Kukra Belt	4
4.	Suket (Dingsi, located on Pampakheri, Atraliya Dhabadeh, Belt	10
5.	Dhabadeh- Teliya Kheri Sahravada, Kukada, Belt	10.00
6.	Manpura- Dhani Extending Jhalawar district	4.00
7.	Jagankheri – Kumbhkot Laxmipura- Satalkheri, Pipakheri, Belt	30.00
8.	Julmi- Belt	5.0
9.	Pipa Kheri- Nayagaon Belt	2

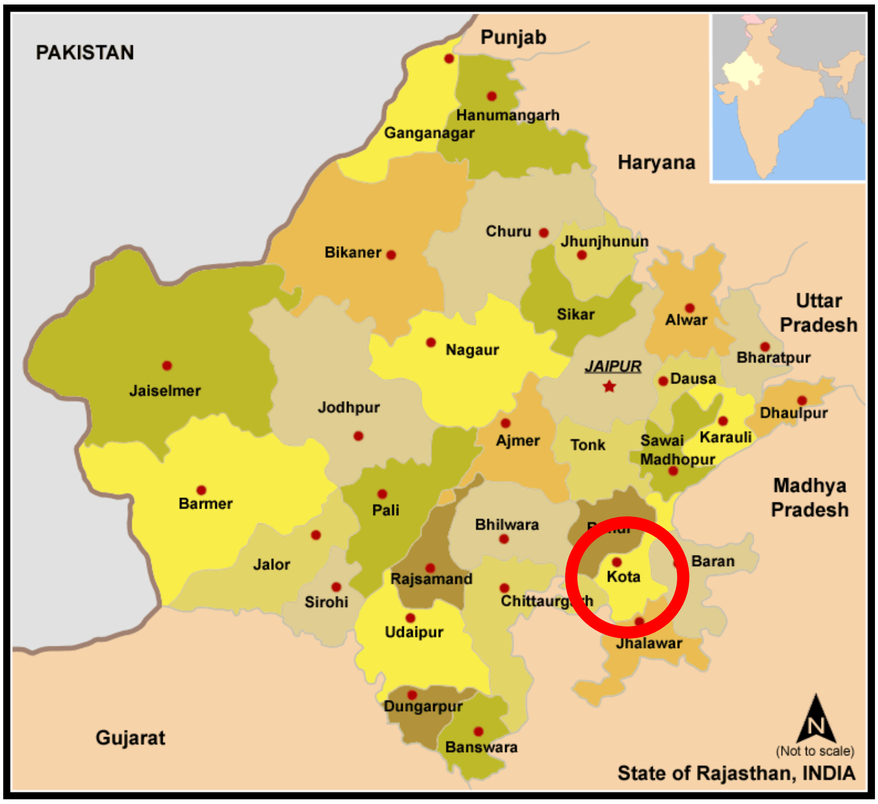


Figure 1.1: Location of Kota, Rajasthan, India

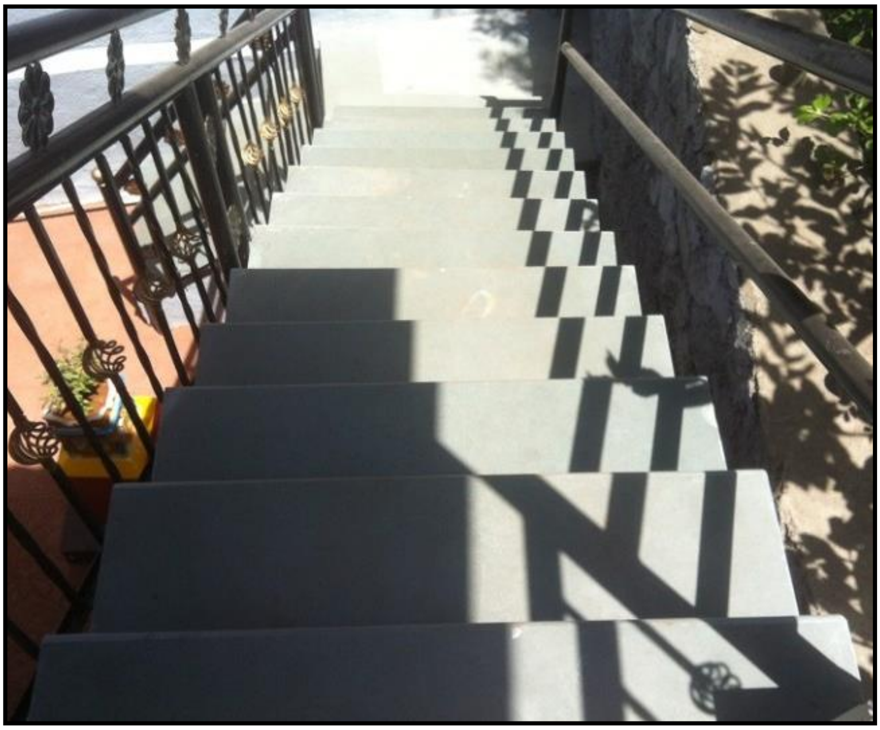


Figure 1.2: Use of Kota stone in Stairs for Decorative Purpose

(Source: Civillane.com)

Figure 1.3: Different texture of Kota stone Used for Flooring Purpose, Giving an Aesthetic Look. (Source: wfm.com)

1.3. Problem Genesis: Quarrying, Cutting and Polishing of Kota Stone

The mining process used for extraction of Kota stone is open pit mining. Here, first, the overburden pressure is removed and then quarrying continues till the end of quarry site.

A conventional quarrying procedure of these stone is summarized in Figure 1.4. Mining process involves simple low technology equipment to heavy-duty machinery. Mining method is mainly depended upon the geology of rock strata. Cutting, splitting and blasting are three methods by which mining is proceeded (British Geological Survey 2005). The large volume of rock is loosened by making primary cut and then splitting it from the parent bed. Splitting process is carried out via drilling series of holes using special tungsten carbide drill and filling them with a splitting agent. Another method used for splitting procedure is plugs and feature technique. This involves drilling holes and wedging steel plug between them. This technique is found suitable when hairline cracks are observed in the parent rock bed. The placing of holes is in alignment with these cracks. The spacing between holes is dependent upon the required quality of split and strength of rock strata. Harder rock with minimum or no fracture surface require closely packed holes. Use of explosive to cause splitting is also in practice(Mancinİ et al. 2001). This is done using gunpowder to achieve a soft split. Gunpowder is basically a deflagrating material which operates by confining the gases produced during the process. Once fracture line widens, the block of Kota stone is separated from parent rock via cutting technique. This is primarily done using diamond wire sawing machine(Mccarthy 2011). This involves drilling two-hole of diameter 25 meters and height of 6-12 meters perpendicular to each other, to the depth till they intersect each other (Ashmole & Motloung 2008). One end of the diamond wire is passed in one hole and received from another. This wire is then joined, forming a closed loop and mounted oversaw flywheel. The heavy-duty saw flywheel is mounted over the rails. As the cutting process starts, the assembly moves over the rails in the opposite direction maintaining tension on the wire and cutting rock strata in blocks.

Once this limestone is separated from the parent bed, the blocks are recovered using cranes and earth moving equipment and temporarily stored for transportation to the polishing site. From there, these blocks are transferred to shaping and polishing units. Here, the blocks are cut into slabs of desired shape and size; after which the surface is polished to give desired shiny texture as per commercial use and demand. The cutting and shaping process is long and laborious processes which usually take minimum 12 to 16 working hour to complete. A slight misdirection or rush can lead to the generation of fine cracks on the surface which make material unfit for commercial use. Polishing section involves using abrasive material like sand/Emery to give shiny texture to the limestone surface. Throughout the cutting, shaping and polishing process, a continuous jet of water is sprayed to counter the heat generated due to friction between the blade and limestone surface and clean the surface from cutting particles.(Hargreaves 2010). Flowchart of the cutting and polishing operation is shown in Figure 1.5.

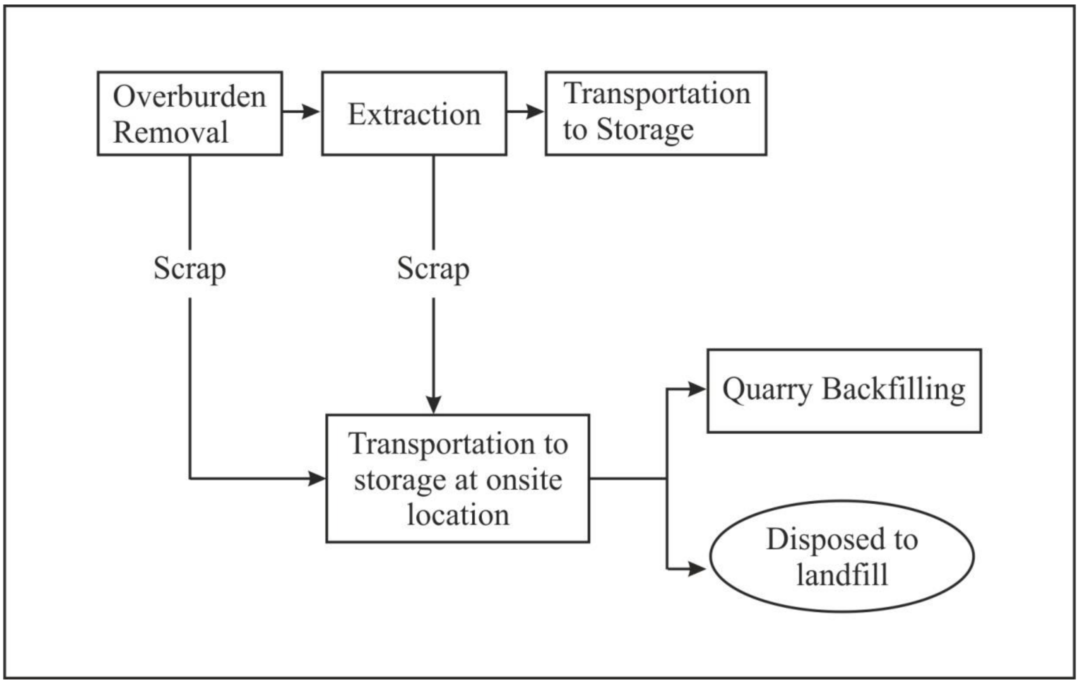


Figure 1.4: Flow Diagram for Quarry Operation.

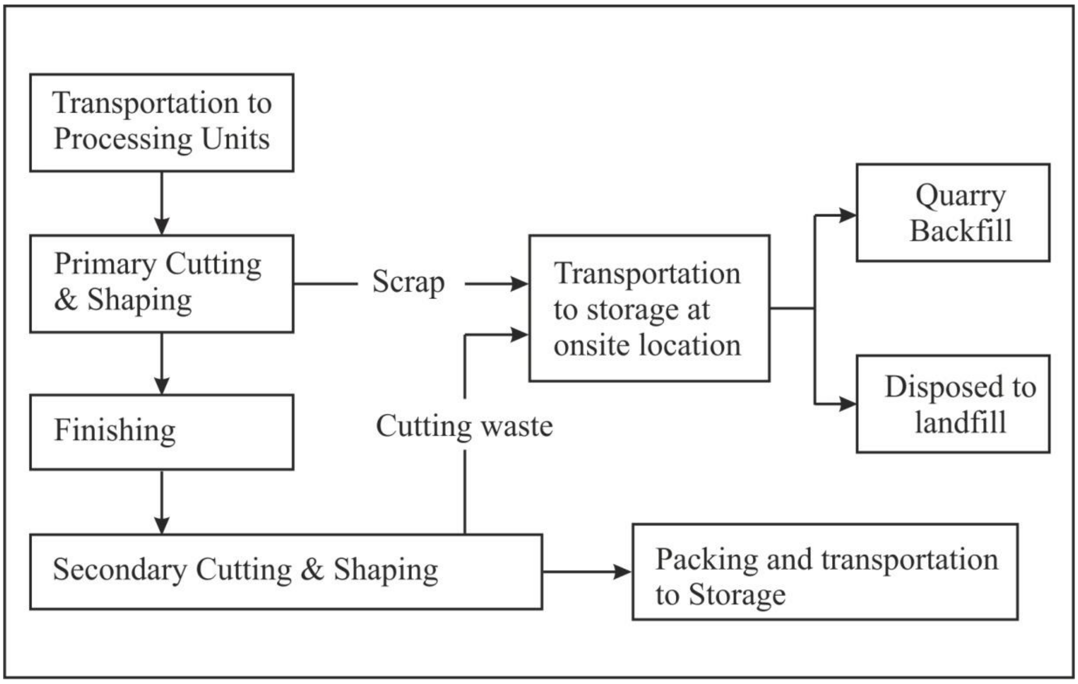


Figure 1.5: Flow diagram for Cutting and Polishing Procedure.

1.4. Waste Production and Characterization

Quarrying and processing stages of Kota stone generate a massive quantity of waste. Nearly 1.2 million tons of Kota stone waste generated in slurry and dust form is being disposed at random sites (Krishnan et al. 2018). Out of the total waste production, 50-60% of waste is generated in blasting process, and 30-40% of the total waste is generated in mechanized cutting, mining and polishing methods(Mehta & Mehta 2015).

The waste produced during the whole process can be classified as:

a) Quarry waste

The waste generated during this process are solid waste in the form of boulders, cobbles, gravels and pebbles. It is estimated that out of total mined material, around 40-50 % of the material is unfit for commercial use, discarded immediately. This waste is either filled back in the quarry site or disposed of in landfill sites (A. Hussain, 2012). Small stone chips and dust, produced during cutting and splitting process, are either left unattended or collected for disposal at landfill. The dust particles being extremely fine, get carried away with blowing wind, polluting resources and affecting health.

b) Polishing waste

Waste generated during shaping and finishing operation like processing, sawing, polishing, cutting, and packaging are included in this category. the During the polishing and cutting activity, a jet of water is continuously projected toward the cutting area to counter heat generated due to friction between blade and stone surface. After cutting rock strata this water jet, takes with it fine particles generated during the activity. This wastewater sludge is diverted into storing pit or tank as per the facilities available for further disposal.

1.5. Environmental Concern

With a consistent increase in commercial demand of Kota stone, many quarry owners shifted their focus towards this dimensional limestone. Within a short duration, the number of mining sites increased around the region.

Competition among industrialist and lack of supervision from government authorities, this mining process turned into a highly unsustainable practice. The predetermined land filled sites reached saturation point within a short duration. To save hauling time, fuel and money in waste disposal, the mining owners started buying cultivable land from local farmers at a reasonable price and offering a job at the mining site. Over the years, this practice resulted in heaps of Kota stone mining and cutting waste (Figure 1.6), stretched over kilometres, as shown in Figure 1.7, Figure 1.8 and Figure 1.9.

Presently, the waste has covered the local roads and cultivable lands, affecting the local environment and ecosystem. Since the inception of quarrying operations, areas which were earlier covered with open scrubs forest have now turned into barren land. During rain, the dump consisting of dry slurry and stone chips get carried as surface runoff; accumulate on adjacent fertile land, infiltrate in the ground and get mixed with local water sources, thus disturbing local ecosystem. Cases of respiratory diseases like silicosis are common among native people, labours living or working near the mining area.

1.6. Measures adopted by Government and Agencies.

Acknowledging the detrimental impact of Kota stone waste, the state government of Rajasthan restrained illegal mining activities by issuing various notification and judgements; few important are mentioned below:

a. Aravali notification dated 7th May 1992, under environment pollution act, prohibiting mining operation in specific areas except with prior environmental clearance from the authority.

b. Mineral Conservation and Development rule 1988 of mine closure plan was modified and rule 23A was included on 10thApril 2003 to support rehabilitation and reclamation work of mines.

c. Order dated 16. 12. 2002 by Supreme court of India restricted mining in areas under Aravali and part of Vindhya range.

National Green Tribunal, a special tribunal court for the conservation of environment has fined and banned the mining of this limestone in the area. However, these steps had little to no effect as they only lead to restriction of the generation of new waste and did not provide any solution for presently accumulated waste. The situation asks for concrete steps to counter this issue efficiently.

Few measures taken by quarry owners to safeguard the health and safety of workers were:

a) To counter blowing of stone-dust during transportation sprinkling of water is done to counter blowing dust.

b) Disposal of waste without obstructing local drainage system.

c) Providing mask and ear plugs for workers.

However, these steps have done little effect to better the situation; no concrete measure has been taken to provide a solution to already accumulated waste.

Figure 1.6: Exhaustive Kota stone Mining site and in the Background, Piles of Waste Generated During the Mining Process.

Figure 1.7: Ariel View Showing the Extent of Cutting and Slurry Waste and Contamination of Water Source.

1.8a) Kota stone mining and quarry waste

1.8 b) Kota stone slurry waste generated during polishing activity.

Figure 1.8(a) and (b): Accumulated Waste Generated During Quarrying and Polishing Activities.

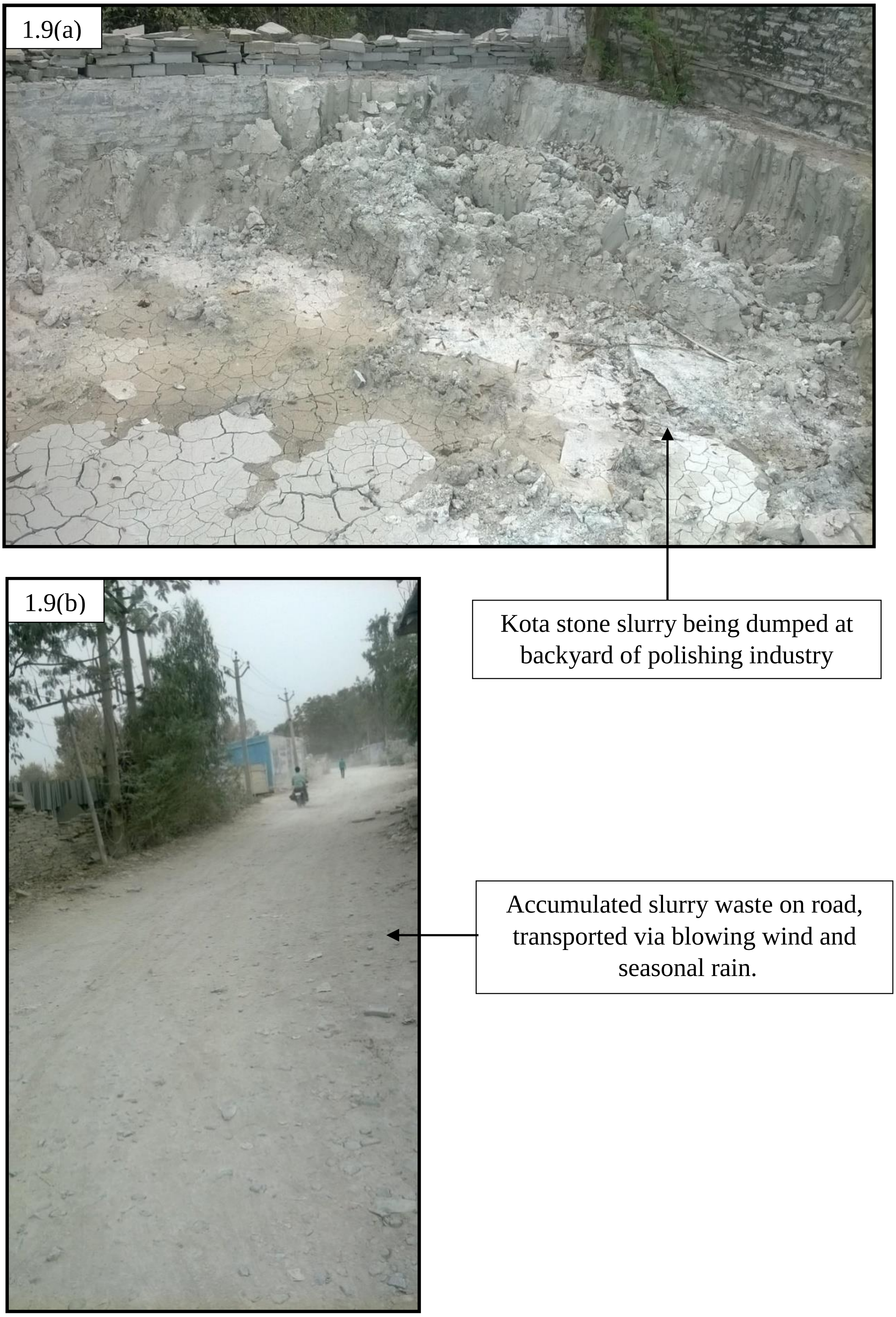


Figure 1.9 (a) and (b): Disposal Problem Due to Cutting and Polishing Waste of Kota Stone

1.7. Research Gaps

1. Previous studies reveal that materials such as cutting and polishing waste, stone waste (marble and granite), fly ash, recycled asphalt pavement (RAP), cement kiln dust has been successfully utilized as pavement material. Above waste material have been used in the range of 30-60% Properties such as plasticity characteristics, strength, workability, shear strength, free swell index, resilient modulus and durability characteristics have been evaluated. Studies on Kota stone slurry as soil stabilizer were found limited only to plasticity characteristics and strength. Properties such as swelling, resilient modulus, unconfined compressive strength have not been investigated in the past.
2. Use of limestone quarry waste as non-bituminous granular subbase course has not been evaluated earlier.
3. Preliminary investigations established the strength properties of Kota stone waste aggregates as HMA material. No study pertaining to the use of KSA as partial replacement of conventional aggregates and their strength and durability study has been carried out so far.
4. No study has been carried out related to use of KSA in open-graded friction course (OGFC).

1.8 Aim of the study

The present study is an attempt to evaluate the Kota stone quarry and polishing waste as flexible pavement material. The primary objective was to study:

1. The physical properties and microstructure of slurry and aggregates mixes derived from Kota stone quarry, polishing waste.
2. Effect of Kota stone slurry on workability, strength, resilient modulus, swelling and morphology of black cotton soil.
3. Effect of Kota stone aggregates (KSA) on mechanical properties of Granular Sub-base course (GSB).
4. Strength and durability properties of bituminous concrete (BC), dense bituminous macadam (DBM) and open-graded friction course (OGFC) mixes containing KSA.

All experimental work (except chemical composition determination dynamic creep test and resilient modulus Test) was conducted at Civil engineering department and Material research Center, Malaviya National Institute of Technology Jaipur. Chemical constitutes of material were determined at Centre for Development of Stone, Jaipur. Dynamic creep test and resilient modulus test were conducted at Central Road Research Institute, Delhi.

1.9 Thesis Organization

The thesis has been divided into 5 chapters. Chapter 1 titled “Introduction” is intended to provide brief information about the study area, problem and prospects. This chapter explains the quarrying and finishing techniques used for extraction of limestone (Kota stone), stages, quantity and type of waste generated. This chapter also explains the genesis of problem, significance of present work and aim of this study. Chapter 2 titled “Literature review” where work done by various researchers are compiled. Material and Methodology adopted for this study as explained in chapter 3 “Experimental Programme”. Details of code and testing procedure followed for this laboratory investigation are explained in this chapter. The findings of experimental investigations are compiled in chapter 4 “Result and Discussion” and the conclusion of the study along with the further scope of work is presented in Chapter 5 titled “Conclusion and Recommendations”.

CHAPTER-2

LITERATURE REVIEW

2.1 Significance

Literature review is an essential part of any research. It helps a researcher to gain knowledge about the study area, the critical parameters on which research should evaluate and also helps in identifying the gaps on which further scope of the study is possible.

2.2 Methodology

The present study is focused on utilizing locally available limestone (called Kota stone) quarry and polishing waste as flexible pavement material. The process of review was started with works on limestone quarry waste as flexible pavement material. Limited studies are available in this area with restricted preliminary findings. Hence the review scope was broadened to the use of locally available waste as pavement material. Reviewed bibliography included articles published in peer-review journals; peer-reviewed thematic conferences and case studies. Available literature pertaining to the use of Kota stone waste as building material was also reviewed in this section. The review of the literature was classified on the basis of pavement layer, i.e. subgrade, sub-base, base course and bituminous surface course.

I) Flexible Pavement Layer and Possible Use of Waste.

a) Subgrade Stabilization Using Stone Waste.

Strength and performance of flexible pavement are dependent not only on good mix design but also on the load-bearing capacity of the subgrade. A quality subgrade reduces pavement thickness and contributes toward an economical construction. Soil stabilization is a technique used to modify the physical and mechanical properties of soil. Conventionally, lime and cement are used as additives to improve soil properties. Their addition leads to the formation of gelatinous and amorphous material which helps in interparticle bonding. The reaction taking place by addition of these compounds are shown below:

Chemical reaction upon the addition of cement as stabilizing material:

$2C_3S + 6H \longrightarrow C_3S_2H_3 + 3Ca(OH)_2$ ………………(1)

$2C_2S + 4H \longrightarrow C_3S_2H_3 + Ca(OH)_2$ ………………(2)

Where C is Cao, H is H_2O and S is SiO_2

As soon as calcium hydroxide is produced in the mixture, immediately, the second stage of reaction takes place,

$Ca(OH)_2 + SiO_2 \longrightarrow CSH$ ………………(3)

$Ca(OH)_2 + Al_2O_3 \longrightarrow CAH$ ………………(4)

Chemical reaction upon the addition of lime is as follows:

$CaO + H_2O \longrightarrow Ca(OH)_2$ ………………(5)

$Ca(OH)_2 \longrightarrow Ca^{+2} + 2[OH]$ ………………(6)

$Ca^{+2} + 2[OH]^{-} + SiO_2 \longrightarrow CSH\ gel$ ………………(7)

$Ca^{+2} + 2[OH]^{-} + Al_2O_3 \longrightarrow CAH\ gel$ ………………(8)

Commonly, lime is preferred in the treatment of soil which is rich in cohesive fine aggregates and clay particles, and cement is found to be more efficient for low cohesion soil particles. This is because, in cohesive soil, majority particles size is smaller than anhydrous cement grains because of which it is difficult to ensure proper coating and distribution of anhydrous stabilizer among cohesive soil (Hall et al. 2012).

Many a time it has been observed that locally generated waste has a mineral composition similar to lime and cement and can be used as an additive to improve properties of sub-base and base course.

Table 2.1 shows the mineral composition of such wastes that have been used by researchers around the world to modify soil properties. This practice helps in reducing the overall quantity of commercial additives, provides an efficient waste management method and also reduces overall project cost (Sen & Mishra 2010). Studies have been conducted in past where the use of locally generated stone waste have been used to improve physical, mechanical and swelling properties of soil subgrade and sub-base. Table 2.2 summarizes the prominent work of using waste in soil stabilization.

(Okagbue & Onyeobi 1999) used marble dust as an additive to modify soil properties of red tropical soil to be used for road construction. Three varieties of red tropical soil were added with marble dust in varying proportion from 2% to 10% in step of 2%. Mixes were evaluated for change in particle size distribution, specific gravity, Atterberg limit, modification in standard compaction characteristics, compressive strength and bearing capacity. The result showed a significant change in engineering properties of soil on addition of marble dust. Plasticity index and compaction strength were observed to improve by 33% and 46% respectively as compared to neat soil sample. Bearing strength of sample measured by CBR also showed improvement by 55%. Based on results, the author suggested marble waste as an additive in base course material for roads subjected to light traffic, and as sub-base material subjected to high traffic roads. Similarly, (Soosan et al. 2005) studied the impact of adding quarry dust to three types of soil namely red soil, kaolinite soil and Cochin marl soil. To each type of soil, waste was added at an increment of 20%, with maximum replacement of 80% to dry weight of soil. Each sample was evaluated for change in engineering properties, i.e. liquid limit, plastic limit, maximum dry density, optimum moisture content and soaked and unsoaked CBR. Using quarry waste improved workability and gave a higher value of MDD and lower value of OMC. The effort to cast samples was reduced with increase of quarry dust in the mix. The bearing capacity of each soil sample was found to improve in both normal and adverse conditions as indicated by increased in respective CBR values. Improvement in angle of shearing resistance of all soil samples with inclusion of quarry dust was also observed. Best result in term of load bearing property was observed in kaolinite-quarry dust mixture followed by marine clay-quarry dust mix and red soil-quarry dust mix respectively.

(Jayawardena & Dissanayake 2006) performed petrographic examination on quarry dust waste produced by crusher plant in the Northern and Central province of Sri Lanka. Sixteen samples were tested for chemical composition and micro studies. Test result indicated that though the composition of quarry dust depends upon the composition of rocks, yet, Crushing and polishing techniques also have a significant effect on the quality of quarry dust. The study concluded that quarry dust is mineralogical diverse enough to be used as partial to full replacement of conventional fines in construction and building materials. However, if used in concrete, care must be taken that mica content should not be higher than 5%, as found in few test samples. Hence, regular trials and strict quality control was recommended by the author before using quarry dust as construction material.

Effect of quarry dust on compaction and shear properties of five varieties of soil was studied by (Sridharan et al. 2006). The soil samples used in this study were two variations of red soil having different particle size distribution obtained from two different locations, a lateritic soil, a Kaolinite soil and marine clay soil. To each soil sample, waste was added up to 80%, in step of 20% of dry weight of soil. Compaction characteristics were found using standardProctor test. The test result showed a consistent improvement in compaction properties of all type of soil with inclusion of quarry dust in samples. An average increase of 21% MDD value and 38% decrease in OMC value was observed in all soil samples on inclusion of 60% quarry dust. Shear strength, especially of clayey soil sample showed improvement on addition of 60% quarry dust indicating better cohesion. Use of quarry and polishing waste as additive improves the engineering properties of soil subgrade which in turn improve the load-bearing capacity of flexible pavement (Ken et al. 2006). This was also demonstrated by (Ghausuddin & Koranne 2011); here, an experimental investigation was carried out to evaluate the possibility of quarry dust as a stabilizing material. This study evaluated three mixes,i.e.a neat soil sample, a mixture of soil and quarry waste in equal proportion and a sample made of 100% quarry dust. Test result showed that among samples neat soil sample gave maximum density of 15.8 KN/m^3 followed by mix containing 50% quarry waste and 50% soil and 100% quarry waste sample giving values as 13.9 KN/m^3 and 12.5 KN/m^3 respectively. Soaked CBR followed similar trend, with minimum CBR value obtained for the sample made of 100% quarry waste and maximum value obtained for neat soil sample. To improve the compaction and load-bearing performance of the mixes, each mix was then added with three variants of polypropylene fibre of diameter 12mm, 24mm and 40mm in ratio of 0.5%, 1%, 1.5% and 2% of total weight of the sample. Samples were then again tested for engineering properties of soil, i.e. MDD, OMC and soaked CBR. This time, the sample made of 100% quarry dust gave best results. Sample made of 100% quarry waste using 2% polypropylene fibres of size 24 mm, gave highest MDD of 13.9 KN/m^3 and maximum

CBR value of 16.63 % among all mixes. The reason cited for this performance was homogeneous mixing of fibre and quarry dust resulting in denser mix. Cost analysis also supported use of polypropylene fibre induced quarry dust and in contrast to using neat soil for subgrade construction, saving natural resource.

(Eze-Uzomaka et al. 2010) studied the possibility of modifying engineering properties of laterite soil, to be used for non-bituminous base course, using cement and quarry dust. For this study, cement was added in step of 2% by weight of soil up to 10%; to each soil-cement mixture, quarry waste was added in step of 10% up to 50%. Each sample was tested for workability, maximum dry density, bearing capacity and durability. Test result showed that with inclusion of quarry dust to cement stabilized soil samples enhanced their geotechnical properties. Plasticity index of neat soil sample, containing no additive was 22%, which on addition of cement reduced to 10%, which was further reduced to 5% on 50% addition of quarry dust by dry weight of soil-cement sample mix. Similar observation was obtained for maximum dry density which was found using standard Proctor test. Combination of 10% cement and 50% quarry dust improved the maximum dry density to 2.12gm/cc from 1.82gm/cc. Formation of much denser mix was attributed to this behaviour. Inclusion of quarry dust improved bearing property of soil, found using CBR test, where it was observed that using 2% cement and 10% quarry dust improved CBR value by 96% of that obtained for control sample containing no additive. The value further increased by 296% on addition of 10% cement and 50% quarry dust. In durability test, measured using dry and wet UCS test, it was observed that sample 10% cement and 50% quarry dust gave best results in both the cases. The study was followed by cost analysis of each mix, where it was observed that though sample containing 10% cement and 50% quarry dust gave best result, using this infield would lead to a spike in overall project cost, hence, based on economic analysis and considering results which satisfied code recommendation, 6% cement and 30% quarry waster was suggested as the most suitable proportion.

(Ogbonnaya & Illobachie 2011) studied the effect of granite dust produced during mining of granite rocks, on geotechnical properties of clayey soil, found in the region of Southeastern Nigeria. Waste was added as dry weight replacement of soil in proportion of 10%, 15% and 20%. Study results were in correlation with other similar studies where it was found that inclusion of dimensional stone waste improved PL, MDD and CBR value of soil. Based on results, author suggested that granite dust stabilized local soil can be used in construction of sub-base course of flexible pavement and as general filling material for embankments. Another study by (Al-Joulani 2012) used stone waste, obtained during cutting and shaping of dimensional stones, to improve compaction and load-bearing properties of local clayey soil. The results were compared with control soil sample and lime stabilized soil sample, containing lime as additive in similar ratio as that of stone waste, i.e. 10%, 20% and 30%. Test result indicated that soil properties were improved with addition of stone waste. Use of 30% stone dust improved the CBR value from 5.2% obtained for neat soil sample to 16%; this CBR value was less yet comparable to that obtained upon addition of 30% lime to soil, having a CBR value of 18%. The study recommended use of stone waste as stabilizing material.

In another study by (Satyanarayana, Pradeep, et al. 2013), the feasibility of using waste quarry dust, produced at local stone crushing plant, as a geotechnical material was assessed. In this experimental investigation, geotechnical properties of stone dust were evaluated and compared with conventionally used material, i.e. sand and red soil. Each material was tested for gradation, plasticity index, OMC, MDD, CBR and angle of shearing resistance. Test result showed that crusher dust had almost similar particles size distribution to that obtained for sand and red soil. Crusher dust showed highest water requirement to achieve maximum compaction, however, the MDD achieved was similar to that of red soil, i.e. 1.9gm/cc which was greater than that obtained for sand, i.e. 1.75gm/cc; same was observations for CBR value where red soil and crusher dust gave same CBR value of 10% against 8% obtained for sand. Another study on gainful utilization of quarry waste was carried by (Amit & Singh 2013) to study impact of marble slurry as stabilizing material. In this study, marble waste was added to soil at replacement proportions of, 40%, 50%, 60%, and 70%. The untreated sample was used as a control sample, and results were evaluated based on the change in the mechanical properties. A consistent increase in MDD value, decrement in OMC value and improved workability were observed with increase in marble waste in soil, indicating improved compaction property. At 50% replacement, maximum CBR of 5.16% was obtained, which was almost four times the CBR value of neat soil sample, after which further increase in proportion gave decrement results. Overall the study suggested that marble dust can be used up to 50% to improve its mechanical properties of black cotton soil

(Gupta & Sharma 2013) used marble dust, fly ash and Beas sand to study subgrade characteristics of expansive soil. Sand was added to soil sample in step of 10% replacement of dry weight of soil. Each sample was then tested for MDD and CBR values, where it was observed that MDD was improved till 50% replacement of soil sample by Beas sand. Addition of fly ash was done to soil-sand mixtures in step of 5% till 15%. It was observed that fly ash reduced MDD and increased OMC of mixture. Marble was added in similar fashion to soil sand and fly ash mixture in two proportions, i.e. 8%, 12% replacement of dry weight of mixture. Test result revealed that inclusion of marble dust by 12% replacement of mix improved the MDD of soil and results were comparable to mix containing 50% soil and sand. Similar observation were made for CBR test results, where inclusion of marble dust gave almost double CBR value compared to that obtained with soil sand combination. Based on the experimental investigation, 52.36%-22.44%-13.20%-12% was considered as most optimum soil-sand-fly ash-marble dust proportion.

(Mishra et al. 2014) used granite slurry waste generated during polishing process to modify engineering properties of lime stabilized black cotton soil. Black cotton soil containing 5% lime by weight of soil was taken as control sample and granite waste was added in ratio of 10%, 20% and 30% by weight of control sample. Test result showed that addition of waste reduced plasticity index from 37.2% to 3.7% on addition of 30% granite waste. A similar observation was made for free swell index test, where it was observed that addition of 30% granite waste reduced swelling from 56.0% to just 4.1%. Another study by (Nayak et al. 2015) enhanced the performance of red lateritic soil using 20% granite and 9% lime content. This study advocated positive impact of granite waste on durability of soil and suggested its use along with lime as additive. Similar study was conducted by (Khader et al. 2017)where the engineering properties of black cotton soil were evaluated by adding different quantity of lime and granite quarry dust. Neat soil sample was added with lime as percentage weight replacement of dry weight of soil sample in four proportions, i.e. 3%, 4%, 5%

and 6%. To each mix, granite dust was added in three proportions, i.e. 10%, 20% and 30% of dry weight of soil-lime mixture. MDD and OMC of each mix were found using standardProctor test. Effect of bearing properties was evaluated using CBR test and the effect of lime and granite dust on swelling properties of soil was assessed by free swell index test. Test result showed that as the percentage of lime and granite dust increased in the mix, PL, MDD, CBR increased and swelling of soil samples decreased. Overall study advocated use 5% to 6% lime along with 20% to 30% granite waste as additive to stabilize black cotton soil. Study on similar ground was carried out by (Zorluer & Gucek 2017). Here, granite slurry waste, obtained after drying polishing sludge, and fly ash were used to study their effect on mechanical and durability properties of granular soil to be used for road construction. Addition of these waste to soil was done in three proportions, i.e. 5% granite waste with 10% fly ash, 10% granite waste with 20% fly ash and 15% granite waste with 30% fly ash. OMC and MDD were determined using standard Proctor test, where it was observed that inclusion of waste improved MDD and reduced OMC. Improvement in bearing capacity was observed in CBR test, where, average CBR increment of about110% on inclusion of waste combination was observed. Sample containing 5% granite dust and 10% fly ash gave consistent best result of 128% increment in CBR value. To estimate durability properties samples were cured for 1, 7, 28 and 56 days and then tested for their UCS value. Test result showed that out of all samples, sample containing 5% granite dust and 10% fly ash gave incremental strength whereas other showed reduced strength on 28 and 56 days curing. Based on the test data, author suggested that 5% granite dust and 10% flyash is suitable additive percentage for tested soil, and its field implementation will not only reduce overall construction cost but will also create environment-friendly roads. (Thirumalai & Naveennayak 2017) also used granite quarry and slurry waste to stabilize black cotton soil. Waste was added in proportion of 10%, 15% and 20% by dry weight of soil. Result from this laboratory investigation suggested that granite quarry and slurry waste has potential to improve geotechnical properties of black cotton soil as upon addition, reduction in liquid limit and improvement in plastic limit, MDD and UCS value was observed.

(Sarvade & Nayak 2014) used quarry dust to improve geotechnical properties of clayey soil found in the region of Karnataka, India. In this study, quarry dust was added in five proportions, i.e. 10%, 20%, 30%, 40%, and 50% by weight of neat soil sample. Each mix was judge on the basis of change in workability, compaction characteristics and durability properties of soil samples. The test results were very encouraging as inclusion of quarry waste reduced the plasticity index indicating an improvement in workability condition of soil samples. The optimum water requirement followed a decreasing trend and maximum dry density improved as proportion of quarry dust increased in the soil samples, suggesting improvement in compaction characteristics of soil whilst reducing overall water required to achieve the same. Durability property evaluated using unconfined compressive strength test, improved till 20% addition of quarry dust in the soil sample after which it decreased. This experimental investigation was then followed by a finite element analysis where it was established that using quarry dust in soil can decrease the settlement and improve the load carrying capacity of footing.

Another study by (Kuamr & Biradar 2014) supported the use of quarry dust to improve the subgrade properties of clayey soil to be used for highway construction. The waste was added at an interval of 10%, beginning with 10% and going till 50%. The results were in correlation with similar studies conducted by various authors, where use of quarry dust as an additive improved geotechnical properties of soil. This study concluded that using 40% of quarry dust by weight of soil sample improved workability, compaction characteristics and bearing capacity of soil and its field implication would provide a viable disposal option for accumulated quarry waste. Similar study by (Chawda 2014) used granite crusher dust to improve engineering properties of lime stabilized black cotton soil. Soil sample containing 5% lime by dry weight of soil was added with granite dust in two proportions, i.e. 10% and 20% by dry weight of sample. Each mix was tested for PI, OMC, and MDD. Test result indicated that inclusion of granite dust improved workability as indicated by PI, which reduced from 31.85% to 6.8%. MDD was observed to increase as proportion of granite waste increased, with best value obtained on 20% addition of waste to the mixture. Reduction in OMC requirement to achieve MDD density was also observed. Based on this laboratory investigation, author concluded that addition of 5% lime and 20% granite crusher dust by weight to black cotton soil will improve its geotechnical properties and its use will help in sustainable construction.

(Keshavan et al. 2017) used combination of marble dust and granite dust to improve workability of black cotton soil. In this study, additive mix was prepared by combining the two waste materials in equal proportion and then adding to soil as weight replacement by dry weight of soil in step of 25% till 75%. The test result showed encouraging result, with a decreased liquid limit value from 36.88% of neat soil sample to 17.33% on 75% addition of additive in soil sample. Improvement in workability was observed by an overall reduction in plasticity index of soil from 13.63% to 3.13%. Addition of marble dust and granite also reduced the permeability of soil, further supporting its suitability as construction material. Overall, authors recommended used of marble waste and granite waste as construction material.

(Husain & Aggarwal 2015) studied effect of stone dust obtained as waste product from stone crusher plant to study its effect on compaction and mechanical properties of low-plastic silt sand found in Kurukshetra region of Haryana, India. In this study, waste stone dust was added at replacement interval of 2%, up to 10% replacement ratio. Modified Proctor test was used to find optimum moisture content and maximum dry density of each mix. Test result indicated that as the percentage of stone dust increased, MDD increased. Best result was obtained with 4% addition of stone dust, where MDD obtained was 2.07gm/cc as compared to 1.19gm/cc obtained for control sample. To assess effect of stone dust on load-bearing properties of soil CBR test was performed for each replacement mix. Each mix was cast on respective OMC. The CBR value increased from 3.50% of control sample to 15.32% for sample containing 10% stone dust as additives, which indicated an improvement in bearing property of soil. Similar study was conducted by (Agarwal 2015) in which waste stone dust procured from commercial stone crusher site was used as additive to study its impact on soil properties of clayey soil found in the region of Pantnagar Uttarakhand India. The addition of waste was done at interval of 10% and continued till addition of waste gave positive results. Standard Proctor test was used to find the OMC and MDD of each mix and CBR was cast on basis respective OMC of each mix. The result was in correlation with other studies conducted on similar ground as it was observed that till 50% addition of stone dust, compaction energy improved and OMC decreased. Addition of waste increased the CBR of soil from 1.95 % to 2.91% on 30% addition of waste. Further addition gave reduced CBR values. Based on test results, 30%

addition of stone waste was suggested as suitable replacement value to improve soil properties. Similar results were reported by (Mahent 2015). The study evaluated optimum proportion of slurry waste to improve properties of gravel soil. Soil was added in proportion of 10%, 15% 20% and 25% and 30%. Test results were evaluated on the basis of improvement in workability, compaction energy and increased bearing capacity. With addition of waste, liquid limit decreased and plastic limit increased, which lead to an overall decrease in plasticity index of soil. Plasticity index reduced from 7.66% of natural gravel soil to 3.86% on addition of 25% stone dust in soil sample, indicating improved workability. To find OMC and MDD, modified Proctor test was used, and result showed improvement in compaction properties of soil with inclusion of stone waste. The MDD increased from 1.70gm/cc of neat soil to 2.07gm/cc on 30% addition of stone waste into the soil. Similar behaviour was observed for bearing property of soil assessed by soaked and unsoaked CBR test.

Al-Khamka, a locally identified slurry waste by stone of same name was used to improve the properties of locally available Jerash cohesive soil found in the area of Jordan by (Masoud 2015). In his study, the slurry waste was added to soil at an interval of 5% going up to 50% replacement ratio. Test result showed improvement in compaction properties of soil until 15% addition of slurry to soil sample after which a decrement trend was followed. The study recommended addition of 15% dry slurry waste to cohesive soil to improve its compaction properties. A similar study was carried by (Prasad & Prasada Raju 2015), here, feasibility of using quarry dust to stabilize expansive soil was studied. The waste was added in three proportion, i.e. 5%, 10% and 15% to black cotton soil, and, each sample was tested for free swell test, CBR test, direct shear test. Test result showed that free swell index of soil reduced to 72% from 100% on 15 % addition of quarry waste. Soaked CBR value was found to be increasing till 10% addition of waste. Shear parameter decreased from 16KN /m^2 to 4 KN/m^2, and angle of internal friction went on increasing from 19° to 29° with addition of 10% quarry dust to expansive soil.

Another study by (Venkateswarlu et al. 2015) studied behaviour of expansive soil induced with quarry dust as stabilizing material. Neat soil samples were mixed with quarry dust at an incremental weight percentage of 5%, going up to 15%. Study evaluated index properties, compaction characteristics and bearing properties of each mix. Test result showed that as the proportion of quarry dust increased, liquid limit decreased and plastic limit increased in the mixes. Plasticity index decreased from 41.26%, obtained for control sample to 36% for sample containing 15% quarry waste in mix. Inclusion of quarry waste up to 10% increased MDD and decreased OMC and CBR increased from 3.2 to 8.24% with 10% quarry waste. Hence 10% was justified.

(Satyanarayana P et al. 2016) in his study used two locally generated waste, i.e. rice husk ash and crusher dust as subgrade construction material. In this study, mixes were prepared by replacing rice husk ash in a subsequent interval of 10% going to 50% by weight replacement of RHA. Mix made of 100% rice husk ash was treated as control sample and results were compared to control sample and code specifications. Test result indicated that as the percentage of crusher dust increased, optimum moisture content reduced and maximum dry density of mixture increased, maximum MDD of 1.54 gm/cc was obtained for sample containing 50% RHA and 50% crusher dust. Similar results were obtained for shear test and CBR, where increase in proportion of crusher dust improved shear resistance and gave higher CBR value of 38.5° and 13% respectively. The study concluded with recommendation that the use of mix prepared from 50% RHA and 50% crusher dust can be used for soil subgrade preparation and its field use will be helpful in sustainable disposal of waste, reduce overall construction cost and helps in creating sustainable construction.

(Kumar et al. 2006) performed an experimental investigation to find most suitable sub-base material among coarse sand, stone dust, fly ash and riverbed containing gravel and sand. Each sample was tested for strength parameters. Maximum dry density, found using standard Proctor test was found maximum for river bed followed by coarse sand, stone dust and fly ash samples respectively. However, bearing strength, evaluated using soaked CBR test, was found maximum for stone dust and minimum of fly ash. To assess long-term performance of material each sample were subjected to cyclic loading where highest permanent strain was obtained by stone dust, indicating higher susceptibility to rutting potential followed by fly ash, coarse sand and riverbed material. Static modulus and resilient modulus values also found maximum for riverbed material. Based on test results, river bed sample was deemed best material for construction purpose; however, use of stone dust and fly ash in construction of pavement subjected to low traffic volume was advocated.

(Roohbakhshan & Kalantari 2016) used polishing sludge waste obtained from stone processing unit along with lime to stabilize the clayey soil. The waste was added in ratio of 3%, 6% and 9% and each mix was then added with 3, 6, 9 and 11% of lime. Mix proportions were assessed based on change in Plasticity index (PI), MDD, CBR value and unconfined compressive strength value (UCS). Test result indicated decrease in liquid limit and increase in plastic limit of soil sample indicating an improvement in workability. Inclusion of waste improved the mechanical and durability properties of soil indicated by CBR and UCS test results. The optimum result were obtained with addition of 3% slurry waste and 6% lime giving CBR value of 160% and UCS value of 1MPa. A similar result were reported by (Saini &Soni 2017). In their study marble slurry waste was used to stabilize the naturally available clayey soil. Addition of waste to soil sample was in ratio of 20%, 25% and 30%. Each mix was tested for improvement in compaction and bearing capacity of soil analyzed by standard Proctor test and CBR test respectively. Test result indicated that with addition of marble polishing waste up to 25% in soil sample modified its compaction and bearing properties. (Pradeep & Imanka 2016) investigated use of quarry dust and cement to modify properties of laterite soil. In this study, quarry dust was added at weight percentage proportion of 10, 20 and 30% by weight of soil samples. To each mix proportion, 4% cement was added. Test result showed decrease in liquid limit and increase in plasticity and maximum dry density of soil with increase in quarry dust proportion. A settlement analysis was carried out for each proportion on 1.5x1.5m footing using finite element modelling. Result showed that as the proportion of quarry dust increased in the soil, settlement of footing, acted under constant load of 200KPa, decreased. The study concluded that use of quarry waste as additive to modify laterite soil properties is justifiable, and its use must be encouraged especially for low volume pavement construction. (Sonthwal & Soni 2016) and (Ganie et al. 2017)in their respective study used quarry waste as stabilizing additive. Where (Sonthwal et al., 2016) used quarry dust to stabilize the clayey soil, (Ganie et al. 2017) used it on sandy loam soil. The resulting pattern was in analogues with each other. Use of quarry dust improved workability, compaction properties and bearing characteristics of soil.

Similarly, (Mishra et al. 2014) used granite dust, generated as waste product during crushing and polishing of granite stone, as stabilizing material for black cotton soil. Waste was added in replacement ratio of 10%, 20% and 30%. Test results were in align with other studies pertaining to dimensional stone waste where addition of granite waste up to 30% improved MDD and CBR value. Another comprehensive study on evaluating role of stone waste in subgrade was carried by (Sivrikaya et al. 2014) in which five variety of stone waste were selected, and their effect on black cotton soil was examined. bentonite, kaolinite, granite powder, calcite marble powder, dolomitic marble powder were used in three variants of artificially made clayey soil from high plastic bentonite and low plastic kaolinite. Waste was added in a proportion of 5, 10, 20, 30, and 50% by weight. All sample showed improvement with increased unit weight, reduced liquid limit, improved plastic limit. Among used waste, dolomite gave the best performance, and up to 30% replacement by weight was deemed suitable. Another study by (Minhas & Devi 2016) investigated the effect of marble dust on alluvial soil. Here, replacement ratio was kept at 5, 10 and 15% respectively. The result was in align with previous studies where improvement in mechanical properties was observed. (Salam et al. 2018) used crushed limestone to study the impact of gradation, quantity of fines, and impact of dust ratio on the strength of mixes to be used for unbound base and sub-base layer of flexible pavement. Mixes were prepared by using two gradation, three plasticity index and three dust ratio. Two gradations with maximum aggregate size of 25mm and 50mm was used, in which three quality of fines identified by their different plasticity index of 5%, 8% and 12 % were added in the ratio of 5%, 9% and 13% respectively to each coarse aggregate, and dust ratio was varied as 0.4, 0.6 and 1 at fine percentage variation. Standard Proctor test was used to find OMC and MDD of each mix, and soaked CBR test was used to find strength. Study found that though PI has little influence on OMC and MDD, variation in quantity of fines had significant impact on MDD. As the quantity of fines increased in the mix, maximum dry density increased and optimum moisture content decreased. However, increased percentage of dust ratio lead to creation of voids which resulted in inferior MDD values. In terms of strength, gradation with large particle size and low fine resulted in lower CBR value.

Table 2.1: Mineral Composition of Various Material.

	Calcium Oxide(CaO)	Silica (SiO_2)	Alumina (Al_2O_3)	Iron Oxide (Fe_2O_3)	Magnesia (MgO)	Potash (K_2O)	Other mineral	LOI*	Source
Cement	64.86	20.44	5.50	-	-	1.59		1.52	(Basha et al. 2005)
Lime	53.4	8.56	4.4	1.12	-	-		-	(Etim et al. 2017)
RHA	0.41	93.51	0.21	0.21	22.31	0.45		2.36	(Basha et al. 2005)
Pumice aggregate	1.75	65.5	17.5	4.5	2.25	4.25	4.5		(Saltan & Selcan Findik 2008)
Iron ore tilling	0.607	45.64	3.36	47.7	0.393	0.607		3	(Etim et al. 2017)
Flyash	3.6	44.5	22.4	7.5	1.5	2.5		4.5	(Mccarthy et al. 2014)
Ground Granulated blast furnace slag	41.5	34.8	11.3	0.6	7.2	0.3		-	(Mccarthy et al. 2014)
Lime dust	6	-	-	-	2	1		0.1	(Brooks et al. 2011)
Cement Klin Dust	49.3	17.1	4.24	2.89	15.8	2.18		15.8	(Siddique 2014)
Marble waste	5.17	36.44	2.07	6.73	20.15	-		16.44	(Abed & Eyada 2012)
Palm oil fuel Ash	8.4	43.6	11.4	4.7	4.8	4.5		18	(Borhan et al. 2010)

*LOI= Loss on Ignition

Table 2.2: Summary of Research on Subgrade Stabilization by Stone Waste.

Waste	Secondary additive	Used as	Evaluated Parameters	Optimum percentage/Conclusion	Reference
Marble Dust	-	Stabilization of red tropical soil	Workability, Strength, Durability	Marble dust can be used as stabilizing material.	Okagbue & Onyeobi 1999
Quarry Dust	-	Stabilization of red soil, kaolinite soil and Cochin marl soil	Engineering properties, Bearing capacity.	Use of 40-60% quarry dust as an optimum range to be used in each soil sample.	Soosan et al. 2005
Quarry Dust	-	Stabilization of five soil type	Compaction and Shear characteristics of soil	Addition of waste improved geotechnical properties of soil. Use possible.	Sridharan et al. 2006
Quarry Dust	Polypropylene fibre	Stabilization of black cotton soil	Workability, Strength, Durability	Quarry dusts with polypropylene fibre improve geotechnical properties of soil.	Ghausuddin & Koranne 2011
Quarry Dust	Cement	Stabilization of laterite soil	Engineering properties, Bearing capacity.	10% cement with 50% quarry dust enhanced geotechnical properties.	Eze-Uzomaka et al. 2010
Granite Dust	-	Stabilization of clayey soil	Engineering properties, Bearing capacity.	Granite stabilized soil can be used in subgrade and embankments,	Ogbonnaya & Illobachie 2011
Stone cutting and polishing waste	-	Stabilization of clayey soil	Workability, Strength, Durability	Addition of stone dust up to 30% improve geotechnical properties of soil.	Al-Joulani 2012

Waste	Secondary additive	Used as	Evaluated Parameters	Optimum percentage/Conclusion	Reference
Quarry Dust	-	Stabilization of red soil results compared with lime stabilized soil	Workability, Strength, Durability	Quarry dust as additive increased optimum water requirement, improved durability properties.	Satyanarayana, et al. 2013
Marble slurry	-	Stabilization of clayey soil	Engineering properties, Strength and Bearing capacity.	Addition of marble powder up to 50% improve bearing strength of soil.	Amit & Singh 2013
Marble Dust	fly ash and Beas sand	Stabilization of clayey soil	Strength and durability properties	Inclusion of marble dust by 12% replacement of mix improved the MDD of soil, comparable to mix containing 50% soil and 50% sand.	Gupta & Sharma 2013
Granite slurry waste	Lime	Stabilization of black cotton soil	Strength, Durability and free swell index	Addition of waste reduced swelling and improved workability.	Mishra et al. 2014
Granite slurry waste	Lime	Stabilization of red laterite soil	Strength and durability properties	Advocated positive impact of granite waste on durability of soil	Nayak et al. 2015
Granite quarry dust	Lime	Stabilization of black cotton soil	Workability, Strength, Durability	5% to 6% lime along with 20% to 30% granite waste as additive to stabilize black cotton soil.	Khader et al. 2017
Granite Dust	Fly ash	Stabilization of black cotton soil	Workability, Strength, Durability	5% granite dust and 10% flyash is suitable additive percentage for tested soil.	Zorluer& Gucek 2017

Waste	Secondary additive	Used as	Evaluated Parameters	Optimum percentage/Conclusion	Reference
Granite Dust and slurry waste	-	Stabilization of black cotton soil	Workability, Strength, Durability	Waste has potential to improve geotechnical properties of black cotton soil.	Thirumalai &Naveennayak 2017
Quarry Dust	-	Stabilization of clayey soil	Strength and durability and settlement characteristics	Quarry dust in soil can decrease the settlement and improve the load carrying capacity of footing.	Sarvade & Nayak 2014
Quarry Dust		Stabilization of black cotton soil	Workability, Strength, Durability	Using 40% of quarry dust by weight of soil sample improved workability, compaction characteristics and bearing capacity of soil.	Kumar& Biradar 2014
Granite Dust	lime	Stabilization of black cotton soil	Workability, Strength, Durability	Use of 5%lime and 20%, granite crusher dust by weight to black cotton soil will improve its geotechnical properties.	Chawda 2014
Marble Dust and Granite Dust	-	Stabilization of black cotton soil	Workability, Strength, Durability, permeability	Addition of marble dust and granite improve engineering properties of soil.	Keshavan et al. 2017
Stone Dust	-	Stabilization of low plastic silt	Engineering property of soil	Addition of stone dust improved MDD.	Husain & Aggarwal 2015

Waste	Secondary additive	Used as	Evaluated Parameters	Optimum percentage/Conclusion	Reference
Stone waste	-	Stabilization of Cohesive Soil	Engineering property of soil	Waste has potential to improve geotechnical properties.	Masoud 2015
Quarry Dust	-	Stabilization of expansive soil	Workability, Strength, Durability, Shear properties	Addition of 10% quarry dust to expansive soil is feasible.	Prasad & Prasada Raju 2015
Quarry Dust		Stabilization of expansive soil	Workability, Strength, Durability	Use of 10% quarry dust is feasible.	Venkateswarlu et al. 2015
Crusher Dust	Rice husk ash	Improvement strength of sub grade	Workability, Strength, Durability	50% RHA and 50% crusher dust can be used for soil subgrade preparation	Satyanarayana P et al. 2016
Coarse sand, stone dust, fly ash and riverbed soil	-	Best suitable sub grade stabilizing material	Strength, resilient modulus,	River bed soil gave optimum results	Kumar et al. 2006
Polishing sludge	Lime	Stabilization of expansive soil	Workability, Strength, Durability	3% slurry waste and 6% lime was considered as optimum mix	Roohbakhshan & Kalantari 2016
Quarry Dust	cement	Stabilization of laterite soil	Workability, Strength, Durability, Settlement analysis	quarry waste as additive to modify laterite soil properties is justifiable	Pradeep & Imanka 2016
Quarry Dust	-	Stabilization of sandy loam soil	Workability, Strength, Durability	30% quarry waste was considered as optimum	Ganie et al. 2017

Waste	Secondary additive	Used as	Evaluated Parameters	Optimum percentage/Conclusion	Reference
				quantity to improve soil property	
Three varieties of Stone waste :Calcite marble, Dolomite marble, and Granite powder	-	Three varieties of artificially made clay samples of different plasticity.	Workability, Strength, Durability,	Improved engineering properties of each soil sample with each waste type.	Sivrikaya et al. 2014
Marble Dust	sand	Stabilization of clayey soil	Workability, Strength, Durability, Swelling properties	Marble dust should be used as an additivein low volume roads	Oncu& Bilsel 2016
Crushed limestone	-	Stabilization of clayey soil	Physical , mechanical and durability properties	Improved gradation, engineering properties, workability and strength	Salam et al. 2018
Marble Dust	Rice husk Ash	Stabilization of black cotton soil	Engineering properties, strength and durability properties	Marble dust had minor effect on MDD and OMC. However, significant effect was observed in soaked CBR and UCS values	Sabat & Nanda 2011
Marble Dust	Rice husk Ash	Stabilization of black cotton soil	Workability, Strength, Durability,	Marble dust is better than rice husk ash to stabilize black cotton soil.	Gandhi 2013

Waste	Secondary additive	Used as	Evaluated Parameters	Optimum percentage/Conclusion	Reference
Marble Dust	Fly ash	Stabilization of black cotton soil	Workability, Strength, Durability.	Use of marble dust in a combination of fly ash and sand to improve black cotton soil properties	Gupta & Sharma 2014
Marble Dust	-	Stabilization of clayey soil	Durability studies	Addition of 10% marble dust by weight of soil gave sufficient stiffness and modified soil properties	Gurbuz 2015
Stone Dust	Fly ash	Stabilization of black cotton soil	Strength and durability parameters	25% fly ash and 30% stone gave most optimum results	Ramadas et al. 2011
Stone Dust	Fly ash	Stabilization of black cotton soil	Swelling properties of black cotton soil	Addition of 20 to 30% of the mixture eliminated swelling properties of soil subgrade	Ali & Koranne 2011
Limestone Dust	Coal fly ash	Stabilization of local soil	Strength and durability parameters	Improved mechanical, and durability properties and it was concluded that soil sub-base and base course subjected to light traffic loads can be stabilized with limestone dust and fly.	Brooks et al. 2011
Quarry waste	Cement kiln dust	Stabilization of black cotton soil	Strength and durability parameters	8-16% is optimum proportion	Amadi 2014

Waste	Secondary additive	Used as	Evaluated Parameters	Optimum percentage/Conclusion	Reference
Quarry waste	RAP	Used as fines in sub-base layer of pavement layer	Strength, durability, long-term performance	Use of RAP and quarry fines as fines is possible in sub-base and non-bituminous layer	Puppala et al. 2012

b) Use of Recycled Aggregates in non-Bituminous Base and Sub-Base Layer

As road construction is one of the highest material consuming industry, many researchers have attempted to analyze potential use of waste materials in pavements. Waste like debris from mining sites, bricks, blocks, ceramic derived at different stages of construction activities are reformed and recycled into desired aggregate sizes and then used in flexible pavement. Recycled aggregates (RA) have found to improve the characteristics of sub-base and base properties. Uses of Construction and demolition waste (C&D) in unbound layer of flexible pavement have been prominent. These categories of waste usually include all kind of waste generated during construction and demolition activities, majorities of which is recycled concrete aggregates, recycled asphalt pavement aggregates obtained by crushing the material which were constructed using conventional limestone aggregates in first place Table 2.3 summarize in brief the prominent reviewed research for use of locally generated waste in Subgrade, Sub-base and base (non-bituminous) layer.

(Poon & Chan 2006) performed a laboratory investigation in which study was carried out on two mixes, one containing 75% recycled concrete aggregate (RCA) and 25%clay bricks (CB) and other 50% RCA and 50% CB, mix prepared from natural aggregates was taken as control mix. The result of this study was evaluated on the basis of maximum dry density, physical properties of materials and CBR value. It was found that crushed clay bricks caused an increase in water absorption, leading to a higher OMC value and a decreased MDD. CBR test result of both replacement mix was within code limitations, indicating their suitability as partial replacement of RCA.

(Leite et al. 2011) carried out laboratory investigation on the use of locally generated C&D waste at Sao Paulo, Brazil as aggregate in subbase course. The waste was a mixture of ceramic, concrete block, mortar, steel, plastic, asbestos, cement and wood. The materials were first separated using visual inspection, sorting and magnetic separation technique, then sieved via 4.75 mm sieve size and retained material were used in this study. Aggregates were divided into four groups, cementitious material, highly porous ceramic material (bricks and roof), less porous material (ceramic tile) and crushed rocks. The mixes were evaluated on the basis of grain size, CBR value, and resilient modulus. Physical property analysis revealed that reformed aggregates exhibit higher water absorption, lower specific gravity, and rough surface texture compared to virgin aggregates. Use of standard and modified compaction method was adopted in this study and change in grain size was reported during compaction due to aggregate breakage. Modified Proctor test result showed higher OMC, lower MDD for all mixes containing C&D waste. Results of CBR for specimen cast on the basis of modified Proctor test result were showed comparable results to the high quality well-graded crushed stone material. Not much difference was observed in resilient modulus test though it was that use of higher compaction reduced the resilient displacement of recycled C&D aggregate by 10 to 20%. Based on test results, use of C&D waste was recommended in an unbound layer of flexible pavement. However strict quality control was recommended.

(Satyanarayana, Teja, et al. 2013) utilized quarry waste as aggregate and fines in granular sub-base course. For this study, waste was transformed into aggregates of required size and waste stone dust was procured from crusher plant. Recycled waste aggregate was first tested for physical properties where it was established that they had required strength, hardness and durability as per MoRT&H to be used as aggregates in GSB. After this, aggregate was cast for six granular subbase grading prescribed by code and test for compaction and bearing properties. Experimental investigation showed that all mix complied with minimum code values.

In a recent study (Arulrajah et al. 2017) used RAP and CB waste as control mixes and evaluated three variant of plastic waste namely low density polyethylene filled with Calcium carbonate, high density polyethylene and low density polyethylene in replacement ratio of 3% and5% in control mix in subgrade and subbase layer of flexible pavement. The study used modified proctor test to find OMC and MDD which showed inclusion of plastic waste reduced MDD and increased OMC. For control mix, RAP exhibit lower OMC than CB in this study. Laboratory investigation summarized that inclusion of plastic waste also reduced specific gravity, CBR value and UCS satisfied the minimum requirement as per standard codes. Reason for such behaviour was attributed to low specific gravity and smooth texture of plastic waste, which was also visible in Scanning microscopic analysis of mixes. Based on results it was suggested that use of plastic waste with CB and RAP is possible and should be used in practical works.

(Arulrajah et al. 2012) studied the usability of waste excavated rock (basalt) in the sub-base layer of flexible pavement. Waste was first crushed into desired size aggregates, subjected to physical properties test and then evaluated on the basis of CBR and repeated triaxial test. Physical property test showed that waste could be used in sub-base layer as mix prepared from the waste performed satisfactorily in CBR and repeated triaxial test. Another study by (Arulrajah et al. 2013) separated C&D waste into a different waste namely recycled concrete aggregate, crushed clay bricks, waste rocks, recycled asphalt pavement and fine recycle glass to study their usability in sub-base laye**r** of pavement. The geotechnical assessment included particle size distribution, particle density, water absorption, compaction, Los Angeles abrasion, post-compaction sieve analysis, flakiness index, hydraulic conductivity, CBR tests and repeated triaxial load. Test result indicated that RCA, WR and CB performed well and satisfied every parameter. In terms of usage in pavement sub-bases, RCA and WR were found to have geotechnical engineering properties equivalent and in some cases superior to that of conventional quarry granular subbase materials. CB was also found to meet the requirements of typical granular subbase materials. The potential use of unbound layer derived from RCA was also assessed by (Ebrahim & Behiry 2012) where partial to full replacement of conventionally used aggregates at 25%, 50%, 75% and 100% replacement by weight was done. Mixes were subjected to California bearing ratio test, unconfined bearing capacity test, tensile strength test, plate load test and resilient modulus test. The test result showed each replacement mix gave higher UCS value than control mix. Also, an increase in strength ratio up to 10% to 20% than control mix was also observed. The overall study found that the use of recycled concrete aggregates was feasible in subbase course.

A field study on the use of RCA in the unbound material was carried by (Pérez et al. 2013). In this case study, RCA treated with cement were used in base and subbase layers as a full replacement of natural coarse aggregates. Study road at Malaga, Spain was used to casting one section of road with RCA and other with natural aggregates at their respective OMC and MDD obtained during laboratory investigation. Performance evaluation was done on the basis of strength, load-bearing capacity. Structural integrity was evaluated using high-performance dynamic monitoring equipment and suing impact deflectometer. The seven days compaction strength of road section prepared using RCA was almost same as that of conventional aggregates with values of 10.15 MPa and 10.95 MPa respectively. Similar performance was also observed in the load-bearing capacity test. Overall, the performance of RCA was found satisfactory. Cost analysis showed that using RCA in the field will be economical to construction projects. Hence incorporation in the field was suggested.

(Saride et al. 2010) studied performance of RAP and cement stabilized quarry fines as pavement base material for highway extension project in Arlington, USA. Before field implication, engineering properties of waste were analyzed where it was observed that the free swell index of soil subgrade was 14.6%, for cement stabilized soil it was zero and RAP had 0.8%. Both wastes had low compaction strength compared to soil subgrade. The UCS value of cement stabilized quarry dust was about four times greater than that of RAP, reason attributed to it was cement particles in fines, forming dense structure due to flocculation and agglomeration between particles. Based on laboratory investigation, two separate test section was constructed, with one containing RAP as base material and another cement stabilized quarry fine as base material. Existing subgrade being expansive in nature was stabilized using lime then overlaid by base material. Data collection was twice a month, and on days following heavy rainfall. Horizontal inclinometer and pressure cell was used to monitor long-term performance. Field investigation showed that in first eight-month both performed satisfactorily, after which a displacement of 10mm was recorded. This was attributed to above average continuous rainfall prior to reading day. Pressure censor cell reading taken once a month recorded high pressure on surface which reduced with depth, indicating that base course was successfully transferring load to subgrade. Surface profile investigated after 2.5 years of construction found to be in satisfactorily condition. Overall, based on investigation, author recommended use of quarry dust and RAP as construction material for flexible pavement.

(Lynn et al. 2016) used municipal incinerated bottom fly ash in unbound pavement layer. Waste was first assessed on the basis of physical, chemical and engineering properties followed by mechanical and durability performance. Laboratory investigation revealed improved compaction in comparison to sandy gravel soil sample. Comparable results were also obtained in permeability, elastic modulus and shear strength test. Abrasion strength was similar to lightweight aggregates and bearing capacity was found sufficient enough to permit its use in lower strength structures like embankments and subbase materials. The overall outcome of the study was that this waste could be implemented in sub-base material with no significant drawbacks.

A study by (Zaumanis et al. 2016) critically evaluated the possibility of using 100% RAP in the pavement. Referring to earlier work carried out by the same author, and a comprehensive literature review, this study enlisted that with technology advancement, it has become possible that RAP can be used as a full replacement of conventional aggregates. In this study first most suitable rejuvenator was selected to enhance RAP properties, then these rejuvenators were added to 100% RAP mix in a dose of 12% by weight. Results were compared with the virgin mix and non-rejuvenated RAP mix. Tested samples were evaluated on the basis of rutting, fatigue, and resistance to moisture where it was observed that there was a reduction in low-temperature cracking, better resistance to moisture conditions in all specimens except samples added with oil plant rejuvenators. A field study was also followed based on laboratory investigation where section of the road was laid. Sample cored out of road section after a two year trial period demonstrate good working conditions. Cost analysis and cradle to grave analysis also established that use of 100% RAP are feasible, economical and environmentally friendly. Performance of RAP as replacement of conventional aggregates in base and subbase was evaluated by (Chandra & Mandal 2017). Addition of RAP at interval of 25% i.e. 0, 25%, 50%, 75% and 100% was done. In each mix proportion, a variable quantity of cement was added as filler material starting from 1% cement to 6% at an interval of 1%. The evaluation was done on the basis of change in soaked and unsoaked CBR value. The test result showed that inclusion of cement enhanced the soaked CBR value in each replacement mix. Based on soaked CBR value it can be ascertained that RAP can be used in sub-base with or without any additive, however, for base course, use of RAP as a partial replacement is suggested along with cement as filler. (Mohammadinia et al. 2017) used lime stabilized C&D waste in crushed clay bricks, Recycled concrete aggregate, recycled aggregate in the unbounded layer. The quantity of hydrated lime was set 1% and5%. UCS test results established that used C&D material has required properties to be used in the unbound layer of flexible pavement, resilient modulus was enhanced by lime stabilization, found suitable for road construction will lower carbon footprint.

Table 2.3: Summary of Research on Use of Waste as Sub-Base and Base (Non-Bituminous) Material.

Waste	**Used as**	**Tested Parameters**	**Result**	**Reference**
C&D mixture (ceramic, concrete block, mortar, steel, plastic, asbestos, cement and wood)	aggregate in subbase course	Physical, mechanical and durability studies	use of C&D waste was recommended in an unbound layer of flexible pavement.	Leite et al. 2011
Quarry Waste	As coarse and fine aggregates in granular sub-base material	Physical, mechanical and durability studies	All mix complied with minimum code values.	Satyanarayana, Teja, et al. 2013
Quarry Waste	As fine aggregates in sub-base layer	Engineering properties, swelling properties of mix	Recommended use of quarry dust and RAP as construction material for flexible pavement.	Saride et al. 2010
C&D waste (Building rubble)	As aggregates	Geotechnical properties, Bearing capacity	satisfied code specification	Behiry, 2015
Basalt waste	As aggregate in sub-base	Physical properties, Strength and durability	Mix satisfied code provision	Arulrajah et al. 2012
C&D waste	As aggregate in sub-base	Physical properties, Strength and durability	Result indicated that RCA, WR and CB performed well and satisfied every parameter	Arulrajah et al. 2013

c) In Base and Surface Course (Bituminous)

The load distribution in flexible pavement is via grain to grain transfer. The wheel load acting on pavement is distributed in wider area and stress is reduced with an increase in depth. Since this layer forms the top layer of the flexible pavement, maximum stress occurs in this layer only(Jain et al. 2013). Hence, the good quality material is an absolute necessity. About 95% of this layer is composed of aggregates, which are extracted from large rock formation through an open excavation and then reduced to required aggregate sizes via mechanical crushing. To provide a sustainable solution, researchers have studied the use of quarry waste as partial to full replacement of conventional aggregates and filler. Table 2.4 summarizes the prominent work, where waste was recycled as pavement material in HMA.

(Rubio et al. 2010) used waste produced from decorative quartz solid surfacing processes as aggregates in HMA. For this study, waste was procured from scrap site and was reduced to particles of mean diameter 0-200mm using jaw crusher. Further reduction of particle size of mean diameter range of 6-12mm and 0-3mm was done using impact crusher. Aggregates were first subjected to physical property test where it was found that these recycled aggregates have the required strength, hardness and durability as required for conventional pavement material. Four different mixes were prepare, one made of 100% coarse and fine recycled quartz aggregates, second mix made of 100% recycled coarse aggregates and 100% conventional fines, mix three contained 50% coarse recycled aggregates and 50% conventional coarse aggregates with 100% fine conventional aggregates and mix four replacing 50% conventional coarse and fine with recycled aggregates. To find optimum binder content Marshall Test was used where all samples satisfied required code parameters. Long-term performance was analyzed using immersion-compression test and wheel tracking test, in which again samples performance was found satisfactory. The laboratory investigation was then followed by field investigation, where four road sections were laid with four different replacement gradations were used for testing. No specific hurdle was encountered on laying and compacting of mixes. Sample of material coming out from spreader was again evaluated for immersion compression test and wheel tracking test where striking resemblance among field and laboratory results were observed. A macro texture study of compacted field specimen also supported admirable performance of mixes. Based on test result, use of recycled quarry waste up to 50% replacement of coarse and fine aggregates was advocated.

(Akbulut & Gürer 2007) used marble quarry waste as aggregates in HMA. In this study, marble quarry waste was reformed into aggregates and was compared with two variants of conventionally used limestone aggregates and aggregates derived from high-quality volcanic rock andesite. All aggregates were evaluated on the basis of physical properties and Marshall test parameters. The test results showed that, among all variety of aggregate used, marble aggregates had maximum abrasion loss, highest impact value, and highest flakiness index. Marshall test result showed that binder content was within the prescribed limit, stability value was higher than conventional limestone aggregates, but less then andesite aggregates. The study suggested that use of marble as aggregate is possible in medium to low traffic roads. Similarly, (Nejad et al. 2013) also used recycled marble aggregates (RMA) as replacement of virgin aggregate in HMA.60/70 penetration grade bitumen was used as adhesive in this study and RMA was used as a replacement of virgin aggregates at 15, 25, 40, and 60% by weight in the mix design. Each sample was tested for resilient modulus, indirect tensile fatigue, dynamic creep, and indirect tensile strength ratio to evaluate the field performance suitability of HMA. Resilient modulus of samples was assessed at three different temperature of 5°C, 25°C and 45°C for better understanding the behaviour of each mix. With and without RMA, resilient modulus was observed to be decreasing which was attributed to the sensitivity of binder toward elevated temperature conditions, with the inclusion of RMA, resilient modulus was observed to be reducing. Same was observed for fatigue failure, where, increasing RMA proportion reduced the cycle number. However it was observed that each RMA replacement sample satisfied minimum criteria necessary for a material to be used for low volume roads, and hence, the author suggested that up to 60% RMA can be used efficiently as a partial replacement to virgin aggregates in low volume roads. Studies pertaining to the potential use of marble waste in the flexible pavement was also done by(Karaşahin & Terzi 2007),here, marble dust was used as filler to study behaviour in HMA**,** 75/100 grade penetration binder was used as adhesive in this study. Marble dust generated during cutting and shaping process of marble blocks was collected, sieved and used as 100% replacement of conventional limestone dust in the asphalt mixtures. The mix was tested for Marshall stability and dynamic plastic deformation. In terms of stability, similar performance was observed in control mix and replacement mix. However, higher plastic deformation was observed in a mix containing marble dust as filler but was overall performance was found suitable enough for low volume roads. Use of marble dust as filler was also analyzed by (Abed & Eyada 2012), where the mix was prepared using 100% marble dust and was tested for Marshall stability, ITS, TSR and dynamic creep. Findings of this study also recommended the use as marble dust as filler. Another study by (SevilKofteci & Niyaziugurkockal 2014) used marble waste as fines in HMA, using 50/70 penetration grade bitumen as a binder. Replacement ratio was kept 50%, 100% by weight of conventional fine aggregates. The test result showed that mix containing RMA fines improved stability value, reduced binder content and provided greater flexibility to mix and suggested the use of RMA as 100% replacement of fines in the binder layer.

Like marble, granite is another type of dimensional stone that is used exhaustively in the construction industry for flooring and other decorative purposes. A Huge amount of granite waste is generated around the globe every year (Hamza et al. 2011)(Lokeshwari & Jagadish 2016).Studies are available where researchers have successfully used it in concrete as fines, filler, aggregates etc. (Medina et al. 2017) (Aydin et al. 2017). However, its use in flexible pavement has been evaluated recently. (Šernas et al. 2014) used granite waste as 100% replacement of conventionally used fines in HMA. Results were evaluated on the basis of Marshall stability, ITS, and rut depth. The performance of mix containing granite fines was found inferior to control mix, and 100% replacement of conventional fines with granite fines was not recommended. However, no comment was made on partial replacement of the mix. Another preliminary laboratory investigation by (Kiran Kumar et al. 2014) used granite waste as aggregate in open-graded friction course. Mix was prepared using granite waste reformed into an aggregate of the required size and tested for durability, permeability and drain down. The test result showed that mix satisfied required criteria set by respective code and can be used in open graded friction courses. However further performance studies test were advised before being used in the field.

Andesite, a variety of volcanic rock, rich in silica has been used in construction and decorative purpose in Turkey for a long time. (Uzun & Terzi 2012) used andesite waste procured from cutting and polishing as mineral filler in HMA. 75–100 penetration grade asphalt cement was used in this study, mixtures with limestone aggregate and limestone mineral filler were prepared and used as control mix. The replacement ratio was kept as 4, 5, 6, 7, and 8% by weight. Stability value was observed to increase up to 6% replacement, which was found greater than that obtained in control mix. Study suggested using andesite waste as filler instead of conventional limestone filler in areas where this waste is easily accessible and using it does not compromise overall cost of project.

Use of ballast, a dark, fine-grained volcanic rock was evaluated by (Ibrahim et al. 2009) as replacement of conventionally used limestone aggregates. For this study, quarry waste was first reformed into required aggregates sizes and then were added as replacement of virgin aggregates. Three different replacement mixes were made, one containing100% basalt coarse and fine aggregates, second having coarse limestone aggregate being entirely replaced by coarse basalt aggregates, and the third 100% replacing LS fine with basalt fines. Results were evaluated on basis of Marshall stability, indirect tensile strength, resilient modulus, rutting, fatigue and creep behaviour of mixes. Study used 60/70 penetration grade bitumen. Mix containing basalt as fine aggregates failed in water sensitivity test and were deemed unfit for further testing. Dry-ITS value of remaining two mixes gave increased values, however, decreased tensile strength ratio was observed, this was attributed to low porosity of basalt which prevented absorption of asphalt and resulted in low bond strength. To counter the problem, mineral filler was replaced by hydrated lime, after which value was found in compliance with specifications. Dynamic creep test results of mix containing coarse basalt aggregates and fine limestone aggregates showed minimum deformation. Similar behaviour was observed in resilient modulus test where, when tested at 25°C, mix containing coarse basalt aggregate showed a 219% increase in resilient modulus value compares to control sample. At 40°C, the resilient modulus value increased from 430MPa of control sample to 896MPa of sample containing coarse basalt aggregates. Superior Marshall strength suggested proper interlocking and hardness of basalt aggregates. Overall based on test results, that best performance was obtained from samples having coarse basalt aggregates and fine limestone aggregates, and use of same was suggested. Study on similar ground was proceeded by (Karakus 2011) where basalt waste obtained from stone processing site was used in SMA. The aggregate was tested for physical properties, chemical compositions and then used in mix design as a full replacement of virgin aggregates, using 50/70 grade bitumen modified by adding 5% polymer and .4% fibre. Marshall test parameter was used to evaluate mix properties, and it was found that mix prepared with basalt aggregates gave high stability values. Parameters like flow value, void filled with bitumen (VFB) and void in mineral aggregates (VMA) were within code standards.The study concluded that it is feasible to use basalt aggregate in SMA.

(Sung Do et al. 2008) replaced filler in HMA with waste lime produced as a by-product of Soda ash manufacturing process. The replacement ratio for this study was kept 25%, 50% 75% and 100%, and each sample was evaluated on Marshall stability, ITS, resilient modulus, permanent deformation, moisture susceptibility and fatigue resistance. PG 64-22 grade bitumen was used as binder for mix preparation. Each mix satisfied minimum stability, flow value and Marshall Quotient. No significant difference was observed in ITS test where all samples satisfied minimum required values. When subjected to lower temperature, i.e., 20° C and 0°C, sample containing waste lime gave better results, establishing that waste lime as miner filler improved resistance to low resistance cracking. In repeated indirect load tensile test, sample containing 50%, 75% and 100% lime waste as filler gave better results than control sample. Rutting resistance, assessed using wheel tracking, showed improvement with increase of lime waste in the mixes. Overall study advocated use of dominant calcium compound waste as filler in HMA, as calcium is effective in improving striping resistance of asphalt concrete.

Table 2.4: Summary of Research on Use of Stone Waste in HMA.

Waste	Used as	Test Parameters	Conclusion	Reference
Marble quarry waste	Aggregate in base course	Physical properties, Strength and stability	Recycled marble aggregates had sufficient strength and stability	Akbulut & Gürer 2007
Marble waste	Aggregate in base course	Physical parameters, Strength, Stability, long-term performance	60% RMA can be used efficiently as a partial replacement to virgin aggregates in low volume roads	Nejad et al. 2013
Marble Dust	Filler	Strength, stability and durability	Marble dust performed similar to limestone dust and can be used as filler	Karaşahin & Terzi 2007
Marble Dust	Fines	Strength, durability and stability	Improved stability value, can be used as 100% replacement of conventional fines	Abed & Eyada 2012
Ballast quarry waste	Coarse and fine aggregates in HMA in individual and combined form	Strength, Stability, Durability, moisture susceptibility, long-term performance	Best performance was obtained from mix containing 100% basalt coarse aggregates and conventional fine aggregates	Ibrahim et al. 2009
Ballast quarry waste	Aggregate in stone matrix asphalt	Strength and Stability	Mix containing recycled waste gave better stability values.	Karakus et al. 2011

Waste	**Used as**	**Test Parameters**	**Conclusion**	**Reference**
Decorative quartz cutting waste	Aggregates in HMA	Strength and Stability	50% replacement of coarse and fine aggregates was advocated	Rubio et al. 2010
Granite waste	Aggregates in Open grade friction courses	Durability, permeability and drain down	Mix satisfied required criteria set by respective code and can be used in open graded friction courses	Kiran Kumar et al. 2014
Andesite	Filler in HMA	Strength	Can be used as filler in replacement of limestone filler is feasible.	Uzun & Terzi 2012
Waste lime	Filler in HMA	Strength, Durability and long-term performance	Satisfied minimum strength value and improved resistance to cracking.	Sung Do et al. 2008
Asphaltite	As filler in HMA	Physical properties, Strength and stability.	Improved resistance to moisture damage and fatigue life.	(Yilmaz et al. 2011

II) Use of Kota Stone as Construction Material.

Studies have been conducted in the past where use Kota stone quarry and slurry waste as construction material has been evaluated.

a) In Manufacturing of High Strength Binder.

A project was undertaken by ASI (K) Ltd. in collaboration CBRI, Roorkee to utilize Kota stone quarry waste in manufacturing of high strength binder. Based on physicochemical test it was established that Kota stone quarry and slurry waste has potential to manufacture a high strength binder. To achieve this, waste was first broken in aggregates of small size and mixed with coal. Mixture was then calcined in shaft kiln at temperature above 900 °C for four hours. During this calcination process lime in Kota stone was mixed with coal ash, which itself inherits pozzolanic properties. The output material was grounded and passed through IS 15 sieve size. Preliminary investigation showed that obtained binder material satisfied soundness and water retention limit as prescribed by IS: 2250-1967. 28-day compressive strength of mixture containing manufactures binder prepared at 1:3 proportion was found to be more than conventional hydraulic lime. To further evaluate its performance as mortar, a wall was constructed and plastered using 1:3 ratio (manufacture lime: conventional sand). No abnormality or deleterious behaviour was reported during one year test period of this study.

b) In Manufacturing of High Strength Bricks.

ASI (K) Ltd. used Kota stone polishing waste and calcined quarry waste in manufacturing of soda lime bricks. The study used two proportions for this, one having slurry waste and polishing waste in proportion of 20% and 80% respectively and other adding slurry waste, polish waste and river sand in proportion for 50%, 30% and 20% respectively. Mixture was tested for compressive strength test where it was observed that strength obtained was 150 to 180 kg/cm^2, which was much better than that obtained for conventional bricks giving strength in range of 20-30 kg/cm^2.

c) In Cement Concrete.

A preliminary investigation carried at Civil Engineering Department of Kota Engineering College, Kota, Rajasthan, used Kota stone slurry and fines as replacement of conventional sandstone fine aggregates in proportion of 15%, 30%, 45%. Each mix was evaluated for 28 and 60 days compressive strength. Test result showed that 15% replacement mix gave satisfactory performance while in other a considerable decrease in strength was observed.

In a detailed laboratory investigation carried by (Rana et al. 2016), Kota stone quarry waste and slurry waste was utilized as fine aggregates in cement concrete. The study used three variants of waste, i.e. quarry waste crushed into sand designated as crushed sand; Kota stone slurry obtained from dumping ground, and a manufactured sand, obtained by combining slurry and crushed sand in a different proportions and adopting trial percentage giving maximum bulk density (15% slurry and 85% crushed sand). Mix was cast on two water-cement ratios i.e. 0.45 and 0.55. The replacement was done in step of 20% by dry weight of fine aggregates. All 26 replacement samples were tested for change in workability, compaction factor, slump, bleeding, effect of waste on void ratio, strength and permeability. Test result showed that where introduction of slurry reduced workability, increased bleeding, the use of manufacture sand improved workability and reduced bleeding to zero. Use of crushed sand up to 20% was observed to give required workability and slump. In term of compressive strength, 100% crushed sand reduced strength of mix by 21% of control mix, while improvement in strength was observed till 10% inclusion of slurry at both water-cement ratios. Inclusion of manufactured sand, however, improved strength of concrete and continued incremental trend till 100% replacement. Similar observations were made in permeability test, where, inclusion of manufacture sand reduced permeability value and inclusion of crushed sand increased the values consistently. Using slurry till 20% replacement level reduced the permeability after which an increasing trend was followed. Based on the test results, author suggested that use of manufactured sand can completely replace river sand in concrete.

d) As Stabilizing Material for Black Cotton Soil.

Soil stabilization of black cotton soil using fly ash and Kota stone slurry was investigated by Kalla et al. 2009. The scope of study was limited to evaluation of change in workability and strength properties upon addition of the two waste in different proportions. The study was divided into four groups where, in group one, fly ash was added in step of 3% till 21% by weight of soil sample. In group two, Kota stone slurry was added in similar fashion. Group three contained fixed proportion of fly ash

(18%) and addition of KSS in variable proportion in step of 3% up to 21%; in group four, percentage replacement of KSS was fixed 18% and fly ash was added in variable proportions, starting from 3% and going up to 21% in step of 3%. Study concluded improvement in workability in all mixes, with mix containing 21% fly ash and 18% Kota stone giving least plasticity index value among all test groups. The best soaked CBR value was obtained for mix containing 3% fly ash and 18% KSS. The study supported the use of both waste material to improve soil properties.

e) As Aggregates in Flexible Pavement.

Mohit Sharma (2013) did a preliminary investigation on possibility of using Kota stone quarry waste as coarse aggregates in base course. For this study, quarry waste were first derived into aggregates of required sizes, they were then subjected to physical property test. Test result showed that recycled stone has desired strength, hardness and stripping value, making them suitable to be used as aggregates. The study further evaluated bituminous concrete mix prepared with 100% Kota stone waste and tested strength and stability values as per MoRT&H 2013. Test result was compared with control mix prepared with conventional materials. Test result indicated that mix prepared with 100% Kota stone waste satisfied required strength, stability and flow values. The mix gave comparable results with respect to control sample. Another study by Pawan Patidar (2014) evaluated the use of reformed Kota stone aggregates (KSA) in Wet Mix Macadam (WMM) and Water Bound Macadam (WBM). The KSA was first tested for physical properties, and then mixes were evaluated for load-bearing capacity using CBR test. Test result indicated that made of KSA satisfied minimum CBR value and deemed suitable to be used for WBM and WMM mixes.

f) As Binding Material in Mortar Mixes.

A preliminary investigation carried out by (Harshwardhan et al. 2017) investigated possibility of using Kota stone slurry waste as replacement of cement in mortar mixes. Test results were evaluated on the basis of change in compressive and flexure strength values. Replacement of cement was done in step of 5% till 30%. Test result indicated that up to 10% replacement of cement with fine slurry improved strength properties of mix.

g) As Carbonate Source in Production of Ternary Cement.

(Krishnan et al. 2018) evaluated the possibility of using Kota stone mining waste, marble waste along with calcined clay as a reactive component in cement hydration process in ternary cement blend. The raw material were mixed by mass, with quantity of ordinary Portland cement, calcined clay and waste material being 55%, 30% and 15% respectively. Hydration process and 1, 3,7, 29 and 90 days compressive strength of the mixes were studied. Test results advocated the use of Kota and marble stone dust as the source of carbonate in ternary cement. The presence of stone dust stabilized ettringite and formed carboalumination during hydration process. 28 days compressive strength was found better than OPC, reason for which was attributed to formation of stratlingite, occupying more volume in the mix.

2.3 Summary of Literature Review.

1. Limestone Waste as Subgrade Material.

Literature suggests that use of limestone waste have a positive impact on soil properties. A general trend of increase in plasticity limit and a decrease in liquid limit was observed with inclusion of this waste in all type of soil. Improvement in plastic limit and decrease in plasticity index improves workability and compaction characteristics of soil (Gadre & Chandrasekaran 1994), (Bomag 2004). A well-compacted soil subgrade ensures better support to overlying layers and promises longer lifespan of flexible pavements. Conventionally used stabilizing material like lime and cement improve compaction properties of soil by mechanism like cation exchange, flocculation and agglomeration reaction, hydration, pozzolanic reaction and potential carbonation (Sargent 2015), these process increase the dry density and load bearing property of sub-grade. Investigation carried by authors using locally generated waste containing calcium oxide as dominant chemical compound reported similar chemical activities taking place in waste stabilized soil. Another prominent observation was that use of quarry and slurry waste have high percentage of fine particles (particles $< 75\mu$), incorporating them in soil as additive resulted in denser well-compacted structure. Studies have reported a general trend of an increase in maximum dry density and decrease in optimum moisture content, advocating the use of stone dust and slurry use as additive in soil. This improvement in workability and dry density had positive impact on the mechanical and durability properties of soil subgrade. Under similar compaction force, the bearing capacity of soil, evaluated using CBR test, was observed to improve upon the addition of limestone waste and quarry dust in the soil sample; similar were the observations in UCS test, where inclusion of waste improved the durability properties of soil sample. The reason attributed to this behaviour was fine slurry particle improving the gradation of mix, resulting in dense and compacted structure. Incorporation of limestone waste reduces swelling in expansive soils. The reason attributed to such behaviour are the non-expansive nature of waste added to soil sample and, reduction in clay content of the sample(Ban & Park 2014).

2. Limestone Waste as Non-Bituminous Sub-Base and Base Course.

Limited studies are available where limestone quarry waste has been used as construction material for granular sub-base course. Except for (Satayanarayan et al. 2013), no specific study pertaining to use of limestone waste as granular base and sub-base course is available. The study suggests that aggregate derived from mining waste has required strength and hardness as required for aggregates as granular sub-base material.

3. Limestone Waste as Aggregates in HMA.

Though ample literature is available where performance of HMA containing stone waste material as coarse aggregates, fine aggregates and filler still no comprehensive study pertaining to use of dimensional limestone waste as HMA was available. A Few preliminary investigations are available where suitability of dimensional stone in HMA has been evaluated by reforming them into coarse and fine aggregates and filler. Physical property assessment of these mixes unanimously supported the use as aggregates and filler material in HMA. Studies suggest that bituminous mixes containing waste improve strength and satisfy minimum durability requirement as per code. Use of limestone waste was found limited to BC and DBM mixes, not a single study was found on its use in OGFC mixes.

It was evident that limestone quarry and polishing waste produced has potential to be used as construction and building material. However, the quantity of waste that can be used depends upon various factors like accessibility, petrography and quality of waste etc. To assess the suitability of any waste material as construction and building material, it must satisfy specific physical, mechanical and durability requirement as per standards. For any stone waste to be used as flexible pavement material it should be tested properties as mentioned in Table 2.5, Table 2.6 and Table 2.7. No comprehensive study was available on use of Kota stone slurry and stone waste as pavement material.

Table 2.5: Property Analysis for Soil Subgrade

Test Name	Property	Code
Gradation of soil using Sieve analysis.	Particle size distribution.	IS 2720 Part IV (1985)
Liquid Limit, Plastic Limit and Plasticity Index of soil.	Atterberg limit.	IS 2720 part V (1985)
Standard Proctor Test.	Optimum Moisture content and Maximum dry density.	IS 2720 part VII (1980)
Specific Gravity of soil specimen.	Density of soil specimen.	IS 2720 part III (1980)
California Bearing Ratio (CBR).	Mechanical property of soil.	IS 2720 part XVI (1987)
Unconfined Compressive Strength of Cohesive Soil.	Durability and Strength property of soil.	IS 2720 part X (1991)
Free Swell Index test.	Swelling property.	IS 2720 part XL

Table 2.6: Physical Properties Test for Aggregates

Test Name	Property	Code
Los Angeles Abrasion loss	Strength	IS:2386 Part IV (1963)
Impact Test		
Water Absorption Test	Water Absorption	IS:2386 Part III (1963)
Flakiness and Elongation Index	Particle Shape	IS 2386 Part I (1963)
Specific Gravity	Density of aggregates	IS:2386 Part III (1963)

Table 2.7: Test and Codes Followed to Evaluate HMA Mixes.

Test	**Property**	**Code**
Marshall mix design method	• To find optimum binder content (= average value of binder content giving maximum stability, percentage air voids and maximum specific gravity) • Assessing samples on the basis of stability value, flow value and Marshall quotient (MQ={stability/flow})	Manual Series-2 Asphalt mix design
Indirect tensile strength	Tensile deformation	ASTM D 6931
Tensile strength ratio	• Water sensitivity of mixes	AASTHO T-283
Resilient modulus test	Used to investigate the mechanical property of mix, behaviour under moving load condition and evaluate low temperature cracking as an index to assess stripping and fatigue performance	ASTM D 4123
Dynamic creep test	This test gives good correlation with measured field rut depth that	BS DD 226
For OGFC only		
Cantabro test	Durability is measured by measuring breakdown of compacted specimen	ASTM C131
Aged Cantabro test	Mix Durability	ASTM C131
Drain down test	Measure the amount of drain down from an uncompacted sample	AASHTO T 305
Falling head permeability test	Permeability of water through samples.	ASTM D3637

CHAPTER-3

EXPERIMENTAL PROGRAMME

To evaluate Kota stone slurry and aggregate as pavement material black cotton soil, Kota stone slurry and stone samples were procured at road material testing laboratory of MNIT Jaipur.

Black cotton soil (BCS) used for this study was procured from Kota city; Kota stone slurry (KSS) and mining waste was procured from processing units and landfill sites of Kota and Jhalawar region. The material was collected from five different locations of dumping site; this was done in order to compensate the variability, if any, in quality. Quarry waste was transported to crusher site, where it was crushed into aggregates of size ranging from 19mm to 0.75mm using commercial jaw crusher. Aggregates of size greater than 19mm were hand crushed at Malaviya National Institute of Technology, derived from selected samples of Kota stone quarrying and cutting waste. In-situ soil sample contained moisture and lumps. Before starting experimental investigation, material was visually inspected for presence of any impurities like pebbles, stone etc. and removed if any.

3.1 Soil Subgrade: Experimental Investigation and Sample Preparation

a) Chemical Analysis

The chemical composition of Kota stone slurry and Black cotton soil was determined at the Centre for Development of Stones, Jaipur (Rajasthan). Test results are summarized in Table no. 4.2., Kota stone slurry had calcium oxide as major constituent (37.15%), whereas in black cotton soil sample the dominant compound was SiO_2 having a total share of 65.45%.

b) Sieve Analysis

To determine the grain size distribution of soil and slurry sieve analysis was performed. Particle size greater than 75 microns were analyzed using mechanical sieve analysis as per IS 2720 part IV (1985). Particle size distribution of material finer than 75 microns was done using laser diffraction particle size analyzer.

c) Atterberg limit

Soil classification was done based on its liquid limit (LL), plastic limit (PL) and plasticity index (PI) properties. Liquid limit is defined as percentage water content at which soil changes from liquid state to plastic state, and is determined using Casagrande's device.

Plastic limit is defined as percentage water content at which soil sample changes from plastic to semi-solid state. The difference of LL and PL is called Plasticity Index.

LL, PL and PI of each replacement mix were determined as per IS: 2720 Part V (1985), shown in Figure 3.1. For the preparation of test samples, first soil and slurry were mixed uniformly at desired proportion, and then the mixture passing 425 micron sieve was used for testing purpose.

Figure 3.1 Liquid Limit and Plastic Limit Testing

d) Optimum Moisture Content and Maximum Dry Density

Soil compaction is the process in which stress is applied mechanically over soil to increase its density. Application of stress displaces air present between soil particles. Addition of water acts as lubricant, enabling easy movement of soil particle over each other under the action of compacting force, thus resulting in much denser structure. Addition of water past the optimum quantity start occupying voids that would otherwise have occupied by soil grains, resulting in reduced dry unit weight. Hence, maximum dry density is achieved at optimum water content.

To determine optimum water content (OMC) and maximum dry density (MDD) of soil samples, Standard Proctor test was performed as per IS: 2720 part VII (1980). Each sample was cast in the mould with detachable collar and detachable base plate, in three layers, each layer subjected to 25 blows by hammer weighing 2.5 kg, from free fall height of 30 cm.

e) *California Bearing Ratio (CBR) Test*

Bearing capacity is the load carrying capacity of soil, evaluated using CBR test. CBR is a penetration test. It is the ratio of force per unit area, required by plunger of diameter 50 mm to penetrate a test soil sample at the rate of 1.25mm/min to that required for corresponding penetration for a standard material, expressed in percentage.

Soaked CBR test was performed as per IS 2720 part XVI (1987). Samples were cast at their respective OMC and then submerged in water at room temperature for 96 hours, under a surcharge weight of 2.5kg.

Figure 3.2 CBR Sample Before and After Testing

f) Resilient Modulus

Resilient modulus is measure of elastic recovery of subgrade under moving load condition. Due to the absence of repetitive triaxial facility, resilient modulus of soil samples was calculated based on the correlation equation given by IRC 37: 2012 between CBR value and resilient modulus; mentioned as follows:

M_R= 10* CBR for CBR ≤ 5 --------------------- (9)

M_R= 17.6* $(CBR)^{0.64}$ for CBR>5 ------------------- (10)

Where, M_R= resilient modulus of subgrade in MPa

g) Unconfined Compressive Strength Test

Unconfined compressive strength (UCS) test is a special case of triaxial strength, conducted on cohesive soil. Here, the confining pressure is zero, and a cylindrical sample is tested under constant strain without lateral support. The failing compressive load per unit area of the specimen is called its unconfined compressive strength. The test was performed per IS 2720 part X (1991); test setup shown in Figure 3.3 The samples were tested for both dry and wet condition both. UCS samples were prepared at their respective OMC. In dry-UCS, samples were tested immediately, while in wet-UCS, samples were cured by wrapping in airtight polythene and submerging in water for seven days prior to testing.

Formula used for calculating UCS is as follows:

$$q_u = \frac{P}{A} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Where, q_u= Unconfined compressive strength (KN), P is Maximum load in KN, A is corrected area, obtained using formula, A = $\frac{a}{1-\varepsilon}$, where a is initial area of specimen, ε is axial strain, ratio of change in length to original length of sample. The shear strength of cohesive soil sample is half the value of the unconfined compressive strength obtained for sample.

$$\text{Shear strength} = q_u/2 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Figure 3.3 UCS Test Setup

h) Free Swell Index

Free swell index test measures net increase in volume of soil under submerged condition, without action of any external constraints. The test was performed as per IS: 2720 part XL (1977). Ten grams of oven dried sample passing 425-micron sieve was used for this study. Each specimen was poured in two glass graduated cylinder of 100ml capacity. One cylindrical test tube was filled with kerosene oil and other with distilled water up to 100ml. After removal of entrapped air, samples were left for 24 hours and then final volume change was noted, and free swell index was calculated using formula

$$\text{Free swell index} = \frac{V\text{d} - V\text{k}}{Vd} \text{x100} \qquad \ldots\ldots\ldots\ldots\ldots (13)$$

Where,

V_{d} = Soil specimen volume read (in cm) from graduated cylinder after 24 hours, read from cylinder containing distilled water

V_{k}=Soil specimen volume read (in cm) from graduated cylinder after 24 hours, read from cylinder containing distilled kerosene

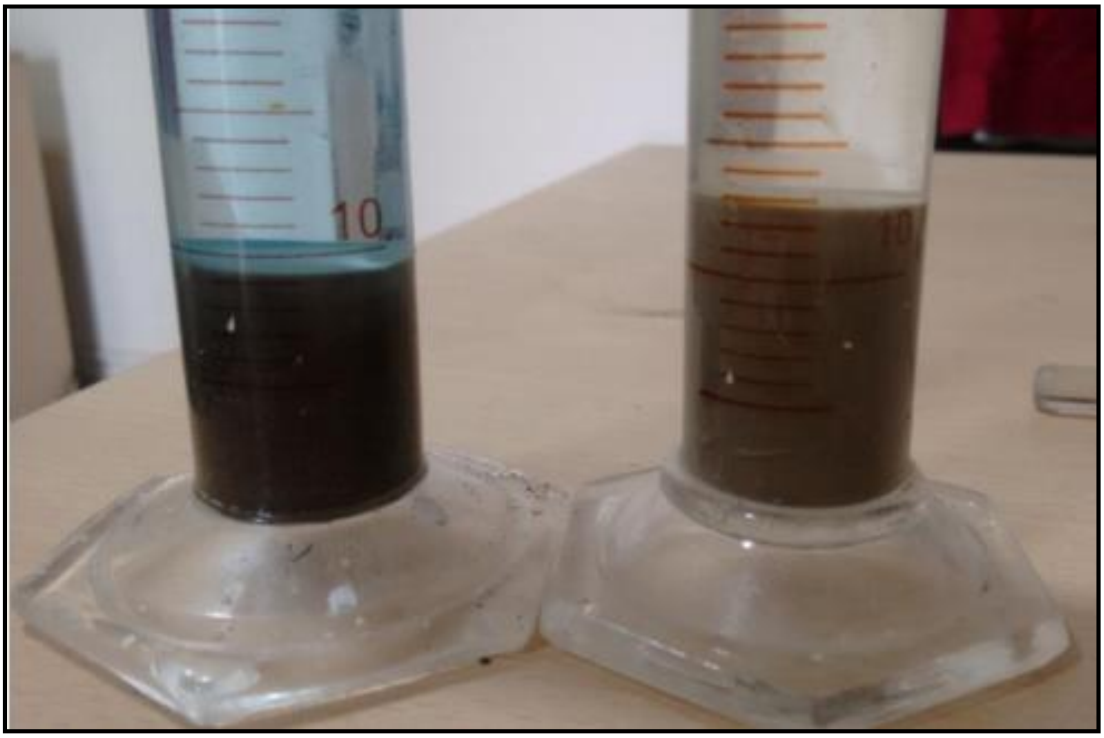


Figure 3.4 Free Swell Index Test

i) Sample preparation and Nomenclature

In this study, Kota stone slurry was added to black cotton soil sample as percentage weight replacement, in between 2.5% to 20%. Changes in soil properties with the addition of slurry were compared with control soil sample having 0% additive and 100% black cotton soil, referred to as BCS. A specific nomenclature was used to identify each mix, the numerical value in between letter B&K indicate the percentage replacement of KSS in BCS, i.e. mix B2.5K, B5K, B7.5K, B10K, B12.5K, B15K, B17.5K, B19K and B20K are black cotton soil sample containing 2.5%, 5%, 7.5%,10%, 12.5%, 15%, 17.5%, 19% and 20% KSS as replacement additive respectively.

3.2) Granular Sub-base: Experimental Investigation and Sample Preparation.

a) Physical Property Test for Aggregates.

KSA was tested for aggregate shape as per (IS: 2386 Part I), for strength (IS: 2386 Part IV), water absorption and stripping (IS: 2386 Part III and IS: 6241), bulk specific gravity of aggregates and fines (IS : 2386 Part III).

Summary of physical strength and durability test performed are as follows:

1. Los Angeles Test

This test is used to assess aggregates hardness and abrasion characteristics by measuring resistance against abrasion and attrition. Aggregates are put in Los Angeles testing machine, along with steel balls of diameter 47 mm. The sample is then subjected to 500 revolutions. Material obtained after 500 revolutions is passed from 1.7mm sieve size, and percentage loss of material is calculated using formula:

$$\text{Percentage loss}=\frac{Initial\ weight-Final\ weight}{Intial\ weight}\times 100 \qquad \text{…….. (14)}$$

2. Impact Test

Impact test measures the toughness of aggregates. This is assessed by percentage loss of material when subjected to 15 blows by hammer weighing 13.5 kg, free falling from height of 380mm. Aggregates passing 12.5mm sieve and retained on 10mm sieve are adopted for testing.

$$\text{Aggregate impact value} = \frac{Weight\ of\ portion\ passing\ 2.36mm\ sieve}{Net\ weight\ of\ aggregates\ in\ cylindrical\ steel\ cup}\text{x}100 \qquad \text{…….. (15)}$$

3. Water Absorption and Specific Gravity Test

Water absorption test and specific gravity test are considered to be a measure of strength and quality of aggregates. Higher specific gravity and lower water absorption indicate good quality aggregates. Recommended specific gravity range for aggregates as pavement material is 2.5gm/cc to 3gm/cc and water absorption should not be more than 2%. These tests were performed as per IS 2486 part III (1963). Formula used to calculate the parameters are as follows:

$$\text{Specific Gravity} =\frac{Dry\ Weight\ of\ aggregates}{Weight\ of\ equal\ volume\ of\ water} =\frac{W4}{W3-(W1-W2)} \qquad \text{…….. (16)}$$

Water Absorption = percentage by weight of water absorbed in terms of oven dried weight of aggregates = $\frac{(W3-W4)}{W4}* 100$ …….. (17)

Where,

W = Weight (grams) of saturated aggregates suspended in water with basket.

W2 = Weight (grams) of basket suspended in water in grams.

W3 = Weight (grams) of saturated surface dry aggregate in air in grams.

W4 = Weight (grams) of oven dry aggregates in grams.

4. Shape Test

This test is conducted to find flakiness and elongation index of aggregates. Flakiness index is defined as percentage by weight of particle whose least thickness is less than 0.6 times mean dimension. Elongation index is the percentage by weight of particle whose greatest dimension is higher than 1.8 times the mean dimension. Presence of flaky and elongated particles are considered undesirable because their inherent weakness leads to breaking under heavy load, thus compromising the structural integrity of pavement. The apparatus consists of a standard thickness gauge and a standard length gauge. The test proceeded as per IS 2386 part I (1963).

5. Stripping Test

This test is used to find the adhesion property of aggregate with binder under adverse condition. It is a visual test in which aggregate passing 20mm sieve and retained on 12.5mm are taken for the study. About 200gm of aggregates were mixed with bitumen amounting to 5% by weight of aggregates. Aggregates and bitumen were mixed at 160°C till uniform coating of binder on aggregates. Once accomplished, mixture was moved into a beaker and allowed to cool for 4 hours. Distilled water was poured on cold mixture and was covered and kept in water bath at 40 °C for 24 hours. After curing period, beaker was taken out, allowed to cool at room temperature and extent of stripping of binder from aggregate surface is observed. By visual estimation, stripping value was recorded in percentage.

Batch of Kota stone aggregate of size 40mm, 20mm, 10mm, 6mm and stone dust were mixed together to achieve the required gradation. Samples were prepared at their optimum moisture content and then tested for properties as per MoRT&H 2013. Each sample was designated as per the relevant gradation, i.e. sample K1, K2, K3, K4, K5, and K6 are granular subbase mix prepared using Kota stone waste as coarse and fine aggregate belonging to gradation I to VI respectively.

Modified Proctor test was used to find OMC and MDD of respective GSB graded material as per IS 2720 part VIII (1983). The test assembly and procedure is similar to that of standard Proctor test with the difference that instead of three layers, material is cast in five layers and a heavy rammer weighing 4.9 kg is used for compaction. Soaked CBR test was performed on each mix as per IS 2727 part XVI (1987) mention above.

3.3) Base Course/ Surface Course: Experimental Investigation and Sample Preparation.

(I) Bituminous Concrete and Dense Bituminous Macadam

A total of ten different mixes were prepared by replacing conventional aggregates with recycled Kota stone aggregates at an interval of 25% by weight ranging from 0 to 100% in BC and DBM. Marshall mix design method was adopted for sample fabrication with 75 blows each side as per MS-2 asphalt mix design method. Blended aggregate sample weighing about 1200 gm was kept in the oven along with cast moulds for 24 hours. The sample was then mixed with bitumen at mixing temperature of 150-160°C till binder uniformly coated aggregates. The mix was then placed in a preheated mould and subjected to 75 blows on both sides by hammer weighing 4.9 kg from a height of 45cm. First trial percentage of bitumen was kept 5.4% for BC and 4% for DBM by weight of aggregates and increased subsequently by 0.5%. Three samples were prepared for each bitumen content, and the average value was adopted for calculation.

(II) Open-Graded Friction Course

Marshall mix design method was used for sample preparation. Procedure was similar to that followed for preparation of BC and DBM samples with a difference that samples were subjected to 50 blows on each side. The specimen obtained after compaction had a thickness of about 63±3mm. In this study, first trial percentage of bitumen was kept at 3.5% (except in 100% Kota stone sample, where the percentage was 3.5%) and was subsequently increased by 0.5%.

For this study, to identify prepared mixes, specific nomenclature was adopted. C indicates conventional mix, K indicates the KSA, numerical value followed by K indicate percentage replacement of conventional aggregates with recycled limestone aggregates, thus designated mix C, 25K, 50K, 75K and 100K indicate conventional stone and replacement of traditional stone by KSA at an interval of 25% respectively.To identify the type of HMA, abbreviation followed was mix K-bc, K-dbm and K-ogfc indicating mixes containing conventional limestone for bituminous concrete, dense bituminous macadam and open-graded friction course respectively. Detail nomenclature for all mixes adopted is shown in Table 3.1.

Table 3.1: Nomenclature Adopted

Nomenclature	**Meaning**
BCS	Neat black cotton soil sample, taken as control mix for soil Stabilization testing.
B2.5K, B5K, B7.5K, B10K, B15K, B17.5K, B19K, B20K	Mix containing 2.5% Kota stone slurry by weight replacement of black cotton soil sample.
Granular Sub-Base	
K1, K2, K3, K4, K5, K6	Granular sub-base mix prepared with Kota stone coarse and fine aggregates of gradation I to VI respectively.
HMA mixes	
C-bc; C-dbm, C-ogfc	Mix prepared with conventional coarse and fine aggregates for bituminous concrete (BC), Dense bituminous macadam (DBM), Open-graded friction course (OGFC)
25K-bc, 25K-dbm, 25K-ogfc	Mix prepared with replacing 25% conventional coarse and fine aggregates with Kota stone coarse and fine aggregates for bituminous concrete (BC), Dense bituminous macadam (DBM), Open-graded friction course (OGFC).
50K-bc, 50K-dbm, 50K-ogfc	Mix prepared with replacing 50% conventional coarse and fine aggregates with Kota stone coarse and fine aggregates for bituminous concrete (BC), Dense bituminous macadam (DBM), Open-graded friction course (OGFC).
75K-bc, 75K-dbm, 75K-ogfc	Mix prepared with replacing 75% conventional coarse and fine aggregates with Kota stone coarse and fine aggregates for bituminous concrete (BC), Dense bituminous macadam (DBM), Open-graded friction course (OGFC).
100K-bc, 100K-dbm, 100K-ogfc	Mix prepared with Kota stone coarse and fine aggregates for bituminous concrete (BC), Dense bituminous macadam (DBM), Open-graded friction course (OGFC)

a) Marshall Design Mix and Properties Test

Optimum binder content plays a very pivotal role in HMA mix design. Insufficient binder content exposes mix surface to air and water which result in rapid hardening and inception of moisture induced damage conditions which eventually results in failure of the pavement structure. Optimum binder requirement becomes critical in the case where aggregates are hydrophilic in nature. In this case, water displaces asphalt, thus compromising asphalt-aggregate cohesion which results in several distress conditions like ravelling and rutting.

Marshall mix design was used to find the optimum binder content for HMA mixes. In this study, an average of binder content giving maximum stability, air void and maximum specific gravity were taken as optimum binder content.

I. Stability: It is defined as maximum load resisted by specimen before deformation. A minimum stability value of 9KN is recommended by MoRT&H 2013 for BC and DBM mixes.

II. Flow: Flow value is noted along with the stability value. It is vertical deformation of a compacted HMA mix corresponding to its maximum stability value. A lower flow value denotes insufficient asphalt in the mix whereas higher flow value denotes a plastic mix, more susceptible to permanent deformation under. MoRT&H 2013 suggest an optimum flow range of 2-4mm.

III. Marshall Quotient: It is the ratio of maximum stability to corresponding flow value of mix. It is a measure of resistance to permanent deformation. An optimum MQ range of 2-5 is suggested by code.

IV. Bulk specific gravity: Density of asphalt varies with the addition of different quantity of binder. The value follows an incremental trend till the point is reached that binder film around aggregate become thick enough that it pushes aggregate particles apart resulting in lower density.

V. Void in Mineral aggregate: In a compacted HMA mix, total volume of void without bitumen is called void in mineral aggregates. It is the total of air voids and volume of air voids not absorbed by aggregates (Marshall Mix Design and Analysis 2007). It is another parameter which indicated either the coating on binder is efficient or not. A low VMA value indicates insufficient binder coating on aggregate, while excess binder indicates the presence of an excess quantity of binder in mix leading to reduced stability value.

VI. Void filled with Bitumen: It is the percentage VMA that is filled with asphalt. This represents the effective binder film over aggregates(Marshall Mix Design and Analysis 2007). A less VFB percentage may lead to weak bonding between aggregate particles, while higher VFB may lead to bleeding during adverse moisture condition both cases resulting in failure of pavement system.

b) Indirect Tensile Strength Test

In field, sudden temperature drop and embrittlement of asphalt concrete generate tensile stress on pavement which lead to distress phenomena like low temperature cracking and ravelling(Baghaee Moghaddam et al. 2014). This test is used to asses the relative quality of bituminous mixture against such stresses. A higher indirect tensile stress value indicates better resistance against these low temperature cracking and rutting (Tayfur et al. 2007).

This test was performed as per ASTM D6931. The loading apparatus consists of a pair of loading strip,where lower strip mounted on base and upper strip free to slide on the post. The loading pattern produces relatively uniform tensile stress on specimen causes a tensile deformation perpendicular to the loading direction, which yields a tensile failure(Kennedy & Anagnos 1983), shown in Figure 3.5. Marshall specimens were loaded across their diametrical plane on the loading device as shown in Figure 3.6. ITS was evaluated by using the following equation:

$$\text{ITS} = \frac{2P}{\pi d t} \qquad \text{…….. (18)}$$

Where P is the maximum applied load (KN), t is the thickness of the specimen (mm), d is the diameter of the sample (mm).

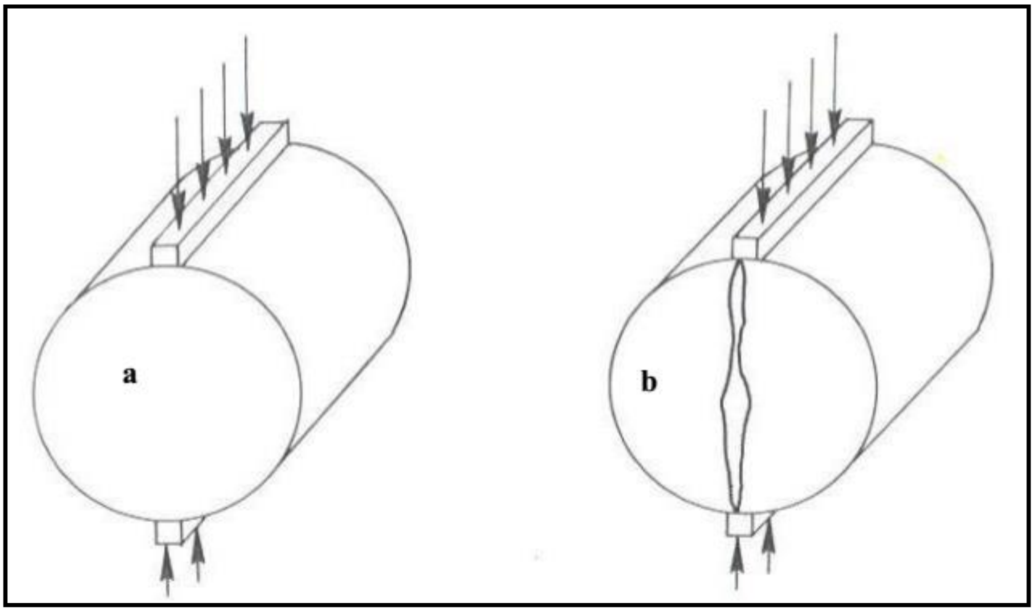


Figure 3.5: Load Action on ITS Test. (Zaniewski & Srinivasan 2004).

Figure 3.6: Laboratory Test Setup for the Indirect Tensile Strength Test.

c) Tensile Strength Ratio

Moisture damage is a widespread problem for asphalt concrete. This distress mechanism can occur from multiple sources among which most common are heavy precipitation, improper drainage facilities, and imperfect pavement design. Moisture deteriorates the durability of the pavement system by hampering adhesion between asphalt and aggregate surface (Washington Transportation Research Board 2015), which leads to accelerated distress development, eventually leading to defects like potholes, cracking and revelling (Shen et al. 2009). Tensile strength ratio (TSR) measures the water sensitivity of the compacted bituminous specimen. It is the ratio of the tensile strength of water conditioned specimen (wet-ITS) to the tensile strength of unconditioned sample (dry-ITS) which is expressed in percentage. A TSR value less than 80% is not desirable.

A higher TSR indicates that the mix exhibit excellent resistance to moisture damage condition. Each Marshall specimen was subjected to series of freeze and thaw cycle as per AASTHO T-283. These samples were then mounted on the conventional Marshall testing apparatus diametrically and load was transferred through loading strip in similar fashion as for dry-ITS.

Since OGFC mixes have an open structure, to avoid water drainage, except top surface, samples were wax coated from all sides prior to conditioning (Shirini & Imaninasab 2016) as shown in Figure 3.7

Figure 3.7: Wax Coated OGFC Samples

d) Scanning Electron Microscopic Analysis (SEM)

SEM was performed at Material Research Centre (MRC) of Malaviya National Institute of Technology Jaipur (MNIT Jaipur) to study the morphology of the mixes. Equipment used in the study is shown in Figure 3.8. It was done to understand bonding and packing behaviour of mixes with inclusion of Kota stone slurry and aggregates in the mixes.

Tested UCS samples were analyzed from their broken surface. Samples were first cut into thin cubes of size 2.5cm x1cm x1cm then coated with a thin gold coating layer(Aldaood et al. 2014) and then observed through high resolution scanning electron microscope. In HMA samples, tested Marshall samples were cut into similar dimensions and observed under high resolution.Thin cleaned section of the sample was placed inside a Field Emission Scanning Electron Microscope (FE-SEM). A beam of the primary electron was focused on the surface. The interaction between the sample surface and primary electron results to secondary electrons which generate a topographic image of the sample(Rana et al. 2016).

Figure 3.8: SEM Equipment and Thin Film Coating Machine.

e) Dynamic Creep Test

Hot mix asphalt is a visco-elastic material. The long-term behaviour of such material is dependent on loading time and temperature. Repeated traffic loading conditions, axial pressure, traffic volume leads to rutting action. This is primarily caused by two mechanisms: a) consolidation of asphalt mixture under traffic b) plastic flow of mixes. Under constant loading conditions, this visco-elastic material undergoes recoverable or non-recoverable deformations which may be time-dependent or independent. Dynamic creep test was used for characterization of mix in term of long-term deformation behaviour. This test provides a better understanding of local material by evaluating long-term rutting susceptibility of asphalt concrete mixture.

The result is expressed in graphical form, where x-axis represents cycle number and y-axis percentage permanent actuator strain value of specimen under the action of repeated cyclic loading condition. The resulted graph can be divided into three phases. Phase one is called primary strain, where strain rate increase abruptly. This is due to particle rearrangement under the action of loading condition. After primary phase comes secondary phase, where the rate of permanent strain is more or less constant. Third phase is tertiary phase; here, the rate of increase of permanent strain increase rapidly as shown in Figure 3.9. The evaluated stress-strain response of sample at any cycle is the flow number of samples. Flow number is defined as the postulated load cycle at which shear deformation of specimen starts, the tertiary flow. Studies are available, where, flow number has given good correlation with long-term material performance relationship.

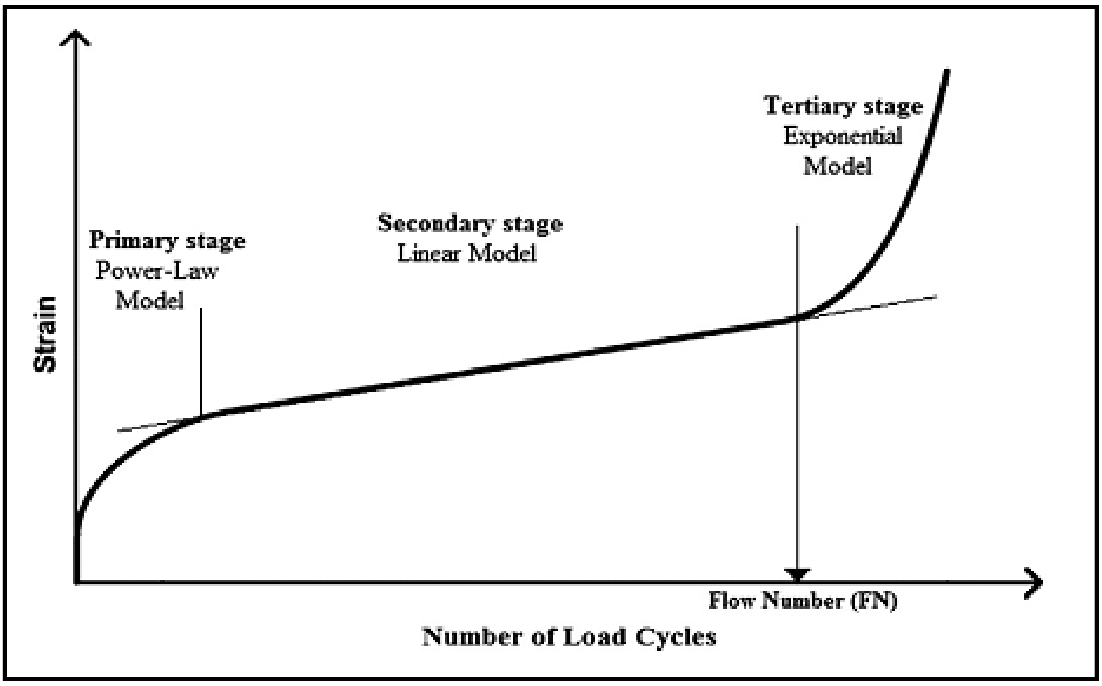


Figure 3.9: Typical Strain Vs. Load Cycle Graph Obtained In Dynamic Creep Test. (Baghaee Moghaddam et al. 2014)

The test was performed as per BS DD 226. Test parameters used are summarized in Table 3.2 Marshall specimens prepared at their respective OBC were used for testing purpose. UTM-25 machine, equipped with environment chamber and computerized data acquisition system was used for testing purpose, shown in Figure 3.10. Samples were cured in the environment chamber for 24 hours prior to testing and immediately placed under loading platens. Two Linear variable displacement transducers were placed in diametrically opposite direction to measure vertical deflection under application of repeated axial stress pulse as shown in Figure 3.11.

Table 3.2: Parameters Used For Dynamic Creep Test.

Parameters	**Values**
Loading Pattern	Rectangular
Loading Period (ms)	500
Rest Period (ms)	1500
Contact Stress (KPa)	10
Applied Repeated Stress (KPa)	200
Temperature(°C)	50

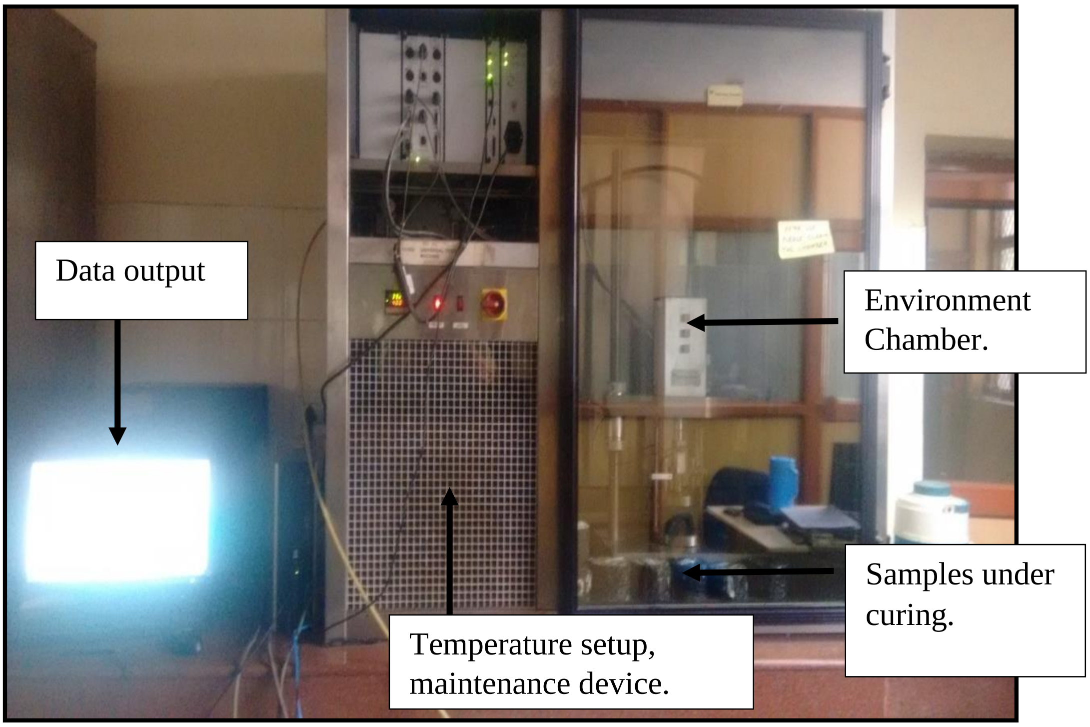


Figure 3.10: Dynamic Creep Testing Assembly.

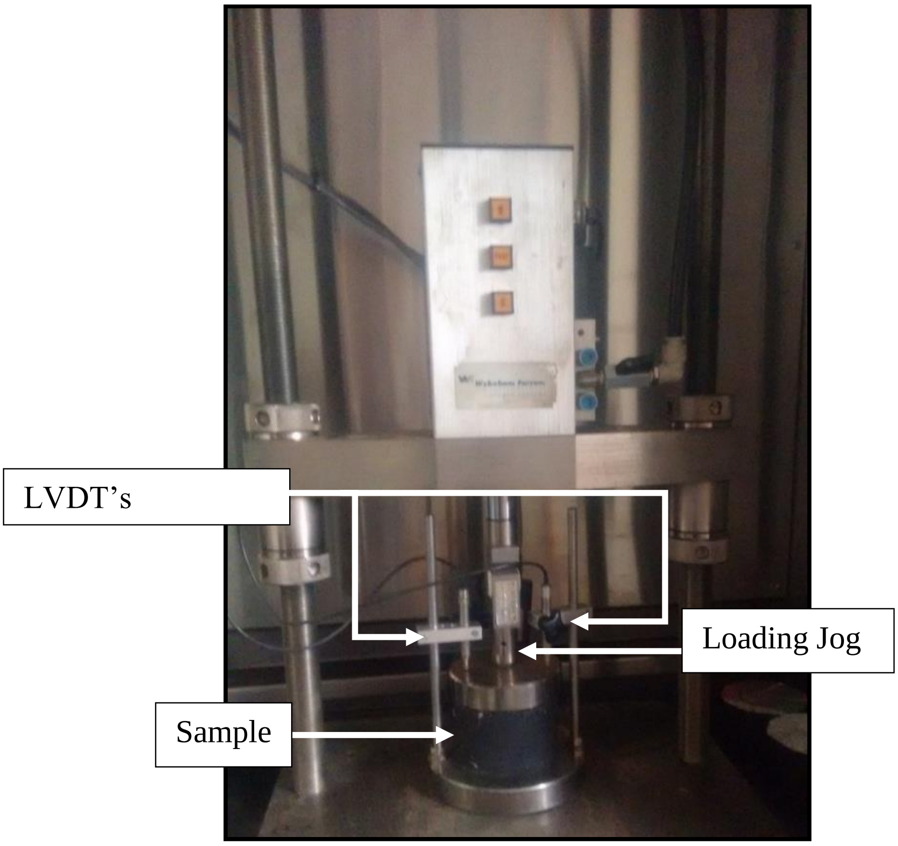


Figure 3.11: Loading Assembly in Dynamic Creep Test.

f) Resilient Modulus Test

Resilient modulus is the ratio of repeated stress to recoverable strain (Huang, 2004). This test was used to investigate the behaviour of mix under moving load and low temperature cracking of HMA mixes as an index to assess stripping and fatigue performance (Wong et al. 2007), (Tayfur et al. 2007). For a lesser pavement thickness whilst maintaining its structural integrity, a higher resilient modulus is desirable (Mills-Beale & You 2010).The test was performed as per ASTM D 4123. For each design mix, three samples were tested; experimental setup as shown in Figure 3.12, and parameters used for this study as presented in Table 3.3.

A pneumatic loading system resilient modulus device was used for this study. The load is applied along the vertical diametric plane of specimen. The device applies repeated havensquare load waveform of frequency 1 Hz. The load duration was 100 millisecond and rest period was of 1000 milliseconds. Horizontal deformation was measured using two linear variable differential transformers (LVDTs) diametrically attached to opposite side of the cylindrical sample. Though the test code suggests that peak loading force should be 10% of sample's respective ITS value; in this study, each sample was tested under uniform load of 1000N. The reason for this was that the primary aim of this study was to evaluate all mixes under similar conditions. This is because, at field, the traffic load acting is same. Assessing materials under similar loading condition give a better understanding of waste material behaviour in the mix design. Also, during the procurement stage of limestone waste used in this study, it was observed that variability in quality (shape, size, impurities like dust, gravel and mixing of other dumped material) was there. Though to counter it, samples were taken from different parts of dumping site and impurities like dust, soil and gravel were removed, however, such quality control is feasible in laboratory studies but usually not taken in consideration in field implementation. To address unwanted variability and assess the performance under uniform loading condition, 1000N was adopted.

Table 3.3: Resilient Modulus Test Parameters.

Parameters	**Values**
Loading pulse width (ms)	100
Pulse repetition period (ms)	1000
Conditioning pulse count	50
Target core temperature (°C)	35
Peak loading force (N)	1000
Estimated Poisson's ratio	0.35

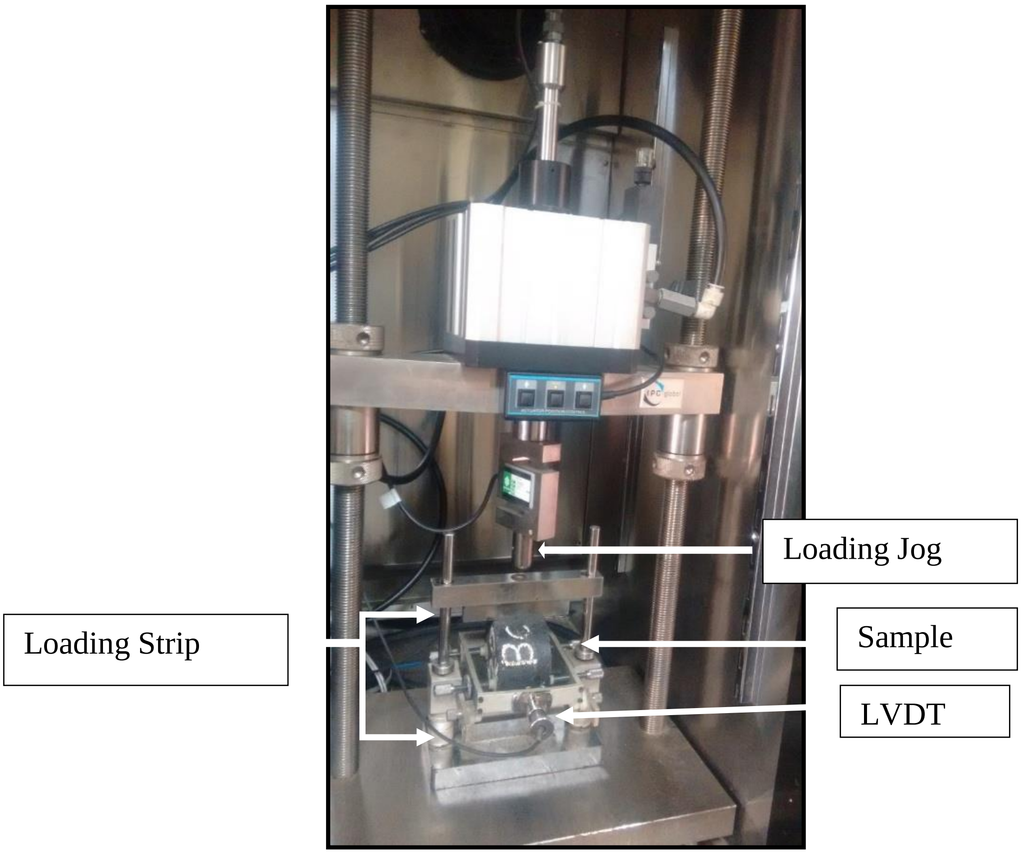


Figure 3.12: Resilient Modulus Test Assembly.

g) Cantabro Test

This test was used to assess the durability property of OGFC mixes by measuring the quantity of material breakdown when subjected to 300 revolutions at the rate of 30-33 rpm without steel balls in Los Angeles Machine. Test procedure as per ASTM C131 was referred for this test. The loose material broken from the test specimen was discarded, and percentage weight loss called Cantabro loss was measured using formula

$$\text{Percentage Cantabro Loss (C.L.)} = \frac{A-B}{A}\times 100 \qquad \text{…….. (19)}$$

Where,

A= Initial Weight (grams)

B= Retained Weight (grams)

For an unaged sample, i.e., a sample subjected to no conditioning; the percentage loss of material shall not be more than 20% (Shirini & Imaninasab 2016).

Since voids in OGFC is very high, hardening takes place at a faster rate which leads to a decrement in cohesion and adhesion which eventually result in ravelling. Hence it becomes mandatory to subject the specimen to accelerated ageing test (Yang et al. 2016). This was done by putting the sample in the oven at 60°C for seven days, then cooled for 4 hours and tested in similar fashion as unaged specimen. The average value of C.L. must not exceed 30%, and individual C.L. value of specimen should not exceed 50% (Mallick et al. 2000).

h) Falling Head Permeability Test

This test method was used to find hydraulic conduction of compacted OGFC samples. ASTM D3637 was referred for this test.

A falling head permeability apparatus was used in this study. Water from graduated cylinder was allowed to flow through saturated sample and time required to achieve predetermined head value was noted A minimum permeability of 100m/day is considered to be sufficient for proper drainage of water (Shen et al. 2009); (Kandhal & Mallick 1999), (Shirini & Imaninasab 2016). The equation for the coefficient of permeability is as follows:

$$k= \frac{a\times L}{A\times t}\times l_n(\frac{ho}{h1}) \qquad \text{……….(20)}$$

where k is coefficient of permeability, a: area of pipe ; L: length of specimen, A: area of sample equal to, t: elapsed time (seconds), h_o: head at the beginning of test, h_t: head at the end of test.

Figure 3.13: Falling Head Permeability Test Setup for OGFC.

i) Drain down Test

The test was proceeded as per AASHTO T305. This test is significant for mixes containing higher coarse content like OGFC. Lack of fines in OGFC under elevated temperature can lead to bleeding problem. The portion of binder along with some fines separate and flows downward is called draindown. This test is used to measure the amount of drain down from an uncompacted sample. This test helps in understanding the behaviour of the mix during production, storage, transportation and placing stages. In this test, the samples were prepared at their respective optimum binder content and then placed immediately in wire basket made of 6.3mm size. The basket was then put on a plate of known weight and together were placed in an oven for one hour at 120°C. After the heating period, amount of material drained out on the plate was measured. Drain down value must not exceed 0.3% by weight of mixture, and is calculated as:

$$\text{Draindown} = \frac{A-B}{C-D} \qquad \text{…….. (21)}$$

Where A is the total weight of material drained and tray after one hour in the oven, B is the empty weight of tray, C is the weight of wire basket with sample and D is the empty weight of wire basket. All weights measured in grams.

3.4) Binder

Ministry of Road Transport and Highways 2013 (MoRT&H 2013), suggest that selection of binder should be based on local temperature condition. The intended use of waste is in local and neighbouring areas of Kota, Rajasthan, where highest daily mean temperature is more than 30ºC, hence as per clause 500.1.2, VG-30 was used as binder agent for bituminous concrete and dense bituminous macadam. For open-graded friction course, use of modified bitumen is recommended (Lyons & Putman 2013), (Lo Presti 2013), (Washington Transportation Research Board 2015). Use of crumb rubber modified bitumen give better performance on properties like rutting resistance, skid resistance, durability and moisture susceptibility resulting in increase in service life of pavement (Frigio et al. 2013), (Shirini & Imaninasab 2016). Hence, in this study, crumb rubber modified bitumen of grade-60 (CRMB-60) was used. Following tests were performed on each binder.

a) Penetration test

This test is used to measure hardness and consistency of bitumen. It is the vertical distance travelled by standard needle of approximate diameter of 1 to 1.02mm and length of 50mm into the bitumen surface. The test proceeded as per IS 1203(1978).

b) Softening Point test

Test procedure followed was as per IS 1205(1978). The test purpose is to find the temperature at which the binder attain specific softening condition. Ring and ball apparatus was used to carry out the test. A brass ring containing binder sample was suspended in water. A steel ball of diameter and weight is placed over the ring. Water is heated at a temperature of 5ºC per minute. The point at which the binder becomes soft and touch the metal plate is noted.

c) Flash and Fire point

Flashpoint is the lowest temperature at which binder start vaporizing and cause fire flickers and Fire is the minimum temperature at which the binder catches fire. The test proceeded as per IS 1209(1978). Binder sample was first softened, stir, removed air bubble if any and then poured in a cup, covered with lid. Thermometer is fixed to measure the flash and fire point temperature. Heating is of sample was proceeded and test flames are applied at regular interval till flash and fire point is recorded.

d) Specific Gravity

Test proceeded as per IS 1202 (1978). Empty weight of clean and dry specific gravity bottle is noted. The bottle was then filled with distilled water and then with binder; both weights were noted. After this weight of specific gravity bottle half filled with biner was noted and then another weight reading was taken where the other half was filled with water. Specific gravity was calculated using formula:

Specific gravity of bitumen= $\frac{C-A}{[(B-A)-(D-C)}$ …….. (22)

Where,

A is empty weight of bottle, B is weight of bottle filled with water, C is weight of specific gravity bottle half filled with bitumen, D is weight of bottle half filled with bitumen and another half with water and E is weight of bottle completely filled with bitumen. All weights are in grams.

CHAPTER-4

RESULT AND DISCUSSION

4.1 Kota Stone Slurry and Aggregates as Pavement Material

For the present study black cotton soil (BCS), Kota stone slurry (KSS) and recycled Kota stone aggregates (KSA) were evaluated on the basis of physical and chemical parameters. 10 soil sample with KSS replacement between 2.5% to 20%, six granular sub-base mixes and 15 HMA (5 each of BC, DBM and OGFC) prepared by replacing basalt aggregates with KSA were evaluated. Beginning from physical, chemical properties of individual material properties of non-bituminous and bituminous mixes presented in this chapter.

4.2 Soil and Slurry Properties

Geotechnical properties of soil and slurry are summarized in Table 4.1. The chemical composition of Kota stone slurry/aggregates are summarized in Table 4.2. Presence of calcium oxide as dominant component establish this material as limestone. Use of calcium oxide based material as stabilizer has always been preferred to improve soil properties (Olinic & Olinic 2016). Studies pertaining to successful use of limestone waste as stabilizing agent for black cotton soil, summarized in literature review, suggest that this waste can also be successfully used to stabilize black cotton soil found in the local area.

Table 4.1: Properties of Black Cotton Soil and Kota Stone Slurry.

Parameters	BCS	KSS	Code
Soil Type	CI	-	IS: 1498 (1970)
Liquid limit (%)	49.2	23.90	IS:2720 Part V (1985)
Plastic limit (%)	20.1	Non-Plastic	
Optimum moisture content (%)	20.5	21.9	IS: 2720 Part VII (1980)
Maximum Dry density (gm/cc)	1.524	1.604	
Specific Gravity	2.62	2.87	IS: 2720 Part III (1980)
Fineness Modulus	5.17	2.16	IS: 383 (1970)

Table 4.2: Chemical Composition of Black Cotton Soil and Kota Stone.

Chemical composition (in %)	CaO	SiO_2	MgO	Fe_2O_3	Al_2O_3	LOI
Black cotton soil	6.15	65.45	2.01	4.98	Traces	Nill
Kota Stone	37.15	23.14	7.02	Traces	Nill	31.89

*LOI= Loss on ignition

a) Gradation

Gradation of Black Cotton Soil (BCS) and Kota Stone Slurry (KSS) material passing is shown in Figure 4.1, Figure 4.2 and Figure 4.3 respectively. Individual particle size distribution test results indicate KSS finer as compared to BCS. Majority of 75 microns passing BCS particle lie between 10 microns to 100 microns where as in KSS particle size range between 0.5 microns to 100 microns.

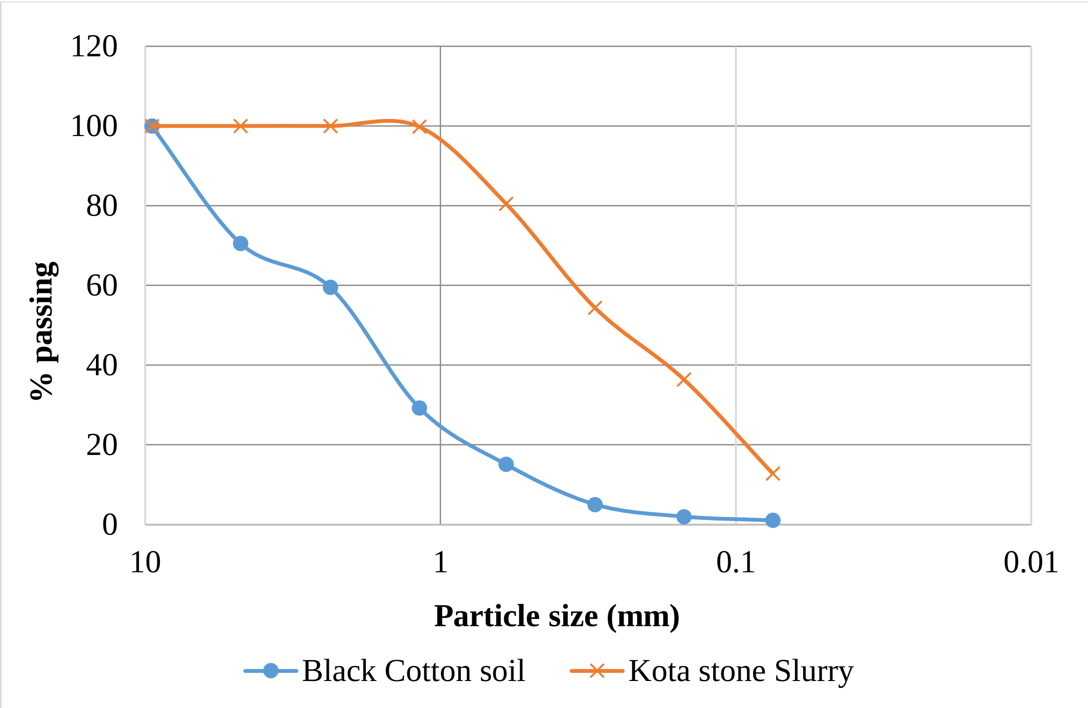


Figure 4.1: Gradation of Soil and Slurry Particles.

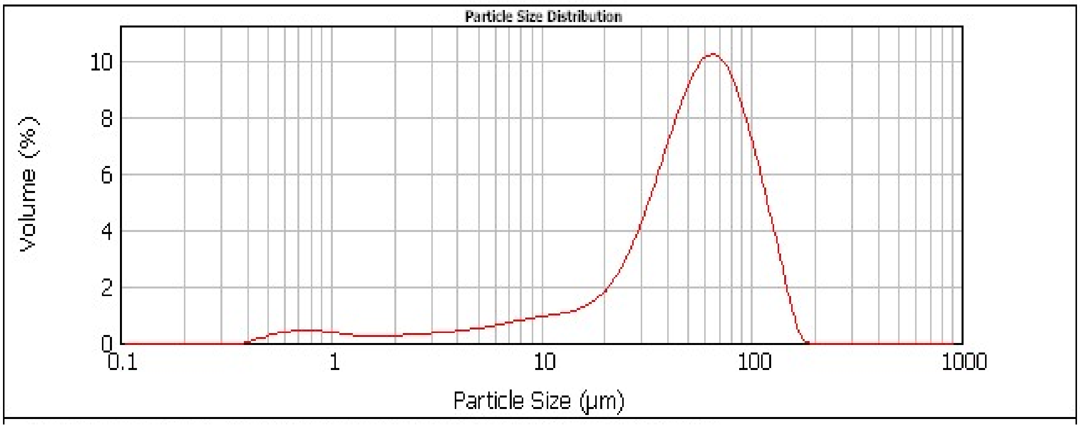


Figure 4.2: Particle Size Distribution (finer than 75 microns) of Black Cotton Soil.

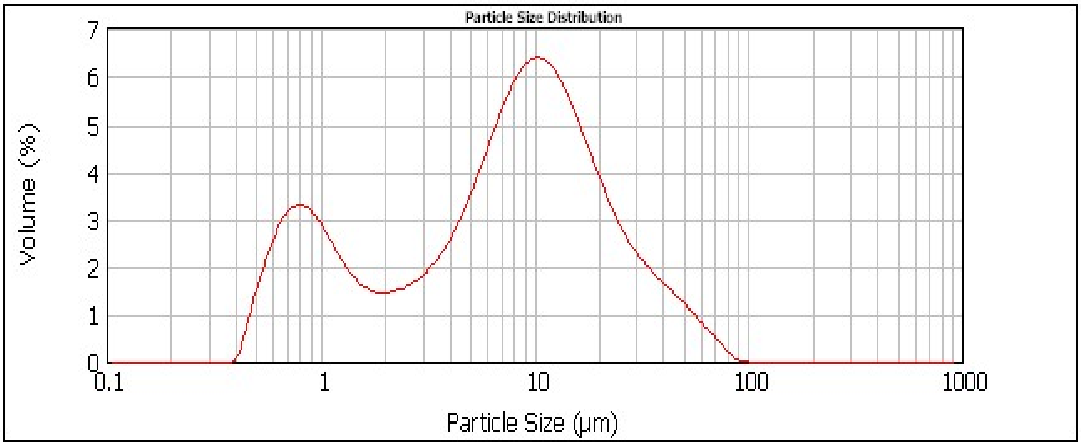


Figure 4.3: Particle Size Distribution (finer than 75 microns) of Kota Stone Slurry.

4.2.1. Black Cotton Soil- Kota Stone Slurry Mixes

a) Index Properties

Figure 4.4 shows the result of liquid limit, plastic limit and plasticity index obtained by replacing Black cotton soil (BCS) with Kota stone slurry (K). With the addition of slurry to the soil samples, the liquid limit decreased, plasticity limit increased which in turn lead to an overall decrease in plasticity Index of soil, indicating improved workability of the mixture. This was also experienced during sample preparation for proctor test and CBR test, where, with an increase in slurry proportion in the mixes, the mixing, casting and extraction of material from the mould required less effort as compared to control soil sample. The reason for decreased plasticity index was attributed to cation exchange reaction taking place between clay particle and calcium ion of slurry, leading to flocculation of particles which in turn behave like silt particles (Bell 1996). Depending on liquid limit value and plasticity index obtained, the classification of soil as per IS 498 (1970) changed from lean clay to mild silt upon addition of 20% slurry to the soil.

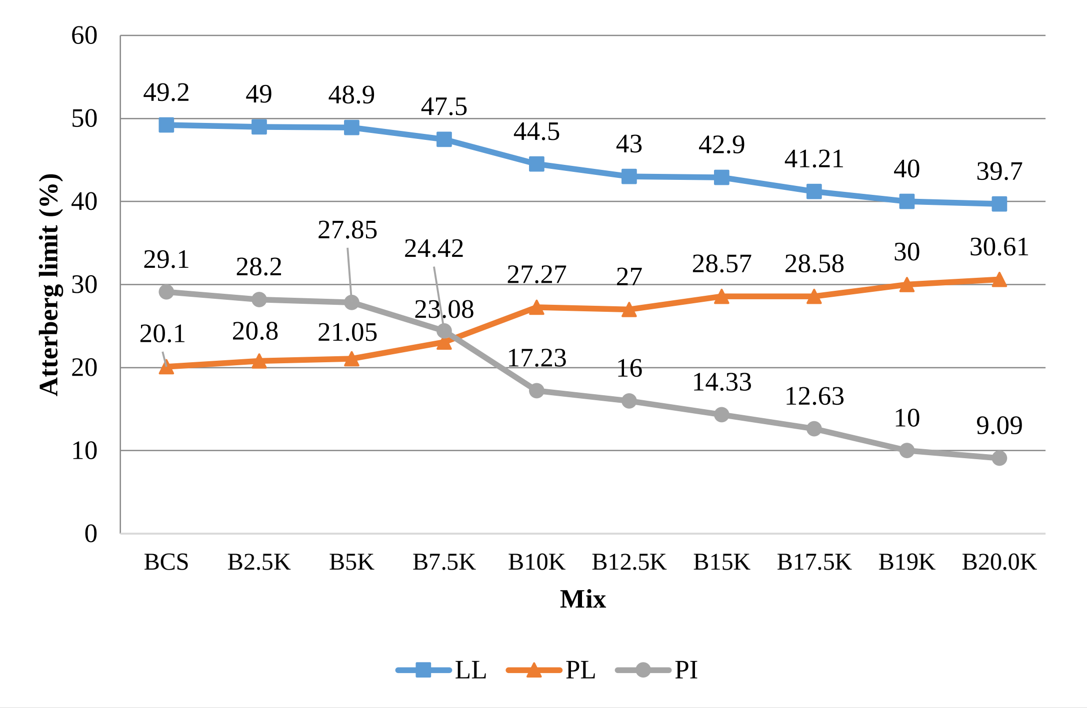


Figure 4.4: BCS-KSS Atterberg Limits.

b) Optimum Moisture Content and Maximum Dry Density

Figure 4.5 shows OMC and MDD of samples obtained with the addition of Kota stone slurry. An overall observation of OMC data summarizes that with the addition of slurry, water requirement and maximum dry density of soil samples followed an incremental trend. The increase in water requirement was attributed to higher proportion of smoothly textured slurry particles, demanding more water for lubrication (Modarres & Nosoudy 2015). Addition of slurry resulted in formation of hard cementitious matrix with improved maximum dry density. MDD of soil improved from 1.524gm/cc to 1.66gm/cc on 19% replacement, after which, an increase in the volume of voids, created due to flocculation and agglomeration of soil and slurry particles lead to decrease in MDD of the mix.

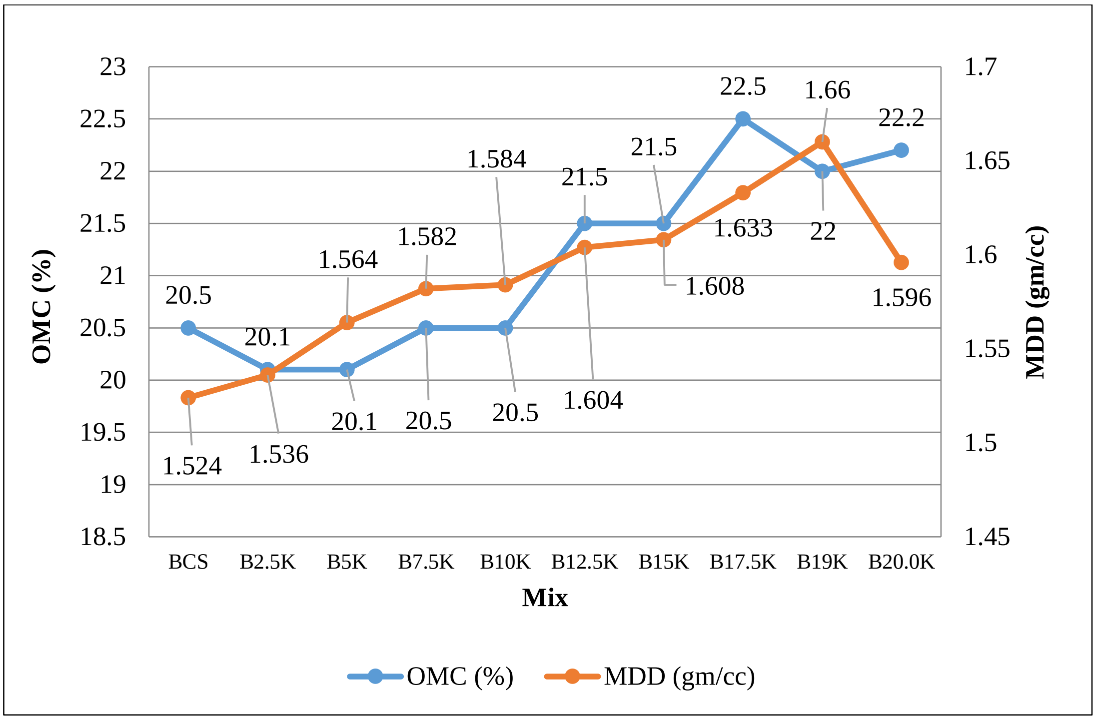


Figure 4.5: BCS-KSS OMC and MDD

c) California Bearing Ratio

Figure 4.6 illustrates the results of soaked CBR test for soil samples. The CBR value increased from 2.05% of neat soil sample to 15.63% with 19% addition of slurry after which it decreased. The increment in bearing capacity was more prominent when slurry proportion increased beyond 7.5% in the mix. This behaviour was attributed to the fact that till 7.5%, KSS was acting as filler material, occupying voids between clay particles. After 7.5% replacement, improvement in strength of sample was attributed to pozzolanic elements present in additive (Bell 1996). Addition of slurry to soil sample lead to pozzolanic activity under submerged water condition, forming calcium silicate hydrate gel leading to improved strength properties. Based on test results, it was established that the use of Kota stone modified black cotton soil can be used as subgrade in flexible pavements.

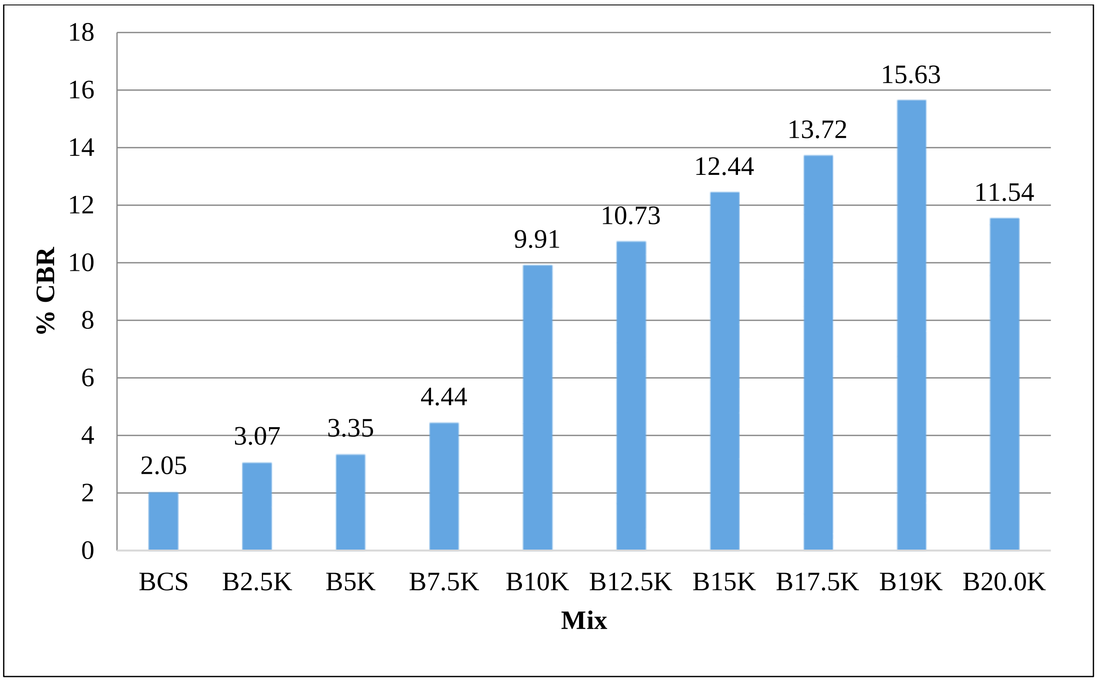


Figure 4.6: BCS-KSS CBR

d) Resilient Modulus

Based on obtained CBR values, resilient modulus of each sample was calculated by correlation equations 9 and 10, results of which are shown in Figure 4.7. Sample containing 19% slurry gave maximum resilient modulus value of 102.25MPa which was about 400% higher than that obtained for the controlled black cotton soil sample which was 20.5 MPa respectively. Since the correlation equation used CBR value for resilient modulus assessment, the improvement in resilient modulus value is directly related to improvement in overall bearing capacity of the samples.

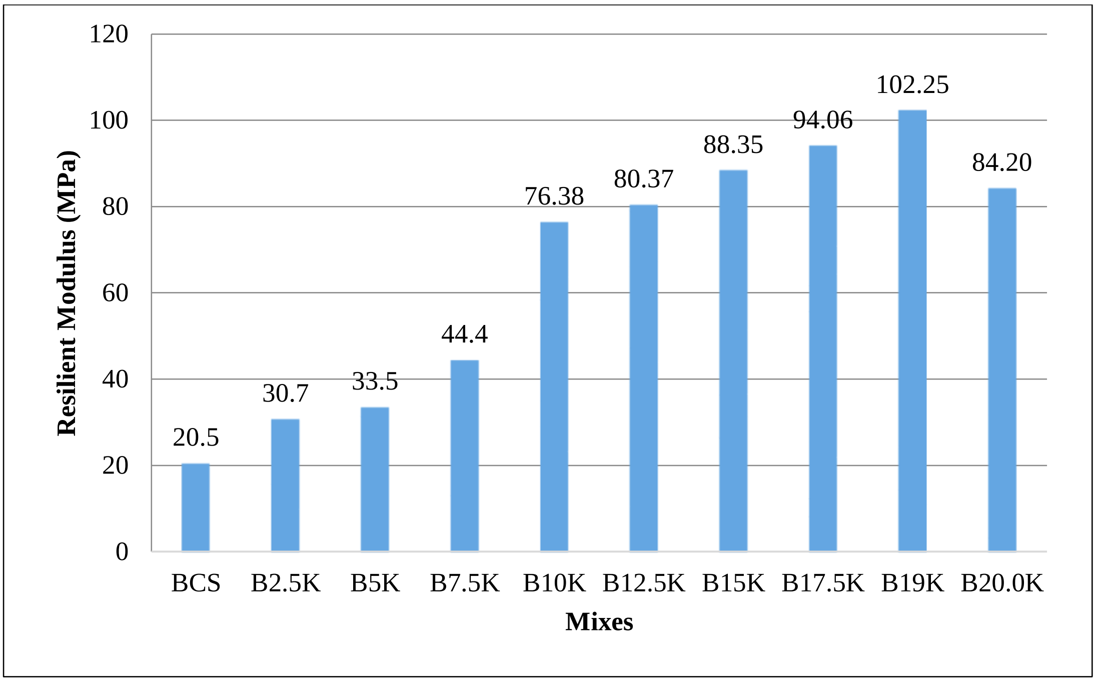


Figure 4.7: BCS-KSS Resilient Modulus.

e) Unconfined Compressive Strength Test

The result of UCS and shear strength of mixes are presented in Figure 4.8. The peak UCS and shear strength value in dry state was obtained with the inclusion of 17.5% Kota stone slurry in soil sample after which it decreased. This increment was due to a well-graded structure between soil and slurry particles.

For Wet-UCS, it was observed that inclusion of KSS improved strength and shear properties, however, obtained values were less compared to their respective Dry-UCS sample. This was because the sample preparation for UCS requires material passing 425 micron sieve size. The material obtained through this majorly consists of slurry particles, which are smooth and have less cohesion. However, each Wet-UCS mix satisfied criteria of maximum allowable strength loss of 20% of Dry UCS value (Eze-Uzomaka et al. 2010).

The axial stress-strain behaviour of KSS stabilized BCS is presented in Figure 4.9 and Figure 4.10 for the dry-UCS and wet UCS respectively. It was observed that no sudden drop in peak stress, indicating ductile failure of the mixes. After attaining peak stress, the failure of sample was attributed to slipping action between round KSS particles.

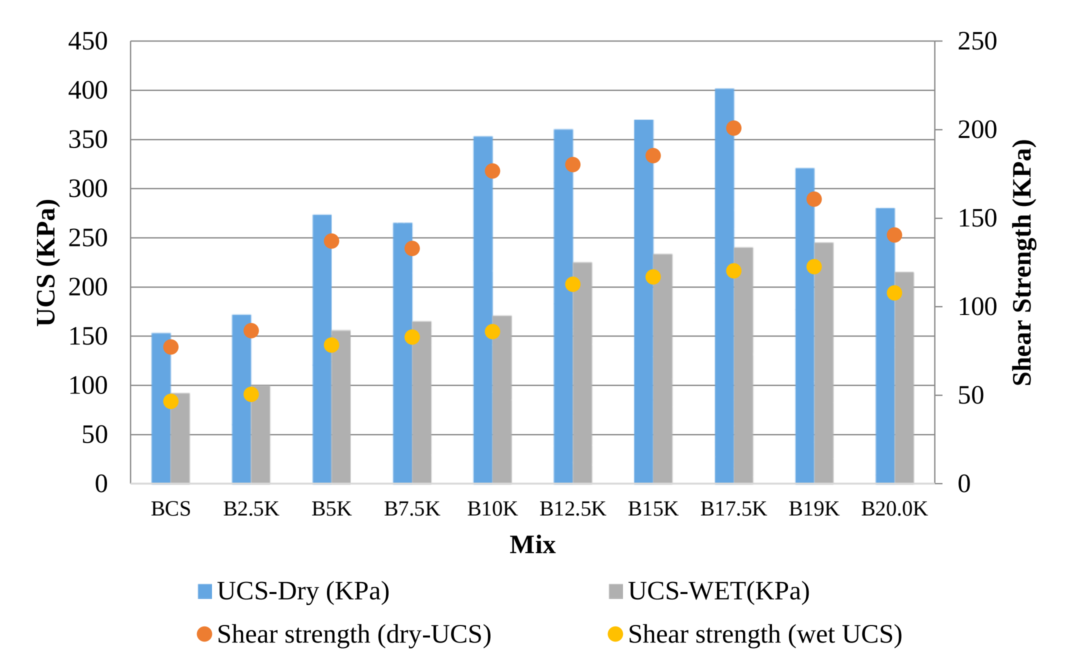


Figure 4.8: Dry and Wet UCS of BCS-KSS.

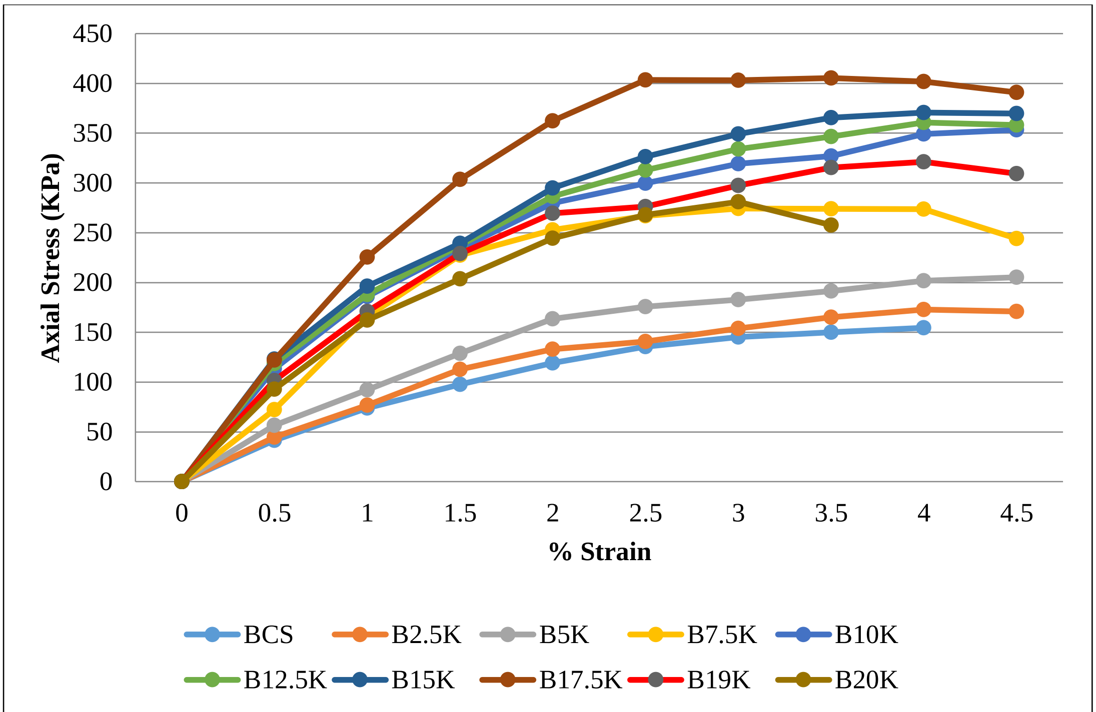


Figure 4.9: Stress-Strain of BCS-KSS in Dry-UCS.

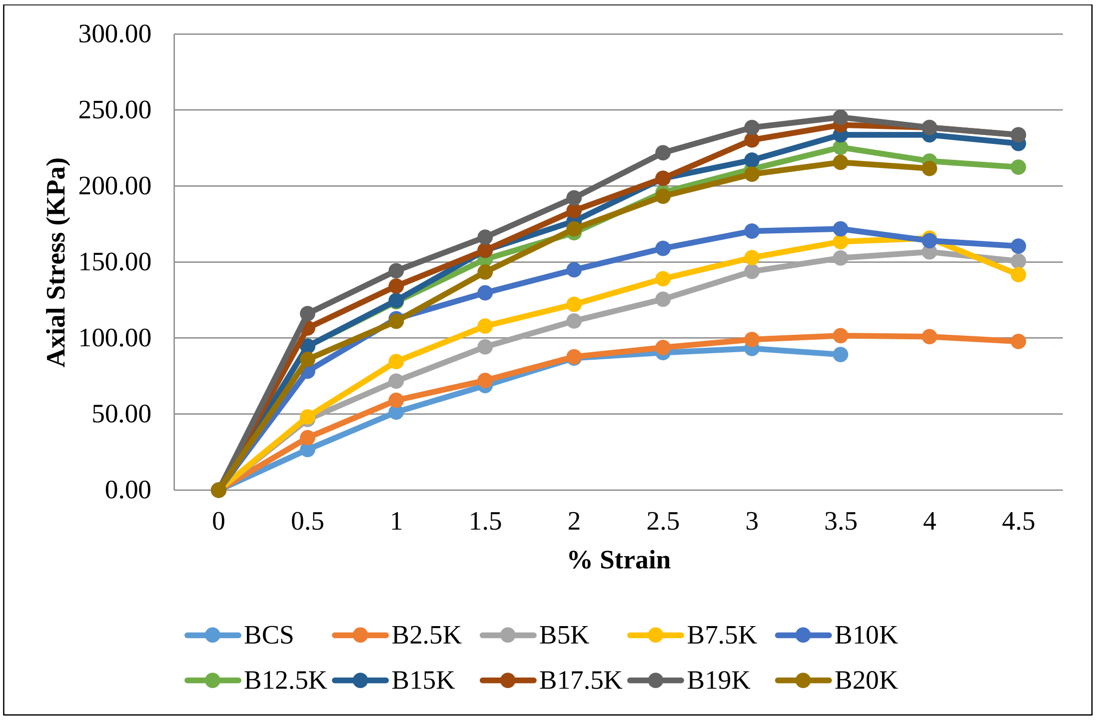


Figure 4.10: Stress-Strain of BCS-KSS in Wet-UCS

f) Free Swell Index

The results of the free swell index of treated and untreated soil sample are presented in Figure 4.11. Swelling in mix decrease with increase in Kota stone slurry. This behaviour was attributed to addition of non-expansive KSS and to reduction of clay content in soil matrix upon the addition of slurry as by weight replacement method. The free swelling index reduced to 34.4% with 20% KSS replacement into BCS. Slurry was not able to control swelling property completely.

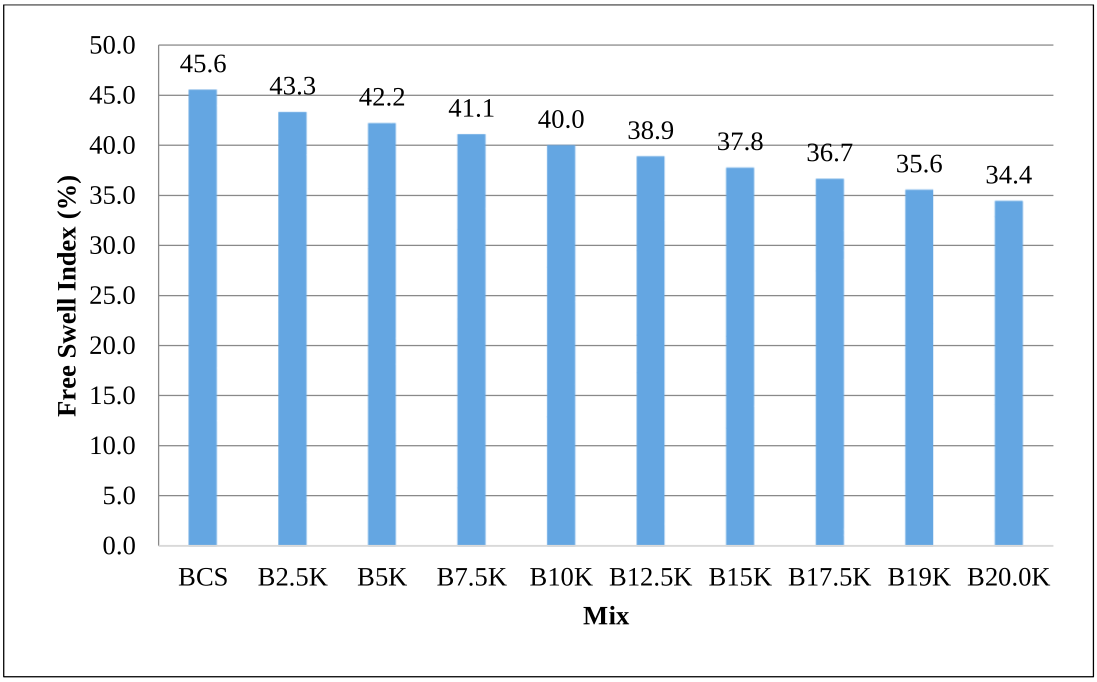
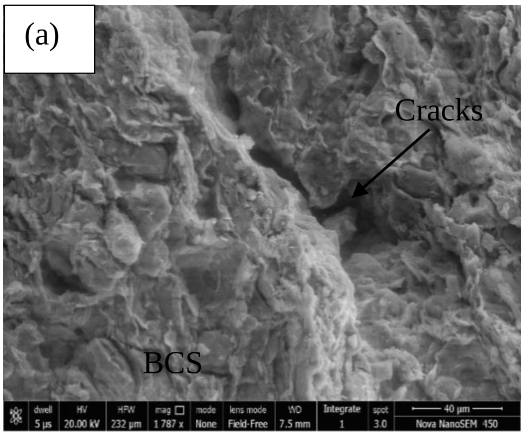


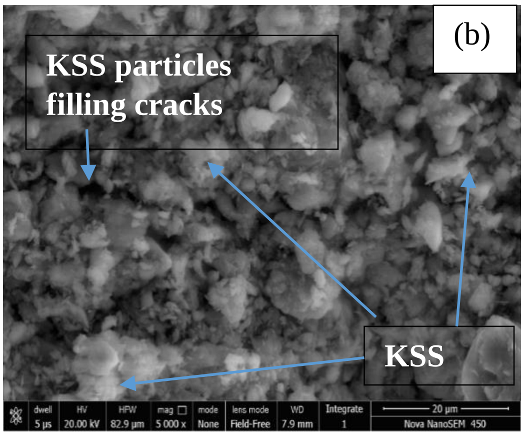
Figure 4.11: BCS-KSS Free Swell Index.

g) Scanning Electron Microscope Analysis

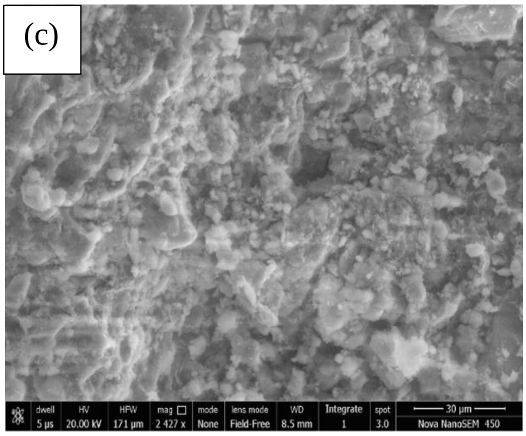
Figure 4.12(a) shows SEM image of black cotton soil sample, where an irregular, discontinued structure containing cracks clearly visible. These cracks were observed to be filled by slurry particle as shown in Figure 4.12 (b) SEM image of sample containing 5% Kota stone slurry. Figure 4.12 (c) shows image of sample B10K, where formation of calcium silicate hydrate visible. The effect of this was observed at lower magnification of same sample, which gives a dense, well structure image (Figure 4.12 (d)) compared to that of SEM of BCS. The CSH gel was more prominent in magnified image of sample B19K as shown in Figure 4.12 (e). A more uniform, well-packed structure with improved MDD, CBR and UCS value of soil sample containing KSS.



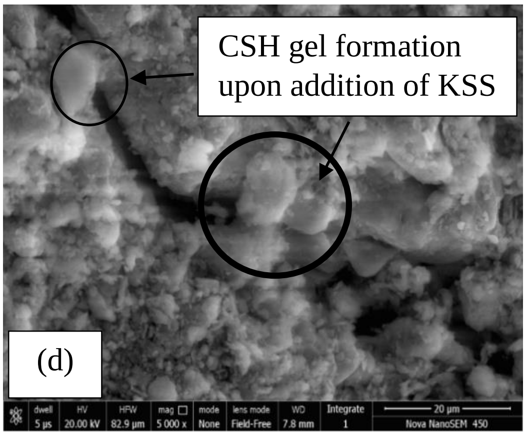
Neat Black Cotton Soil Sample



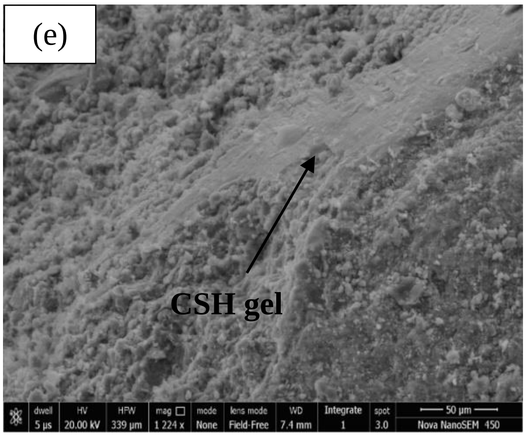
B5K sample



B10K Sample



B10K sample at higher magnification



B19K sample

Figure 4.12 (a-e) SEM images of BCS-KSS samples.

4.3 As Aggregate Material in Granular Sub-Base Course.

The KSA was subjected to physical property tests, results of which are summarized in Table 4.3. Figure 4.13 shows a relative difference in the physical texture of KSA and conventional aggregates used for the study. The surface of KSA observed comparatively smoother than conventional aggregates.

From the test result, it was established that recycled/reformed Kota stone aggregates (KSA) has required physical attributes which make it fit to be used as aggregates in GSB and HMA.

Figure 4.13: Texture Difference of Kota Stone Aggregates (left) Compared to Conventional Aggregate (right)

Table 4.3: Aggregate Property Test Results.

Property	**KSA**	**Conventional aggregate**	**Permissible Value**	**Test Method**
Los Angeles test (500 revolution)	25.34 %	14.26%	35% max.	IS:2386 Part IV (1963)
Impact test	18.41%	13.53%	27% max.	IS:2386 Part IV (1963)
Water Absorption Test	0.23%	0.18%	2% max.	IS:2386 Part III (1963)
Combined Flakiness and Elongation indices	33 %	28.24%	35% max	IS: 2386 Part I (1963)
Bulk Specific Gravity of Coarse Aggregate (gm/cc)	2.87	2.75	-	IS :2386 Part III (1963)
Stripping value	100%	99%	Minimum retained coating 95%	IS:6241 (1971)

Section 401.2.1 of MoRT&H 2013 specifies six gradation for granular sub-base material. Table 4.4 shows gradation achieved using recycled KSA and recommended gradation range as per code. Gradation of reformed Kota stone aggregates (KSA) in granular sub-base course and base course were achieved using hit and trial approach.

Table 4.4 KSA Gradation with Recommended Limits.

Sieve Size (mm)	Combined Grading Achieved / **Recommended Passing Percentage**					
	Grade 1	**Grade 2**	**Grade 3**	**Grade 4**	**Grade 5**	**Grade 6**
75	100.00% / **100**	-	-	-	100.00% / **100**	-
53	94.75% / **80-100**	100.00% / **100**	100% / **100**	100.00% / **100**	100.00% / **80-100**	100.00% / **100**
26.5	68.15% / **55-90**	81.80% / **70-100**	65.42% / **55-75**	65.42% / **50-80**	86.35% / **55-90**	81.80% / **75-100**
9.5	56.27% / **35-65**	66.91% / **50-80**	-	-	64.05% / **35-65**	66.91% / **55-75**
4.75	37.85% / **25-55**	44.05% / **40-65**	29.08% / **10-30**	27.74% / **15-35**	36.12% / **25-50**	44.05% / **30-55**
2.36	31.25% / **20-40**	30.50% / **30-50**	-	-	19.50% / **10-20**	22.50% / **10-25**
.85	-	-	-	-	5.45% / **2-10**	-
.425	11.77% / **10-15**	8.97% / **10-15**	-	-	1.87% / **0-5**	7.97% / **0-8**
0.075	2.32% / **< 5**	2.57% / **< 5**	2.46% / **< 5**	1.63% / **< 5**	-	2.57% / **< 5**

a) Optimum Moisture Content and Maximum Dry Density

After ascertaining that aggregates derived from Kota stone fulfil the physical parameters, they were mixed in respective gradations; OMC and MDD of each sample were found using modified proctor test. Test result showed that all sample gave satisfactory MDD value. Highest compaction value was obtained by sample K2 while sample K3 and sample K6 gave comparatively lesser MDD value. Samples prepared for soaked CBR were on respective OMC obtained. Figure 4.14 shows OMC and MDD obtained.

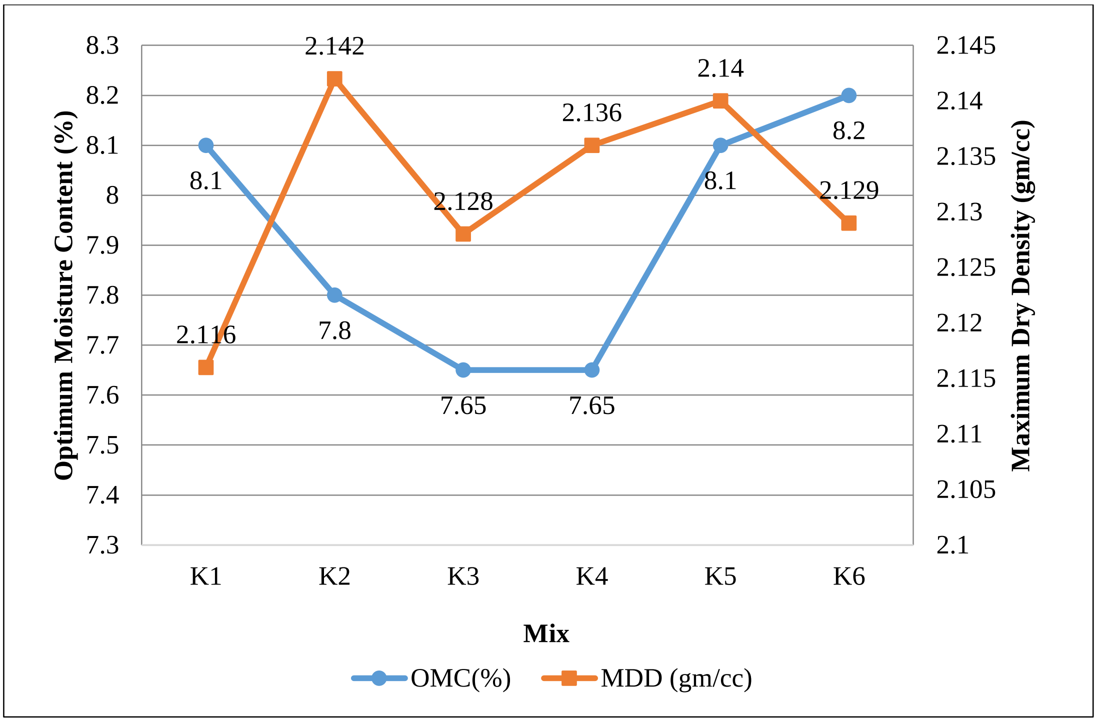


Figure 4.14: OMC and MDD of GSB mixes

b) California Bearing Ratio

Figure 4.15 compiles the values obtained by soaked CBR test. All the GSB specimen satisfied minimum CBR value of 30% indicating suitability of waste Kota stone aggregate as granular sub-base material. Highest CBR value was obtained for sample K1 and K2 belonging to gradation 1 and 2 respectively. The reason for this can be attributed to well-graded gradation specification resulting in dense well-compacted sample which resulted in higher bearing capacity. Using KSA as Water Bound Macadam (WBM) and Wet Mix Macadam (WMM) mixes were prepared and tested for their suitability as base course material by Pawan Patidar (2014). The Result of this study align with the study by Pawan Patidar. (2014), supporting the use of KSA as granular sub-base.

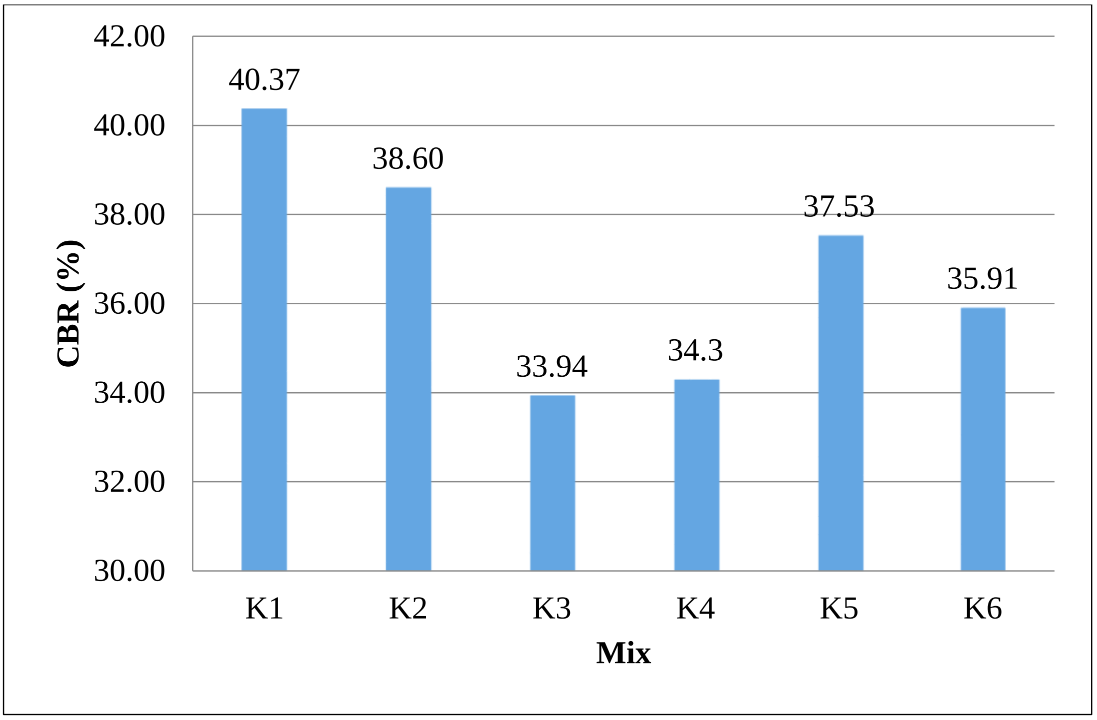


Figure 4.15: Soaked CBR of GSB mixes.

4.4 As Aggregates in Base Course/Wearing Course.

An aggregate to be used in HMA should be hydrophobic, i.e. water hating in nature (Tarrer & Wagh 1991). Carbonate rock, such as limestone is known to exhibit water repelling characteristics and exhibiting excellent resistance against stripping of asphalt. Same was observed in stripping test conducted on KSA, seen in Table 4.3 supporting its usability in HMA.

For bituminous concrete and dense bituminous macadam, gradation type 2 was used as specified by section 505 and 507 of MoRT&H 2013. For Open graded friction course (OGFC), gradation specified by National Centre for Asphalt Technology (NCAT) was adopted. In HMA, the procedure adopted for replacement of KSA as replacement of conventional aggregates was done similar to Montegomry et al. (1996). KSA were washed, dried and sieved through standard sieves and then mixed to obtain gradation similar to that for conventional aggregates. This method helps in maintaining homogeneous gradation in all mix replacements, eliminates chances of variation in binder content for durability and mechanical property analysis (Qasrawi & Asi 2016). Properties of the VG-30 and CRMB-60 are summarized in Table 4.5

Table 4.5: Binder Properties of VG-30 and CRMB-60 Bitumen.

Properties	**Value for VG-30**	**Values for CRMB-60**	**Test Method**
Penetration value at 25°C (0.1mm, 5sec)	64	55	IS: 1203(1978)
Softening point	47°C	60°C	IS: 1205(1978)
Flashpoint	220°C	220°C	IS: 1209(1978)
Bulk specific gravity (g /cm^3)	0.99	1.01	IS:1202(1978)

I. Bituminous Concrete

a) Gradation and Marshall Test Results

The gradation used for BC mixes as shown in Figure 4.16. Once the aggregate achieved desired gradation, Marshall mix design method was used for sample preparation and finding Optimum binder content (OBC). OBC was taken as average of binder content giving maximum stability, 4% air void and maximum density. Each replacement mix was fabricated at their respective OBC and tested for Marshall Parameters; results of which are summarized in Table 4.6. Detail graphs showing mix properties viz binder vs stability, bulk density, VMA, VFB and flow values are attached in Appendix.

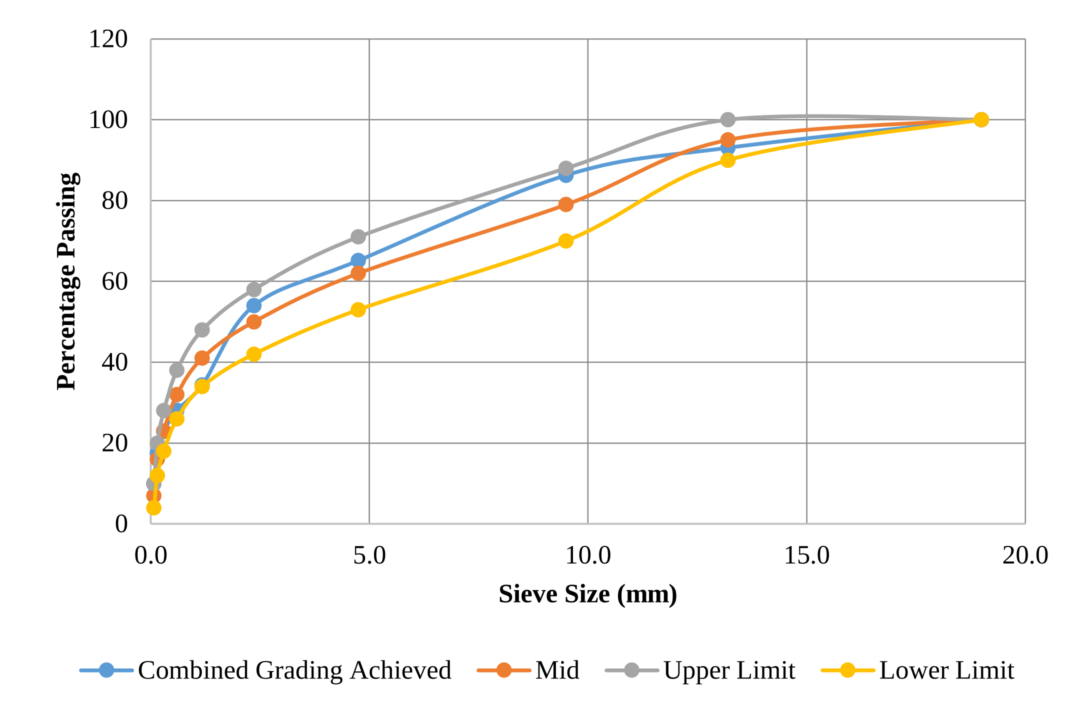


Figure 4.16: Gradation Curve for BC Mix

All BC mixes satisfied the minimum binder content requirement as per specifications. Stability values were observed decreasing with inclusion of KSA. However, all BC mixes satisfied the minimum stability criteria(9KN) ; except 100K-bc, mix flow value of mixes were within permissible limits, indicating proper interlocking and friction between aggregates particles. The reason for mix 100K-bc to surpass the recommended value was attributed to smooth texture of KSA which may have caused sliding of aggregate particles over one another, thus giving a higher flow value. As for overall mix behaviour, shown by Marshall quotient, BC mixes satisfied the required criteria indicating required strength, rigidity, and flexibility. The bulk specific gravity was observed increasing with increase in KSA proportion; this increment was attributed to the higher specific gravity of KSA as compared to conventional aggregates. Decrease in air voids with addition of KSA resulted into improved bulk density of mixes. A marginal decrease in binder content was also observed with increase in KSA content in BC mixes.

Table 4.6: Marshall Parameters at Respective OBC

	C-bc	25K-bc	50K-bc	75K-bc	100K-bc
Stability (KN)	12.08	11.72	11.242	10.291	10.346
Flow Value (mm)	3.34	3.51	3.78	3.91	4.4
Bulk Density (gm/cc)	2.415	2.415	2.421	2.43	2.512
Air Void (%)	4.32	4.1	4.1	3.9	3
VMA (%)	18.9	18.14	18.94	18.46	17.83
VFB (%)	77.219	78.09	78.51	79.58	83.30
OBC (%)	6.3	6.13	6.37	6.27	6.1

b) Indirect Tensile Strength and Tensile Strength Ratio

Figure 4.17 and Figure 4.18 shows ITS and TSR results of BC mixes. In general, a decreasing trend was observed with inclusion of KSA in the mixes. For dry-ITS test, the rate of decrease in strength was about 11-16% with inclusion of KSA. In wet-ITS, similar trend was observed. The reason for the decrease in strength was attributed to flakiness of KSA, which compromise the tensile strength of mixes. Due to breaking down of weak edges and accumulation of fines at aggregate edges (as can be seen in SEM images Figure 4.19). During conditioning of samples for Wet-ITS test, interlocking between KSA aggregates reduced which resulted in further decrease in strength. A minimum recommended TSR value of 80% was satisfied by mixes 25K-bc and 50K-bc establishing their effectiveness in resistance against moisture condition.

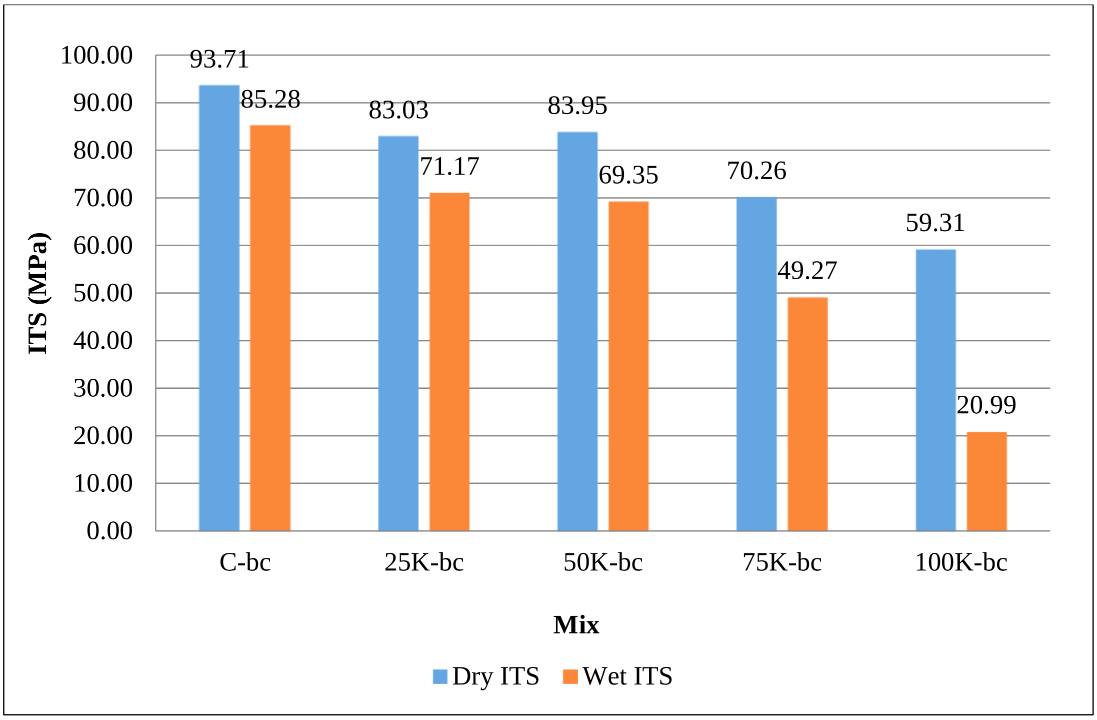


Figure 4.17: ITS of BC Mixes

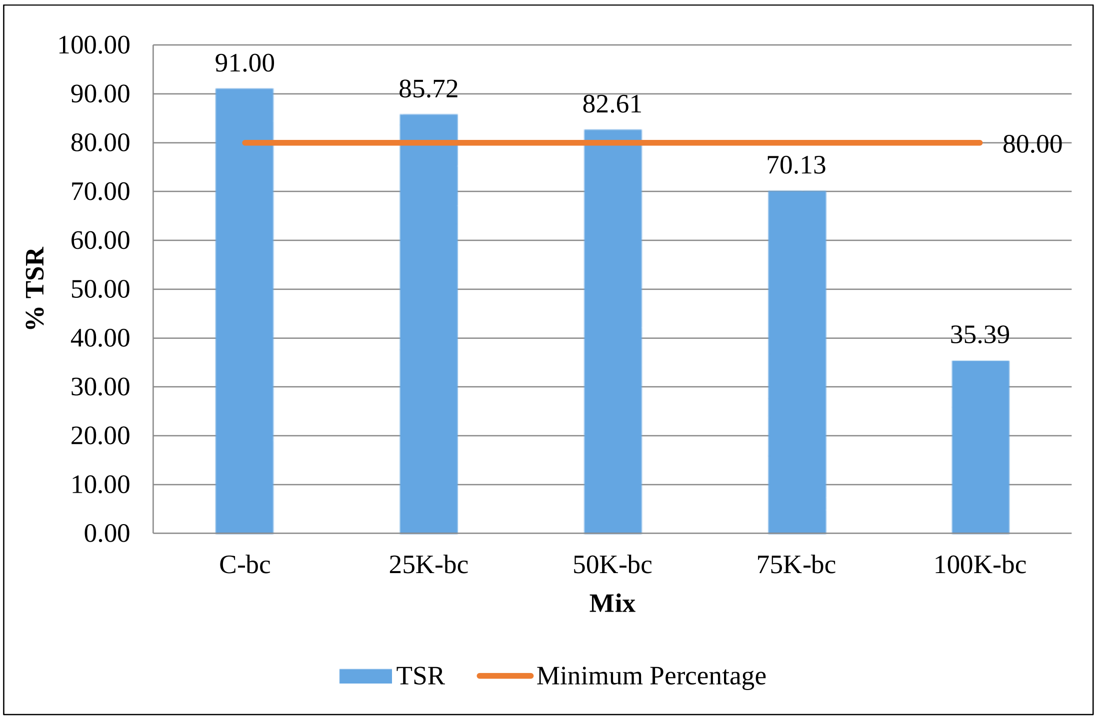
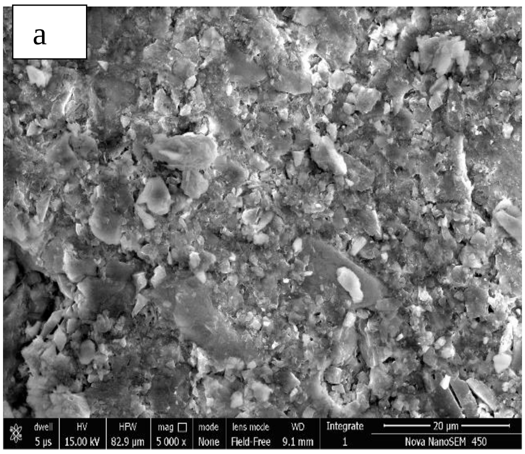
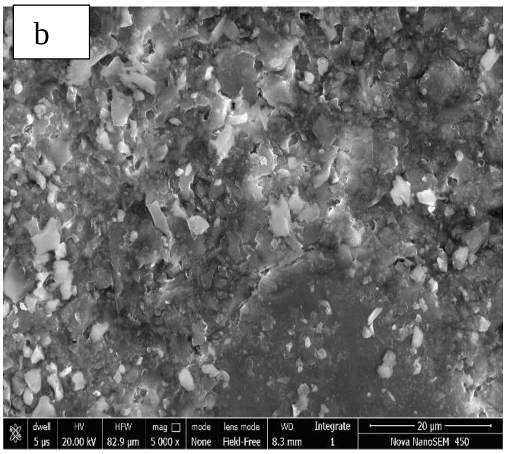


Figure 4.18: Tensile Strength Ratio Values for BC Mixes.

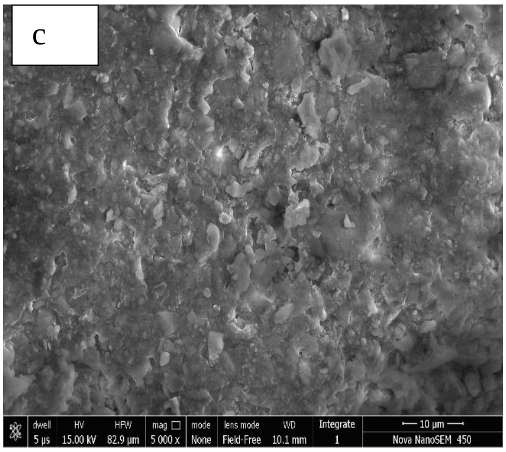
Figure 4.19 shows surface morphology images of 25K-bc and 50K-bc showing dense, well compactedplate like pattern similar to that of sample C-bc. As the proportion of KSA increases beyond 50%, a more irregular structure pattern was observed. Samples containing 75% KSA and 100% KSA showed segregation of fines along the edges of KSA. Uneven distribution of fines compromised the overall strength of mix 75K-bc and 100K-bc. The effect of which was more prominent when samples were subjected to resistance to moisture condition, where, sample 75K-bc and sample 100K-bc failed to achieve the desired standards.



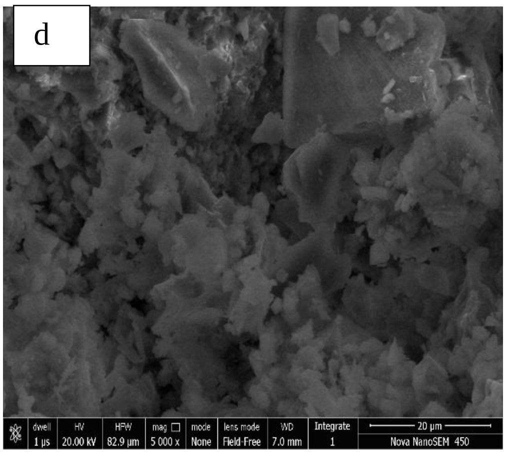
C-bc sample



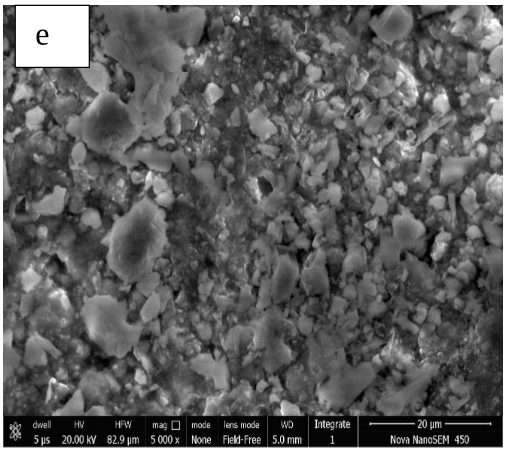
25K-bc sample



50K-bc Sample



75K-bc Sample



100K-bc

Figure 4.19: SEM images of C-bc, 25K-bc, 50K-bc, 75K-bc, 100K-bc

c) Dynamic Creep Test

Figure 4.20 shows the test results of dynamic creep test. As the proportion of KSA increases, accumulated strain was also observed increasing, indicating early permanent deformation and decrease in service life. It was noted that by 6485th cycle all mixes reached the tertiary stage. Percentage actuator strain value at 6485th pulse count as shown in Table 4.7 for each BC mix. With increase in KSA content in BC mixes flow number observed decreasing, indicating low resistance of these mixes toward permanent deformation.

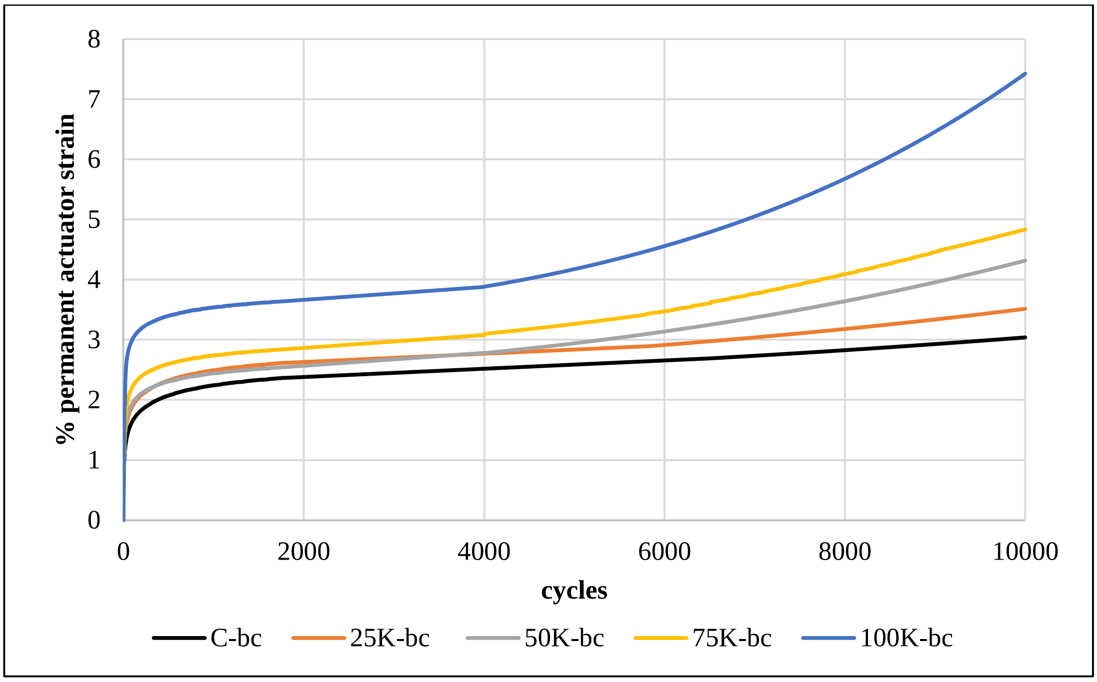


Figure 4.20: Dynamic Creep Test Result for BC Mixes

Table 4.7: Percentage Actuator Strain Value for BC Mixes

Mix	**Permanent actuator strain (%)**
C-bc	2.689
25K-bc	2.972
50K-bc	3.245
75K-bc	3.601
100K-bc	4.782

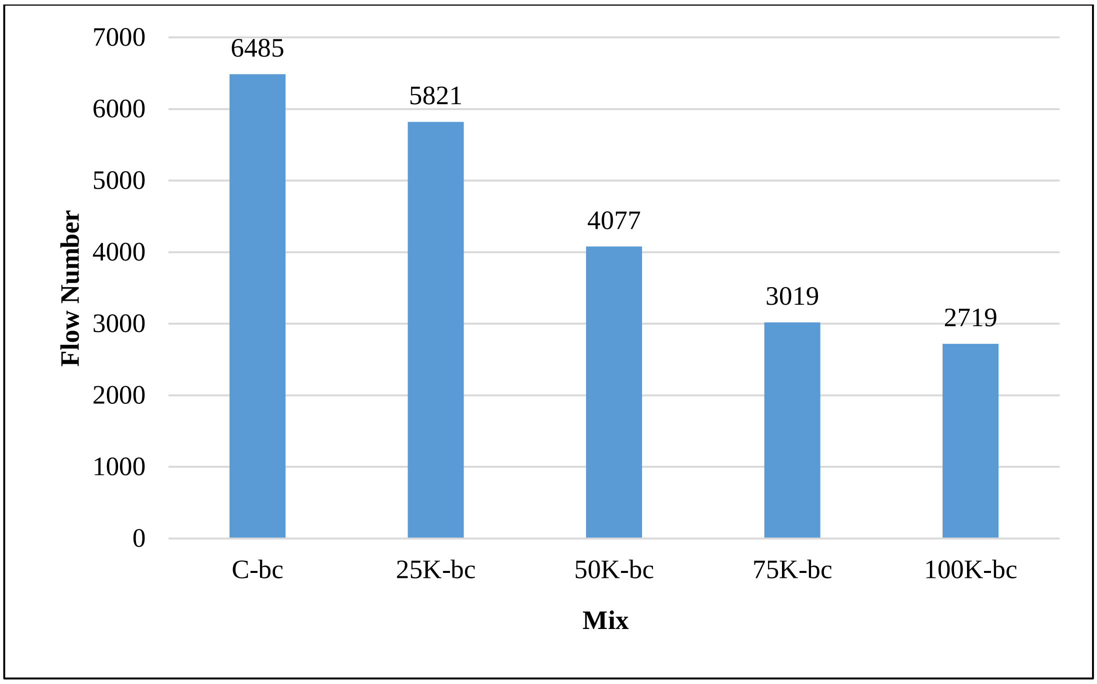


Figure 4.21: Flow Number Results for BC Mixes.

d) Resilient Modulus Test

As per guidelines of IRC 37 (2012): Design of flexible pavement, under section 7.4, Table 7.1 recommend that for BC and DBM mixes with using VG30 as binder (tested at 35°C) must have a minimum resilient modulus value of 1700 MPa. Using KSA up to 50% in BC satisfies desired specification; results as shown in Figure 4.22.

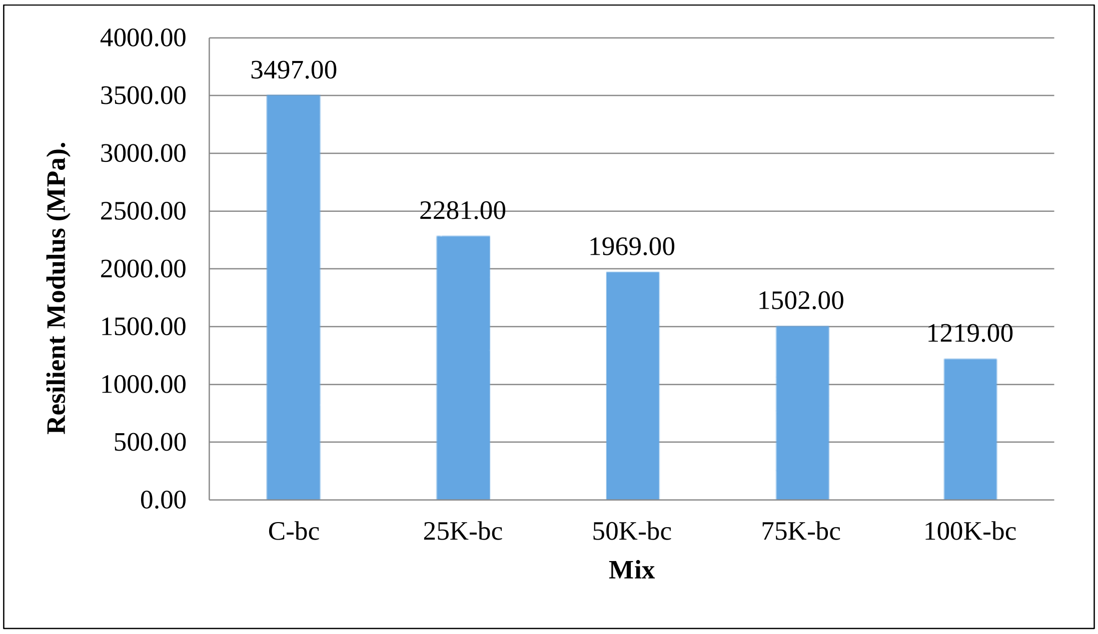


Figure 4.22: Resilient Modulus Results of BC Mixes.

II. Dense Bituminous Macadam

a) Gradation and Marshall Test Results

Procedure for gradation and mix preparation for DBM mixes was similar to that of BC mixes. Gradation type 2 was selected for DBM mixes, results as is summarized in Figure 4.23. The Marshall parameters obtained at respective OBC of each mix are summarized in Table 4.8. Result of Marshall test are attached as Appendix.

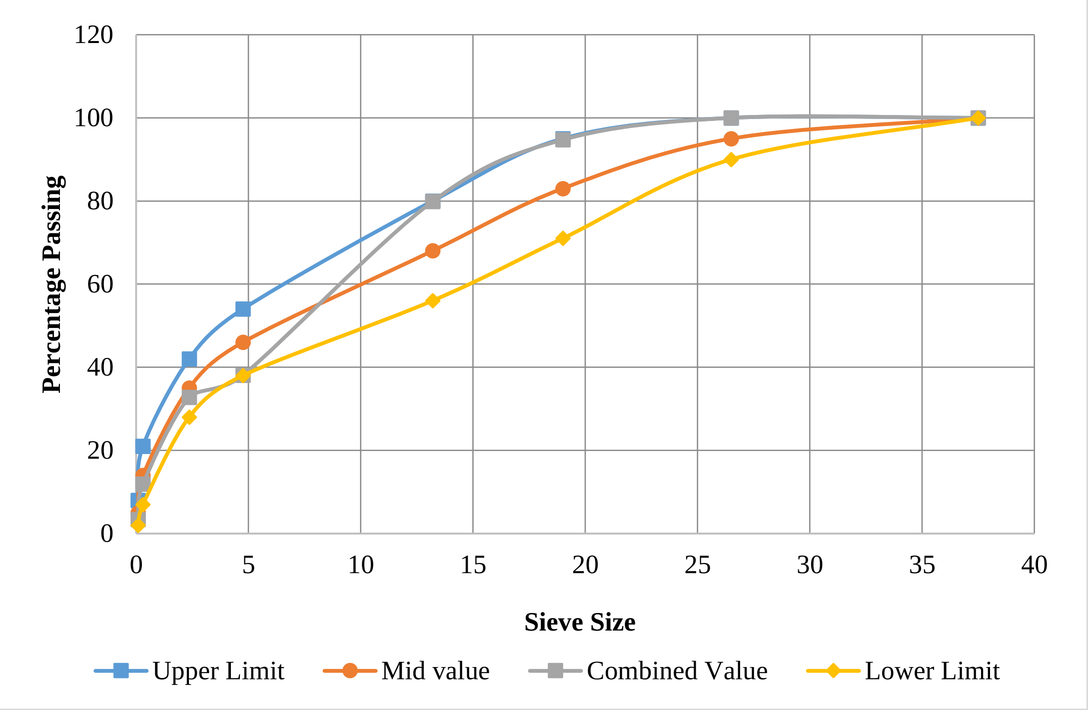


Figure 4.23: Gradation Curve for DBM Mixes

Results of stability value were on similar line to that of BC mixes, with, inclusion of KSA mix stability reduced. Mix 100K-dbm failed to achieve the minimum stability value at OBC. Except mix 75K-bc and 100K-bc, flow value of all mixes were within permissible limit. Mix 100K-dbm failed the required Marshall Quotient (MQ) criteria while all other mixes satisfied the criteria. The reason for failure was attributed to lower stability value and higher flow value obtained for the mix. As the proportion of KSA gains majority in DBM mixes, the overall compactness of the mix was compromised due to elongated particles marginal change in VFB and air voids was observed.

Table 4.8: Marshall Test Results of DBM Mixes

	C-dbm	25K-dbm	50K-dbm	75K-dbm	100K-dbm
Stability (KN)	13.481	10.7	10.83	9.87	8.143
Flow Value (mm)	3.34	2.82	3.75	4.16	4.16
Bulk Density (gm/cc)	2.429	2.459	2.466	2.44	2.440
Air Void (%)	4.6	4.2	4.1	4.2	4.5
VMA (%)	17.59	16.69	16.81	17.23	17.39
VFB (%)	73.72	75.05	75.39	75.69	75.9
OBC (%)	5.47	5.2	5.3	5.5	5.5

b) Indirect Tensile Strength and Tensile Strength Ratio

Figure 4.24 and Figure 4.25 shows result of ITS and TSR. The resistance of DBM mixes against tensile failure, moisture, was observed to decrease with inclusion of KSA in the mixes. Mix 50K-dbm, 75K-dbm and 100K-dbm failed to achieve the minimum TSR of 80%. Marginal difference in dry-ITS values was observed at each KSA replacement level. Significant fall in strength was observed for wet-ITS at 100% KSA replacement. Based on TSR, only 25% replacement of conventional aggregate in DBM mixes showed moisture susceptibility.

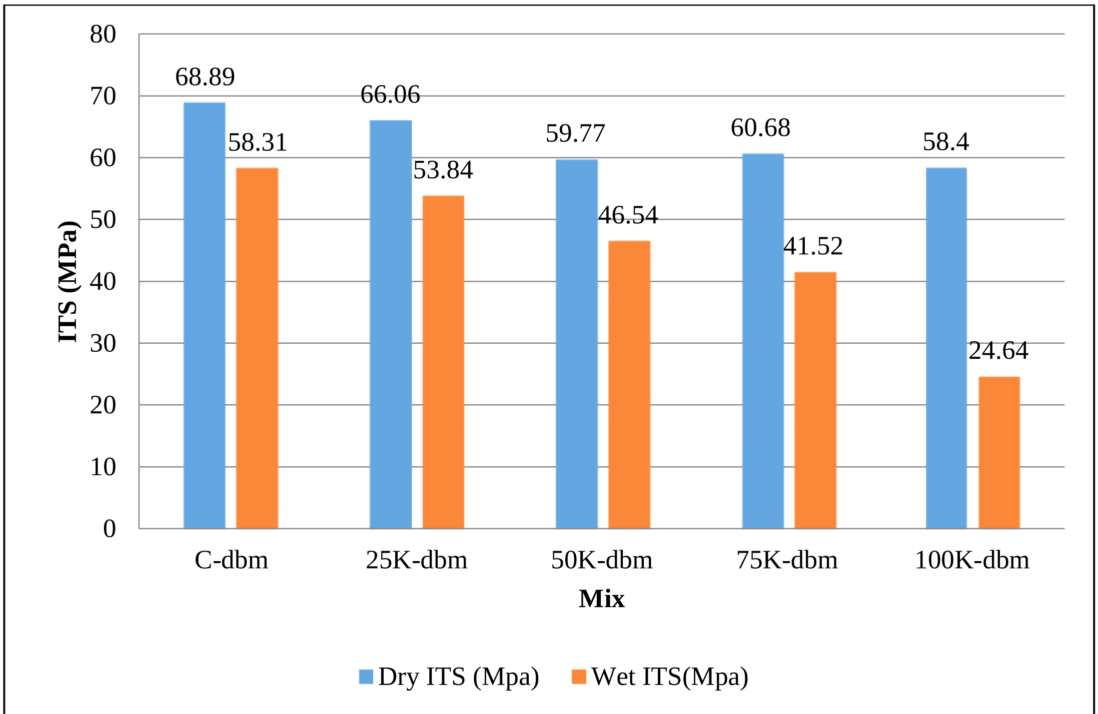


Figure 4.24: Dry and Wet ITS Values for DBM Mixes.

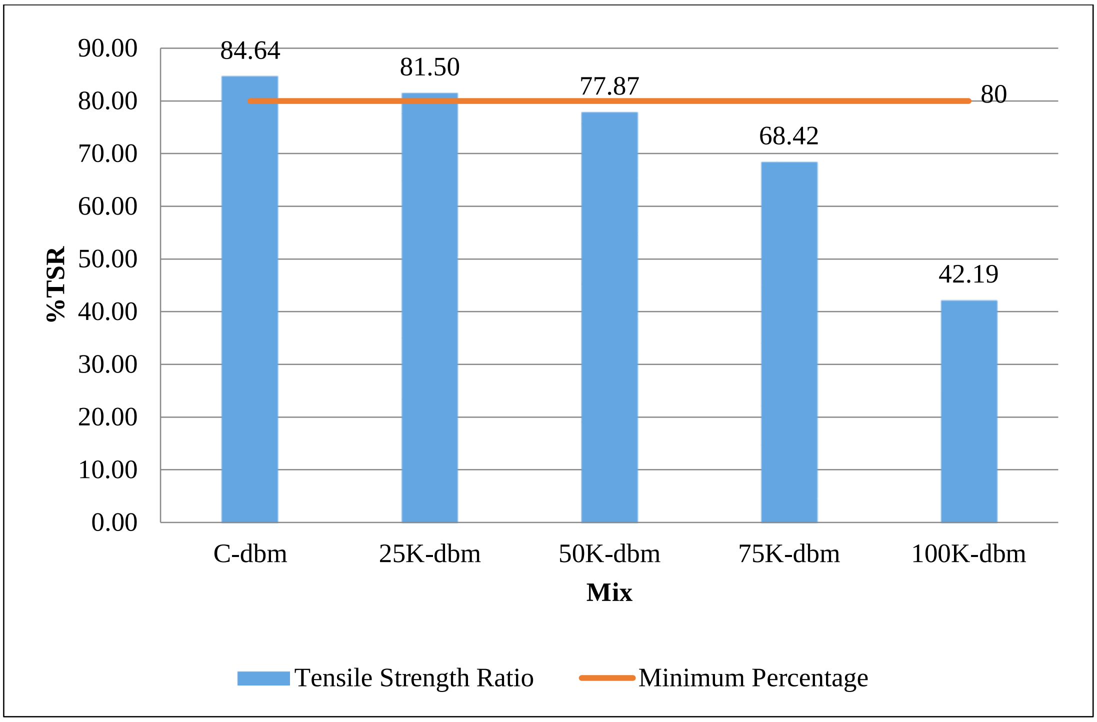


Figure 4.25: Tensile Strength Ratio Values for DBM Mixes.

Decrease in ITS ratio of DBM mixes was attributed to weak KSA, the SEM image at higher magnification for 75K-dbm as shown in Figure 4.26 (a) and (b) witness hairline crack on surface of KSA due to compactness which results into poor mix performance.

SEM analysis of each DBM mix was done to understand change in microstructure with increase in KSA content shown in Figure 4.27. SEM of sample 25K-dbm shows well-arranged structural matrix, similar to that of conventional sample. However, as percentage of KSA increased beyond 25%, an irregular pattern was observed, due to breaking of flaky edges. This could be reason for reduced stability and Marshall Quotient values observed during Marshall testing of specimen. This aggregate performance also justifies the obtained ITS ratio of the mixes. Since flaky particle has low tensile strength(Chen et al. 2005); (Naidu & Adiseshu 2013), as the proportion of KSA increased the ITS value of the mix kept on decreasing.

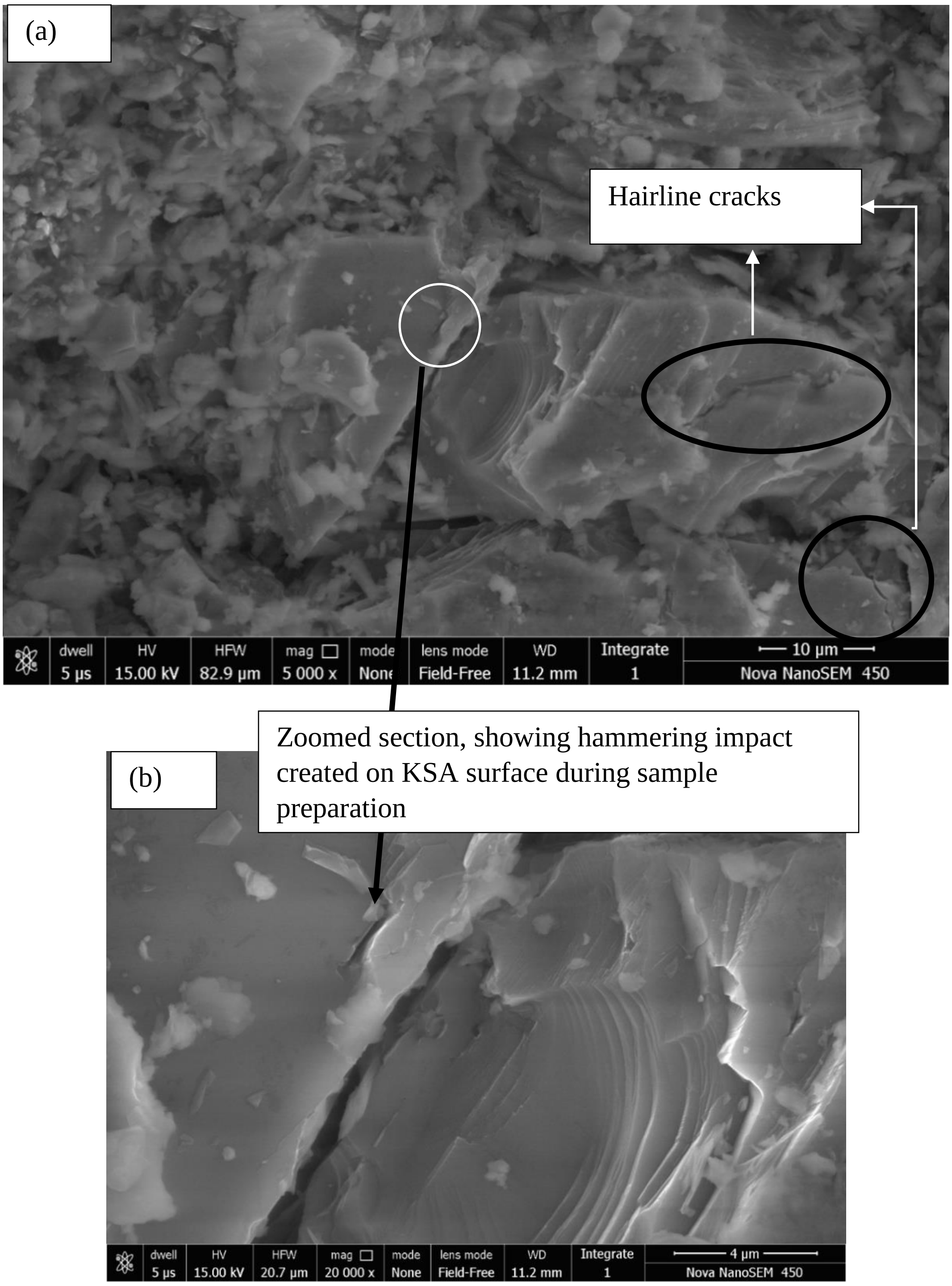
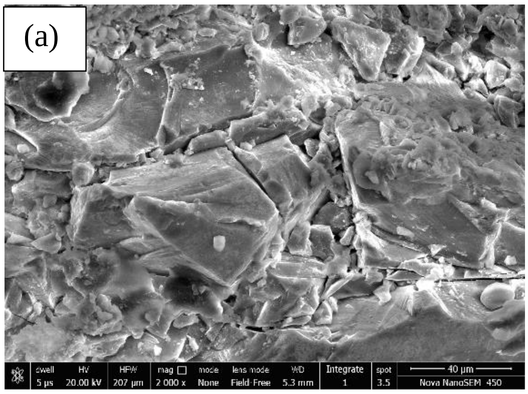
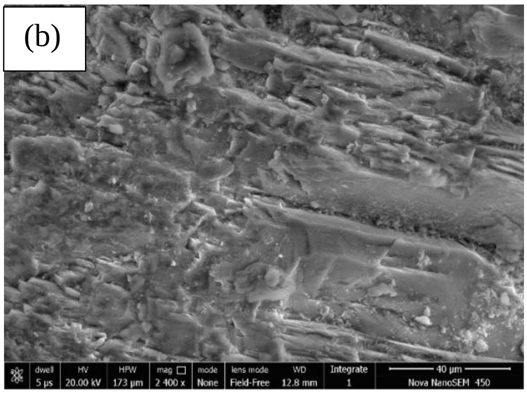


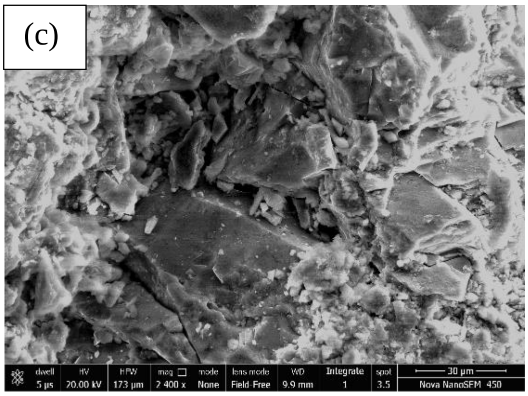
Figure 4.26: SEM Image Showing Cracks on KSA Aggregates.



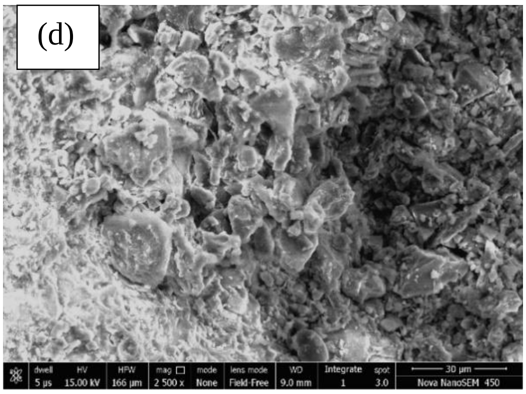
C-dbm



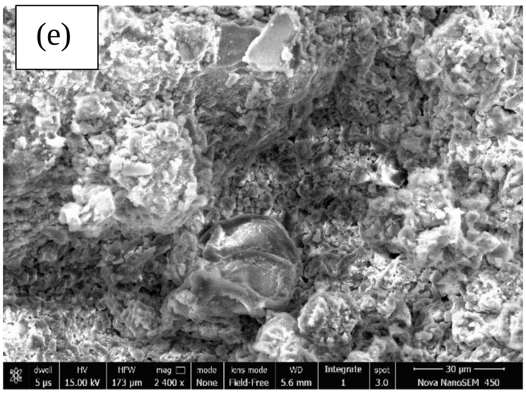
25K-dbm



50K-dbm



75K-dbm



100K-dbm

Figure 4.27: SEM Images C-dbm, 25K-dbm, 50K-dbm, 75K-dbm, 100K-dbm

c) Dynamic Creep Test

Result of dynamic creep test was on similar line to that obtained for BC mixes. With increase in KSA proportions, percentage permanent actuator strain value increased. Percentage accumulated strain value at 4561st pulse count as shown in Table 4.9. Figure 4.28 shows that 25K-dbm mix with almost similar performance to control mix C-dbm, indicating substantial resistance to rutting. The flow number was observed decreasing upon inclusion of KSA as shown in Figure 4.29

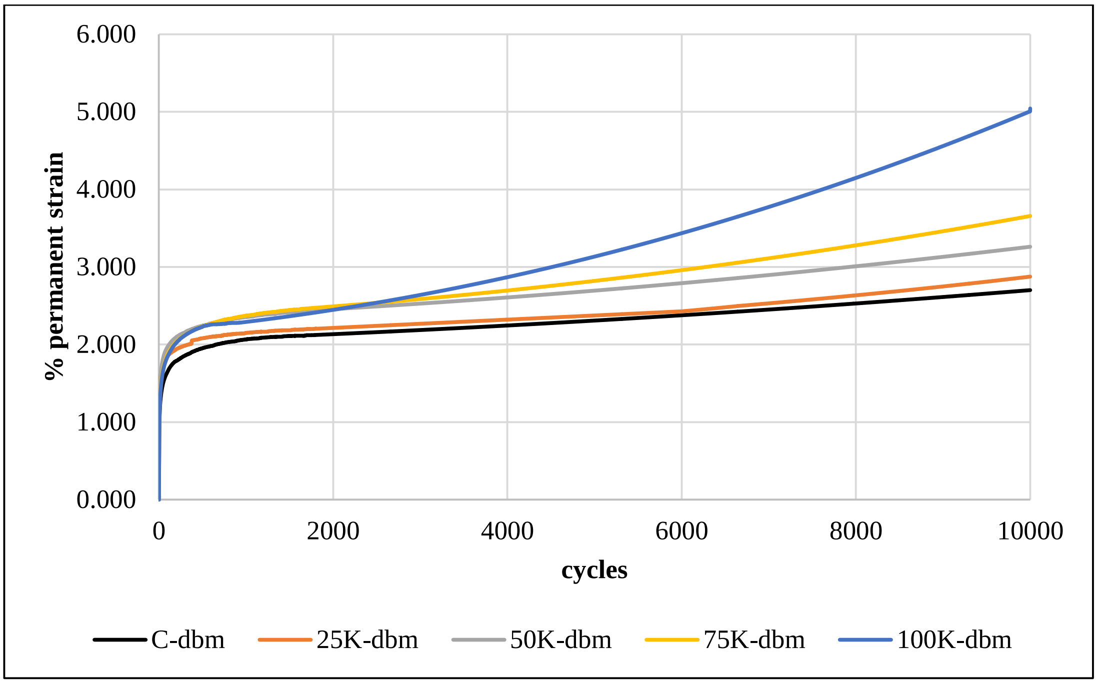


Figure 4.28: Dynamic Creep Result for DBM Mixes.

Table 4.9: Percentage Actuator Strain Value for DBM mixes.

Mix	**Permanent actuator strain (%)**
C-dbm	2.282
25K-dbm	2.351
50K-dbm	2.658
75K-dbm	2.763
100K-dbm	3.102

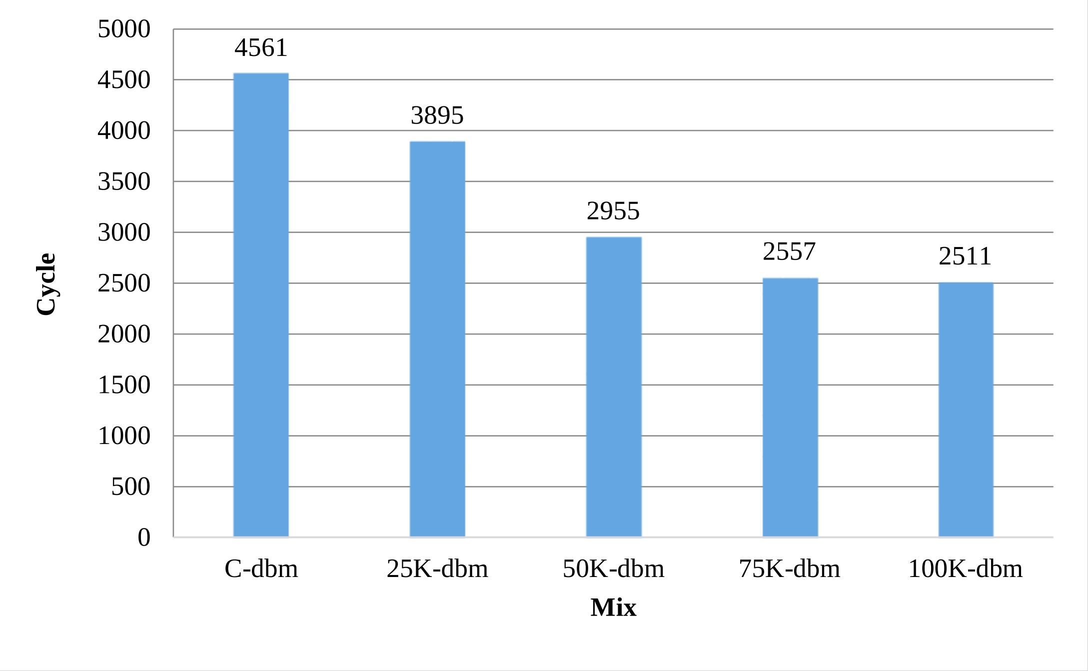


Figure 4.29: Flow Number Results for DBM Mixes.

e) *Resilient Modulus*

Figure 4.30 shows resilient modulus test results. Mix 25K-dbm satisfied the recommended resilient modulus value, while other KSA mix failed to achieve the minimum value. The reason for low resilient modulus value this was attributed to the fact that KSA observed inferior to conventional aggregates on physical parameters.

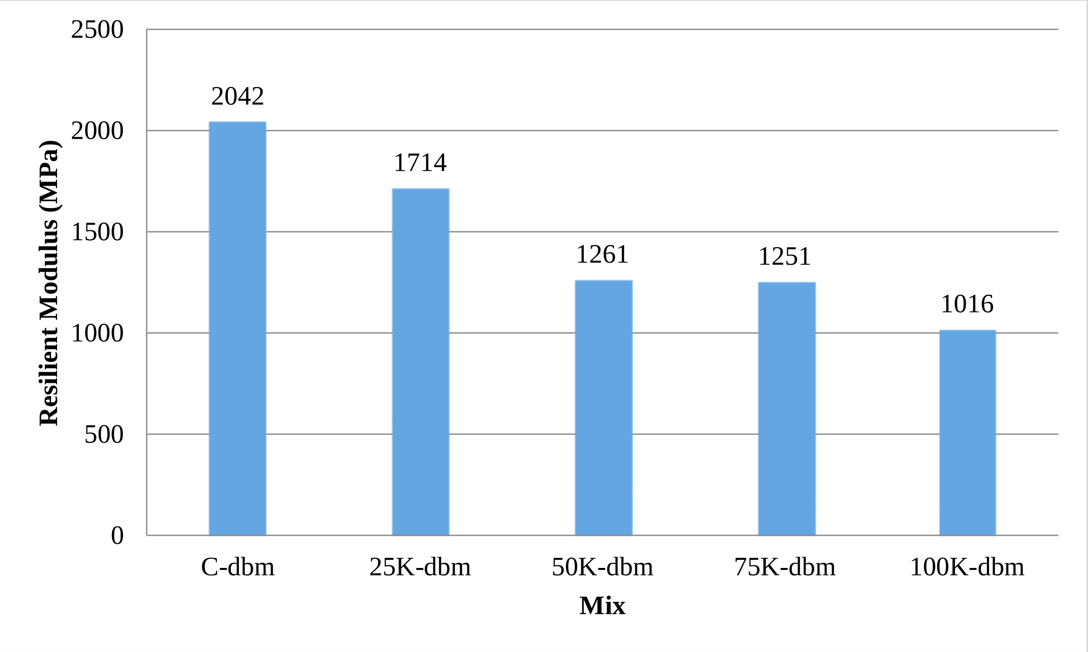


Figure 4.30: Resilient Modulus Results of DBM Mixes.

III. Open Graded Friction Course

a) Gradation and Marshall Test Parameters

The gradation obtained for OGFC samples shown in Figure 4.31. In OGFC samples, OBC was obtained by taking average value of binder content of mixes with maximum stability, 20% air voids and maximum of bulk specific gravity. Graphical results of Marshall Test for OGFC mixes are attached in appendix, results at OBC are shown in Table 4.10

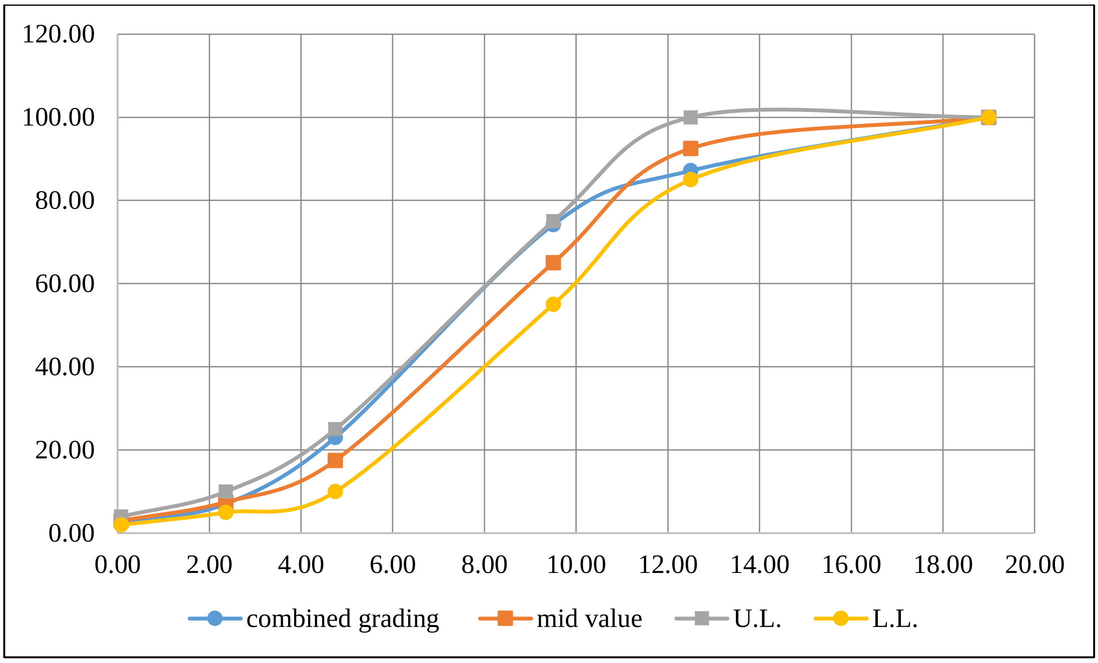


Figure 4.31: Gradation Curve for OGFC Mixes.

Table 4.10: Marshall Test Results for OGFC Samples.

	C-ogfc	25K-ogfc	50K-ogfc	75K-ogfc	100K-ogfc
Stability (KN)	3.7	3.61	3.51	3.24	3.26
Bulk Density (gm/cc)	2.07	2.02	2.08	2.07	2.18
Air Void (%)	22.6	20.30	19.60	20.22	20.33
OBC (%)	5.6	5.6	5.5	5.3	4.7

b) *Indirect Tensile Strength and Indirect Tensile Strength Ratio.*

Figure 4.32 and Figure 4.33 results of dry-ITS and wet-ITS for OGFC mixes. Inclusion of KSA reduced the ITS value of mixes. Mix 25K-ogfc and 50K-ogfc were found to satisfy the moisture resistance condition as upto 50% KSA replacement OGFC mixes fulfilled criteria of 80% TSR. Use of crumb rubber modified bitumen improved moisture susceptibility of mixes(Shirini & Imaninasab 2016). Test results indicate that KSA aggregate can be used only as a partial replacement to conventional.

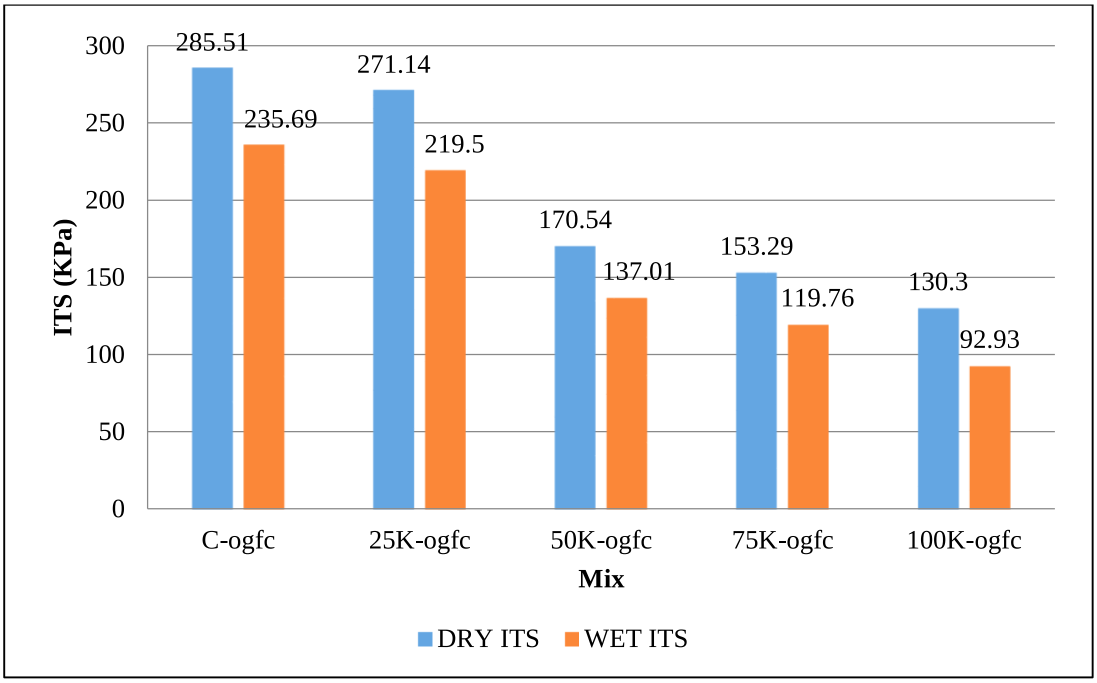


Figure 4.32: Dry and Wet ITS Values for OGFC Mixes.

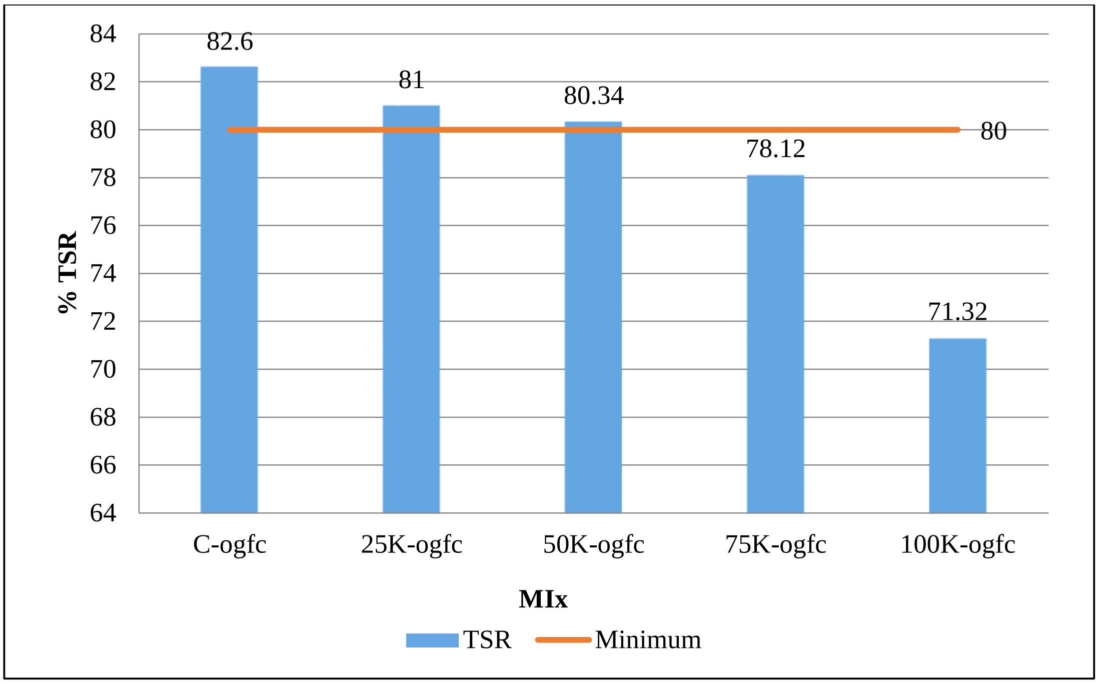


Figure 4.33: Tensile Strength Ratio of OGFC Mixes

c) Cantabro Test

Result of cantabro test as shown in Figure 4.34 reveals that with inclusion of KSA percentage loss reduce up to 75% replacement. Loss of material was observed maximum (10.45%) for 100K-ogfc mix and minimum (5%) for 50K-ogfc mix.

Results of aged cantabro as shown in Figure 4.34 show that sample of 100K-ogfc mix was found to be partially dismembered and deemed unfit for testing purpose. With increase in KSA proportion aged cantabro performance reduced. As seen in microstructure studies of different mixes in Figure 4.36 at elevated temperature, the binding between KSA and bitumen become weak leading to loosening of material. Interlocking among aggregates reduced due to uneven fines distribution and smooth texture of aggregates were unable to uphold the overall stone matrix resulting in reduce material strength and higher material loss.

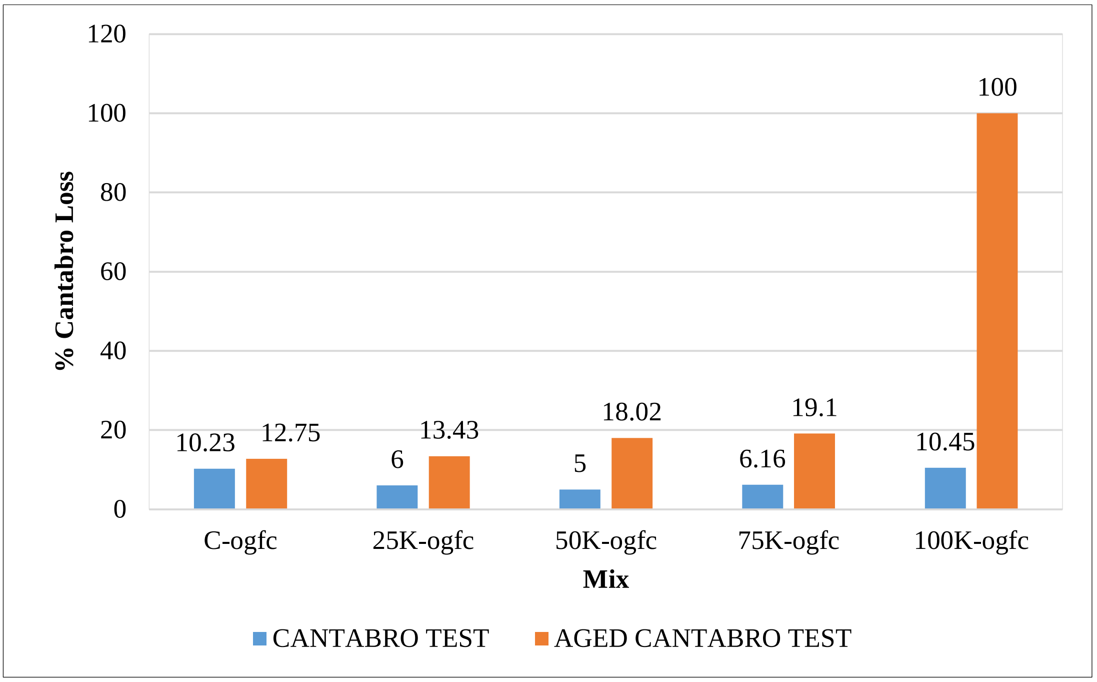


Figure 4.34: Aged and Unaged Cantabro Loss Test Results

d) Falling Head Permeability Test

Figure 4.35 compiles result of falling head permeability test. Minimum permeability requirement was satisfied by all sample. Permeability value was observed less than the control, the reason for this is higher air voids at OBC in control mix compared to other samples containing KSA.

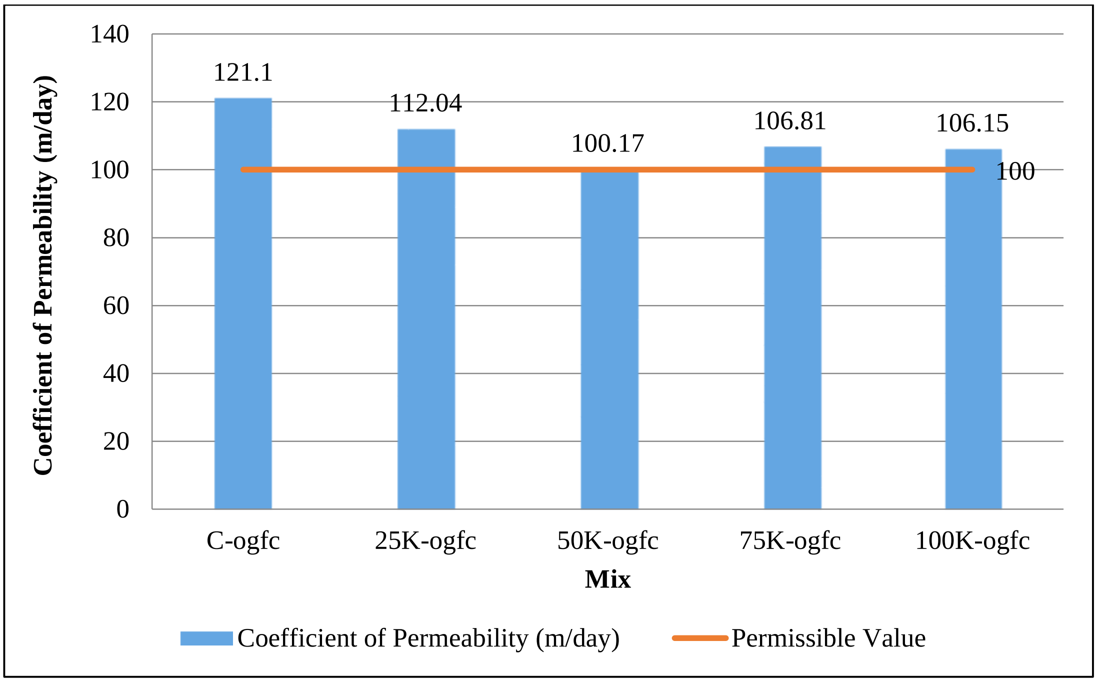


Figure 4.35: Falling Head Permeability Test Result for OGFC Samples.

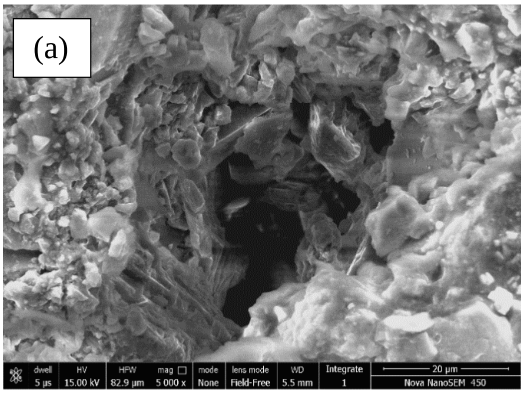
e) *Draindown Test*

Drain down test results, shown in Table 4.11, were observed within a prescribed range (0.3%), indicating excellent adhesion between KSA, conventional aggregate and binder at elevated temperature.

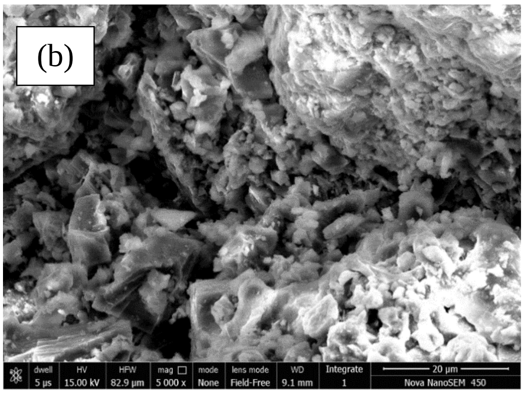
Table 4.11: Drain down Test Result.

	C-ogfc	**25K-ogfc**	**50K-ogfc**	**75K-ogfc**	**100K-ogfc**
Weight of basket (gm)	2878	2878	2878	2878	2878
Weight of tray (gm)	858	858	858	858	858
Weight of basket + sample (gm)	4039	4040	4036.5	4039.5	4040.5
Weight of tray after an hour in oven (gm)	860	859.5	859.5	859.5	859.5
Percentage Drain down	0.129	0.086	0.086	0.086	0.086

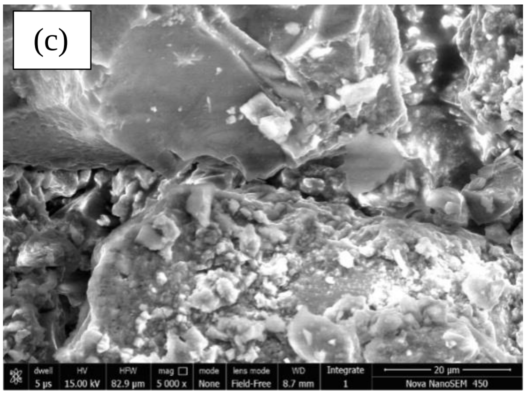
All OGFC mixes showed satisfactory bonding between conventional aggregates, KSA and binder. A clear difference in surface texture of Kota stone aggregates and conventional aggregates was visible as shown in Figure 4.36. This justifies the decrease in durability values obtained in TSR and aged Cantabro test. As the samples were subjected to elevated temperature.



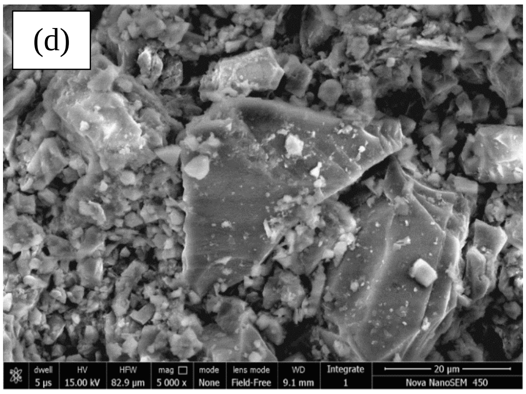
C-ogfc



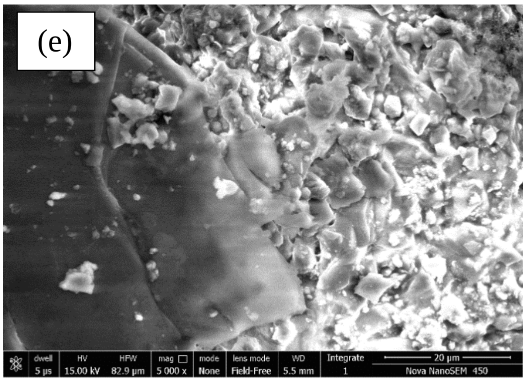
25K-ogfc



50K-ogfc



75K-ogfc



100K-ogfc

Figure 4.36: SEM Image of C-ogfc, 25K-ogfc, 50K-ogfc, 75K-ogfc, 100K-ogfc

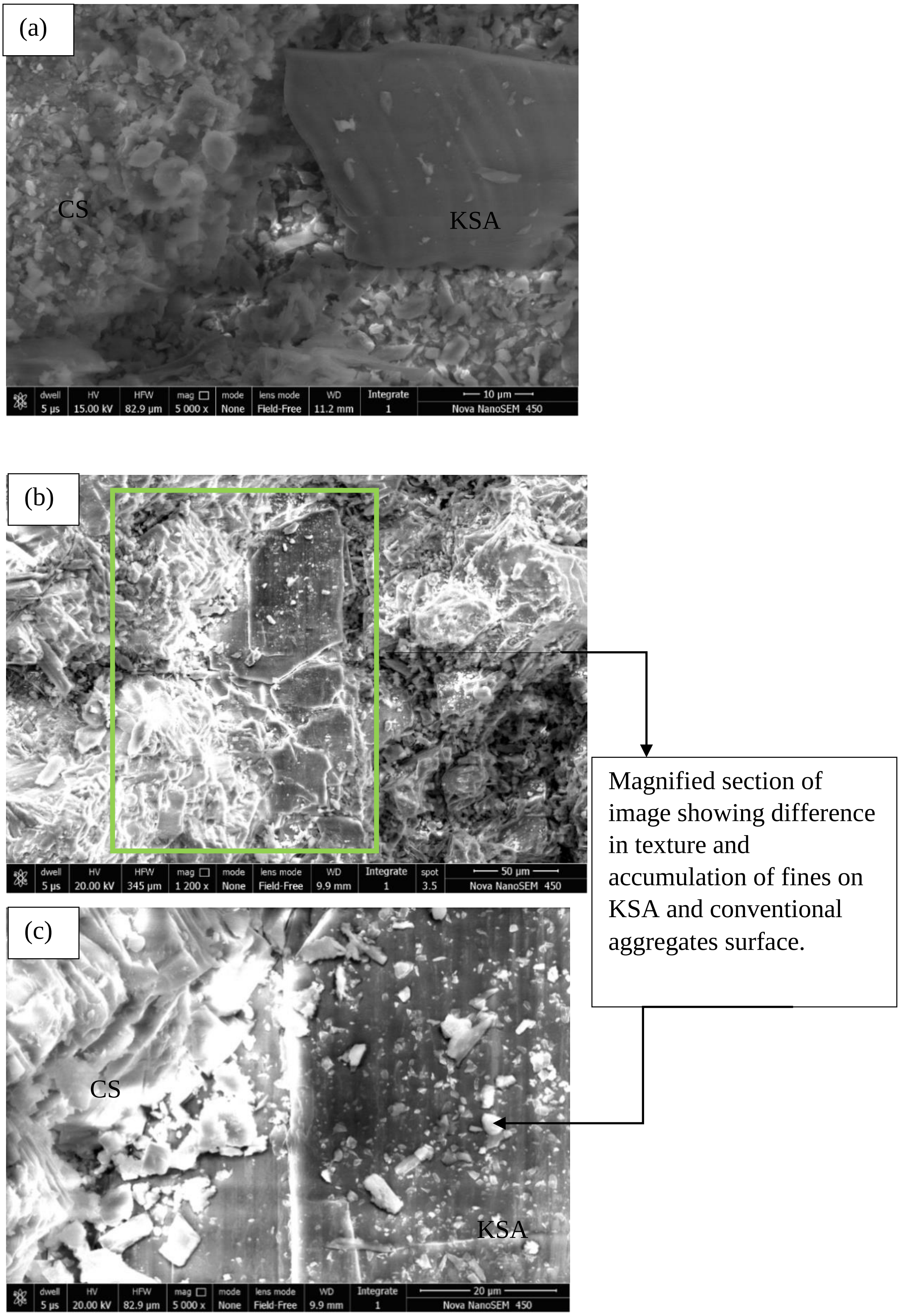


Figure 4.37 (a-c): SEM Images of OGFC Sample

f) Dynamic Creep Test

The results of dynamic creep test for OGFC mixes containing KSA as shown in Figure 4.38, Figure 4.39. were observed on similar line to BC and DBM mixes,indicating reduced resistance to rutting. It was observed that by 1713th cycle all samples attained tertiary phase; value of percentage actuator stain obtained at this cycle number as shown in Table 4.12. In OGFC, low fines and smooth surface of KSA effects binding which in turn make specimen sensitive against rising temperature and diminish the elastic property of mix. Mix 75K-ogfc and 100K-ogfc with high actutator strain (9.010% for 75K-ogfc and 12.681% for 100K-ogfc) showed poor susceptibility towards rutting.

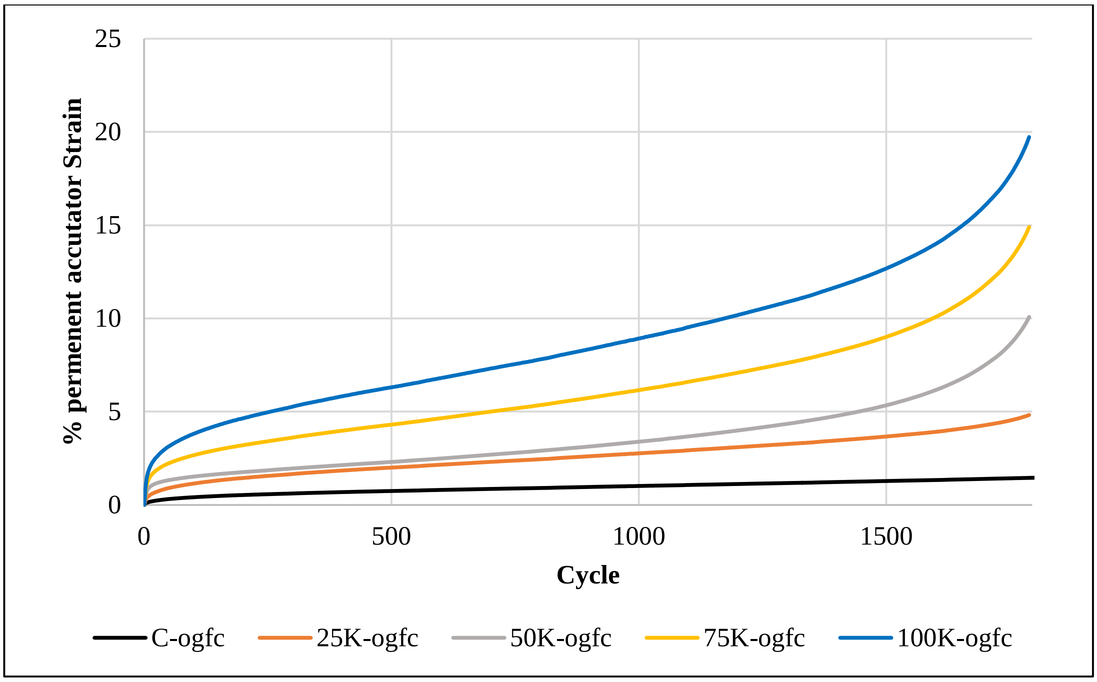


Figure 4.38: Dynamic Creep Test Results for OGFC Mixes.

Table 4.12: Percentage Actuator Strain Value of OGFC Mixes.

Mix	Permanent actuator strain (%)
C-ogfc	1.282
25K-ogfc	3.347
50K-ogfc	3.668
75K-ogfc	9.010
100K-ogfc	12.681

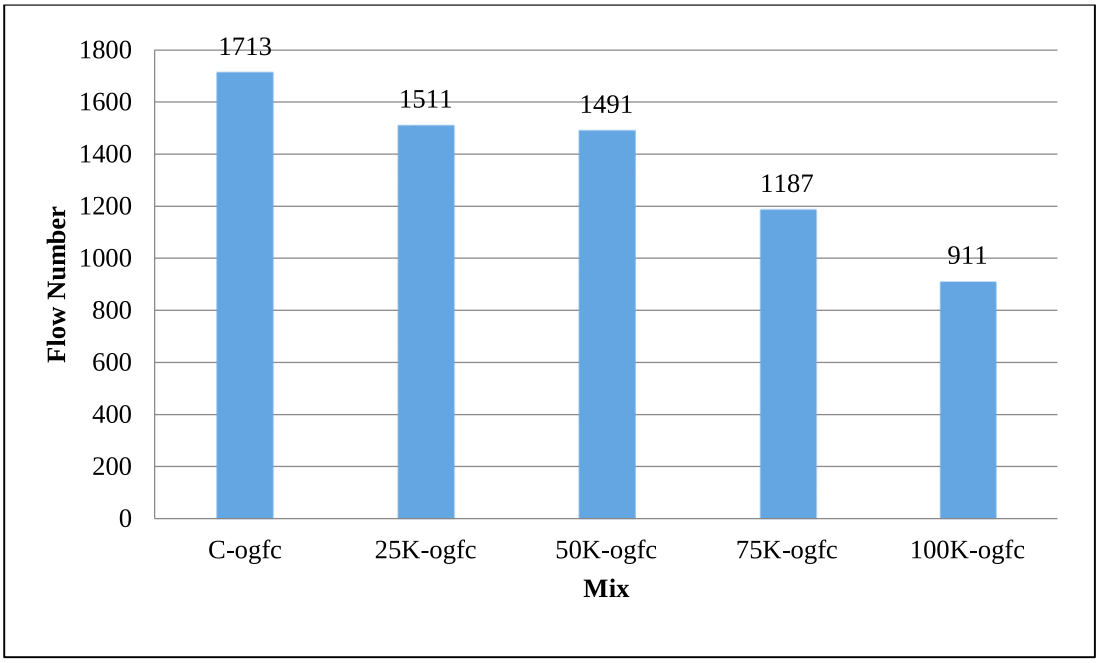


Figure 4.39: Flow Number Results of OGFC Mixes.

g) Resilient Modulus Test.

With the inclusion of KSA in OGFC mixes, Resilient Modulus decreased. Resilient modulus was obtained maximum (2418 MPa) for C-ogfc mix and minimum (1481MPa) for 100K-ogfc mix.

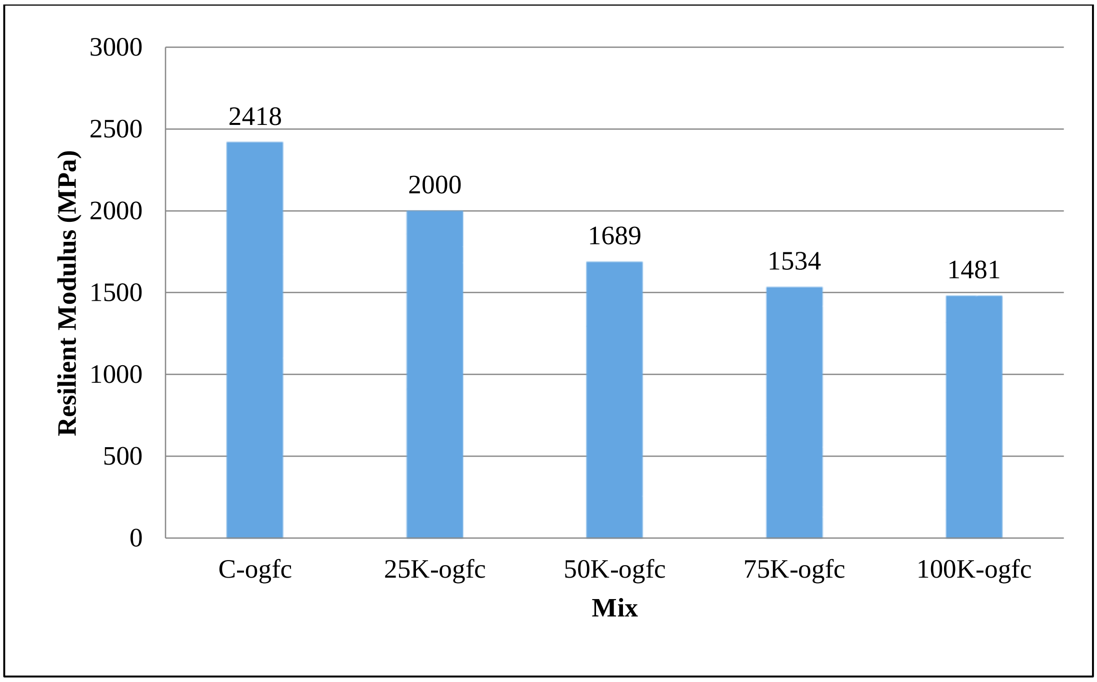


Figure 4.40: Resilient Modulus Results of OGFC Mixes.

Chapter-5

CONCLUSION AND RECOMMENDATIONS

In the present study, an attempt was made to utilize locally available Kota stone mining, processing waste as a construction material in the flexible pavement. Based on laboratory investigation following conclusion were drawn:

1. The test results indicate that inclusion of slurry modified the engineering properties of black cotton soil. Replacement of Kota stone slurry between 17-19% in black cotton soil increase workability (decreasing Liquid limit, increasing the plastic limit and reducing plasticity index) and strength (MDD, CBR, UCS and M_R Values). Improvement in soil properties was attributed to high calcium oxide content, non-plastic nature and fineness of slurry.
2. Kota stone aggregates, though satisfied specifications, were observed inferior to basalt aggregate. Mixes prepared with Kota stone satisfied the required specifications for granular sub-base (GSB), non-bituminous base course (WBM, WMM; Pawan et al. 2014) and bituminous base and wearing course (DBM, BC, OGFC).
3. Strength and durability parameters of hot mix asphalt mix indicated property enhancement up to a certain replacement level. Test results show that mixes containing Kota stone aggregate perform well compare with conventional stones at normal test condition. However, at adverse test condition, hot asphalt mixes with Kota stone aggregates above showed poor performance.
4. The reason for poor performance of HMA mixes with increase in Kota stone aggregates was accounted for low abrasion, impact values, high flaky, elongated particles and smooth texture of Kota stone aggregates which compromise overall structural matrix of product. SEM images of these HMA mixes were observed with accumulation of fines near broken flaky-elongated particles with hairline cracks along the edges.
5. Marginal change in binder content was observed for BC and DBM mixes containing Kota stone aggregates. However, a noticeable decrease in binder content of OGFC mixes was observed with increase in KSA content. This

decrease in binder content was attributed to affinity of CRMB-60 binder with Kota stone aggregates.

6. Replacement of Kota stone aggregate in place of conventional aggregates was found suitable up to 50% for BC and OGFC mixes and upto 25% for DBM mixes.

Recommendation and Future Scope

From this study, it can be deduced that Kota stone aggregate and slurry derived from mining, cutting and polishing waste has potential to be used as construction material for flexible pavement system and hence, their use is recommended. The scope of this study was limited to laboratory investigation. A test section containing slurry as additive and KSA as partial replacement of conventional aggregates should be laid and behaviour of pavement under actual traffic and environmental condition must be studied. Comprehensive laboratory investigation using Kota stone aggregates as partial or complete replacement of conventional aggregates with plastic waste, rubber waste modified bitumen also recommended.

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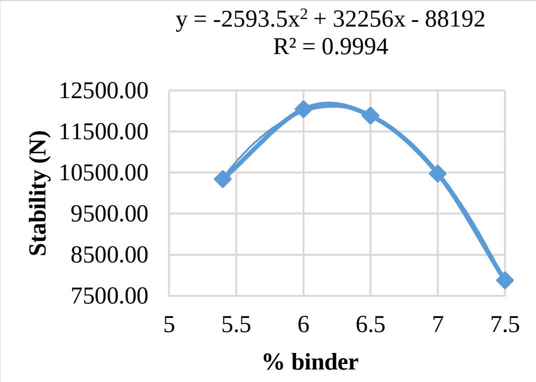
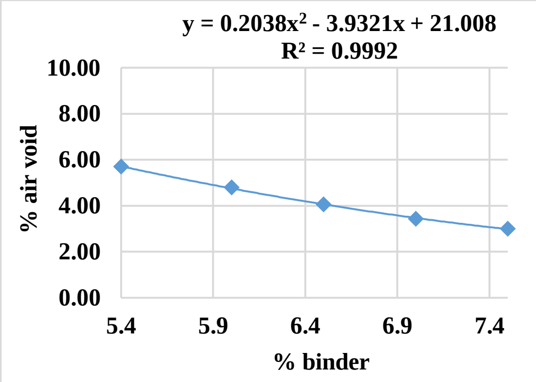
LIST OF PUBLICATIONS FROM THESIS

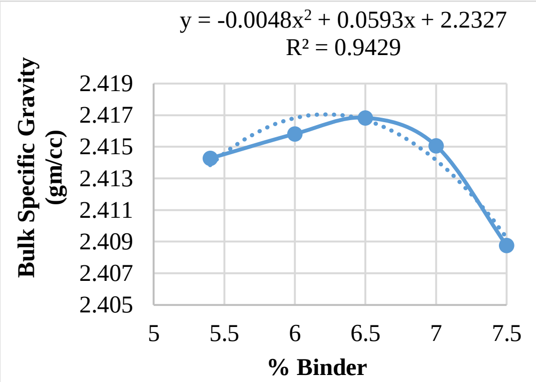
- **Gautam, P. K**., Kalla, P., Jethoo, A. S., Agrawal, R., & Singh, H. (2018). Sustainable use of waste in flexible pavement: A review. ***Construction and Building Materials***, *180*, 239–253, **SCI**
- http://doi.org/10.1016/j.conbuildmat. 2018.04.067
- **Gautam, P. K**., Kalla, P., Nagar, R., & Jethoo, A. S. (2018). Laboratory investigation on use of quarry waste in open graded friction course. ***Resources Policy***, (February), 0–1. http://doi.org/10.1016/j.resourpol. 2018.02.009, **SCI**
- Gautam, P. K., Kalla, P., Nagar, R., Agrawal, R., & Jethoo, A. S. (2018). Laboratory investigations on hot mix asphalt containing mining waste as aggregates. ***Construction and Building Materials***, *168*, 143–152. http://doi.org/ 10.1016/j.conbuildmat.2018.02.115, **SCI**
    - **P.Gautam**, P.Kalla, A.S. Jethoo, Use of quarry waste as building material: A review at International Conference on Science, Innovation and Management, London, U.K. 7-8th June 2018, **International Conference.**
    - **P.K. Gautam**, P. Kalla, A.S. Jethoo, S.C. Harshwardhan, Dimensional Stone Waste Characterization in Rajasthan and Suggesting their possible Remedies, Int. J. Emerg. Technol. 8 (2017) 40–42, **National Conference.**

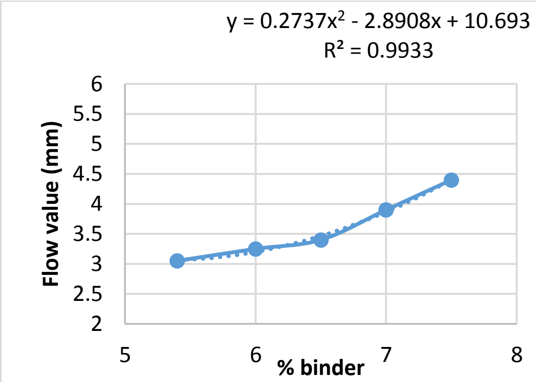
Marshall Test Results of BC Mixes

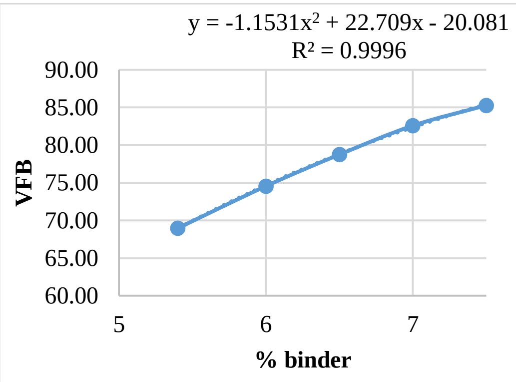
a) C-bc

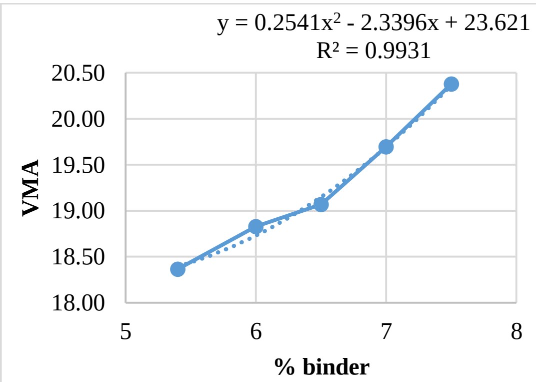




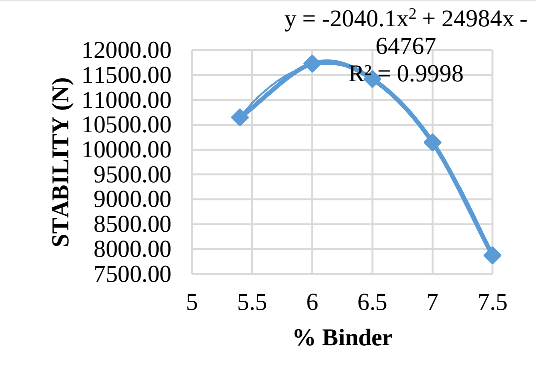




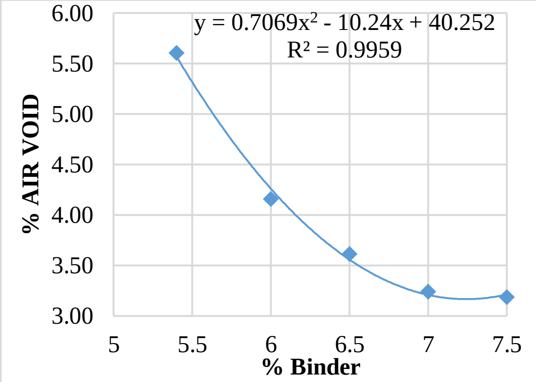




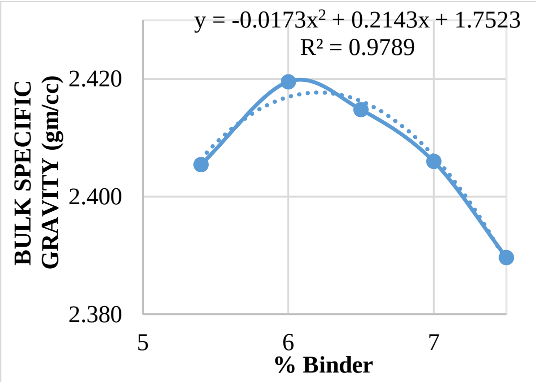
b) 25K-bc



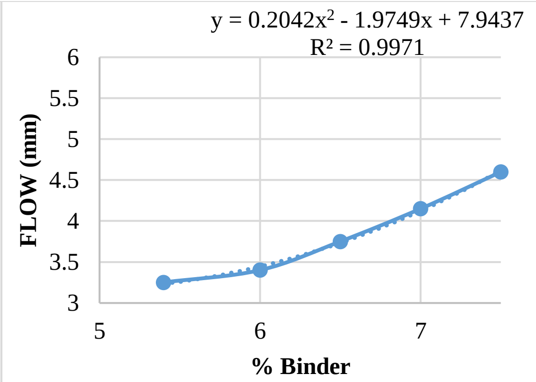
y = -2040.1x² + 24984x - 64767
R² = 0.9998
STABILITY (N)
12000.00
11500.00
11000.00
10500.00
10000.00
9500.00
9000.00
8500.00
8000.00
7500.00
5 5.5 6 6.5 7 7.5
% Binder



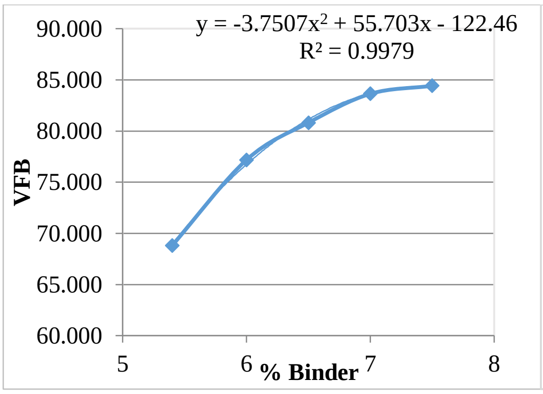
y = 0.7069x² - 10.24x + 40.252
R² = 0.9959
% AIR VOID
6.00
5.50
5.00
4.50
4.00
3.50
3.00
5 5.5 6 6.5 7 7.5
% Binder



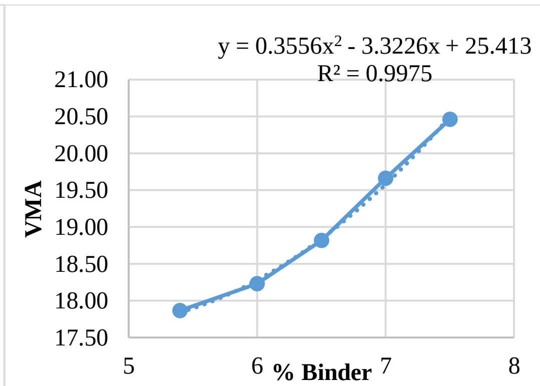
y = -0.0173x² + 0.2143x + 1.7523
R² = 0.9789
BULK SPECIFIC GRAVITY (gm/cc)
2.420
2.400
2.380
5 6 7
% Binder



y = 0.2042x² - 1.9749x + 7.9437
R² = 0.9971
FLOW (mm)
6
5.5
5
4.5
4
3.5
3
5 6 7
% Binder

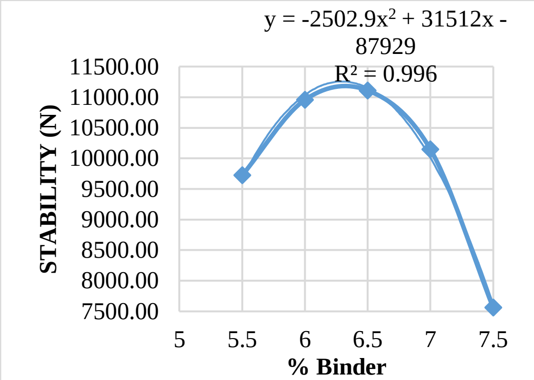


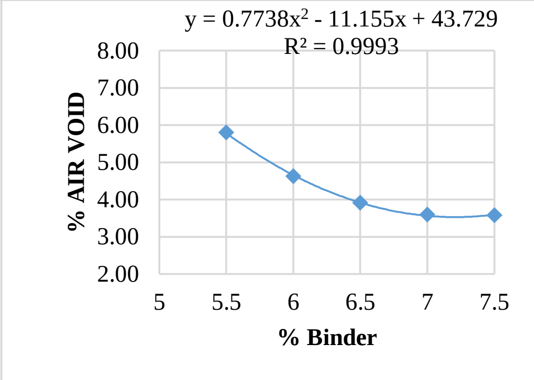
y = -3.7507x² + 55.703x - 122.46
R² = 0.9979
VFB
90.000
85.000
80.000
75.000
70.000
65.000
60.000
5 6 7 8
% Binder

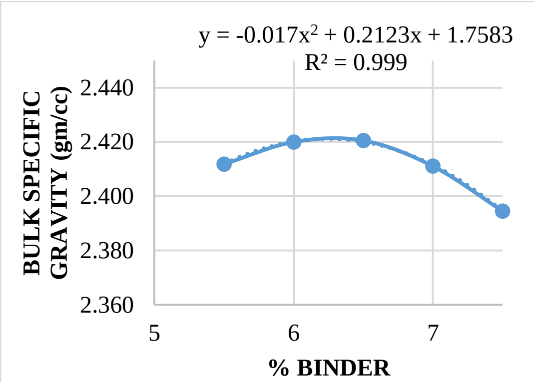


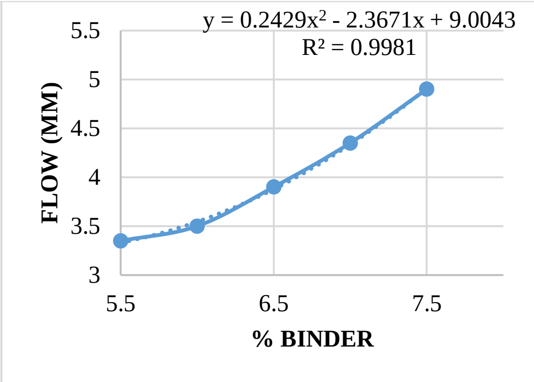
y = 0.3556x² - 3.3226x + 25.413
R² = 0.9975
VMA
21.00
20.50
20.00
19.50
19.00
18.50
18.00
17.50
5 6 7 8
% Binder

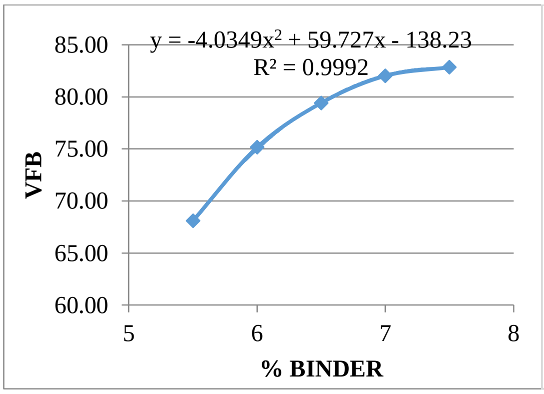
c) 50K-bc

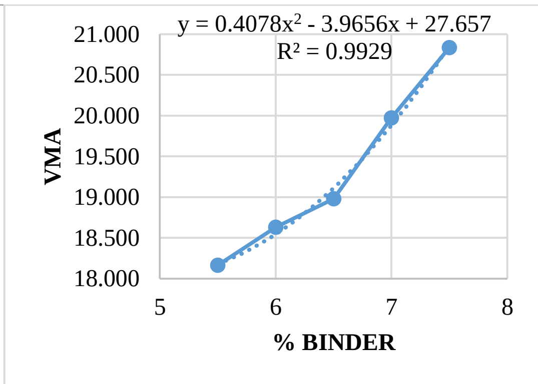

y = -2502.9x² + 31512x - 87929
R² = 0.996
STABILITY (N)
11500.00
11000.00
10500.00
10000.00
9500.00
9000.00
8500.00
8000.00
7500.00
5
5.5
6
6.5
7
7.5
% Binder


y = 0.7738x² - 11.155x + 43.729
R² = 0.9993
% AIR VOID
8.00
7.00
6.00
5.00
4.00
3.00
2.00
5
5.5
6
6.5
7
7.5
% Binder

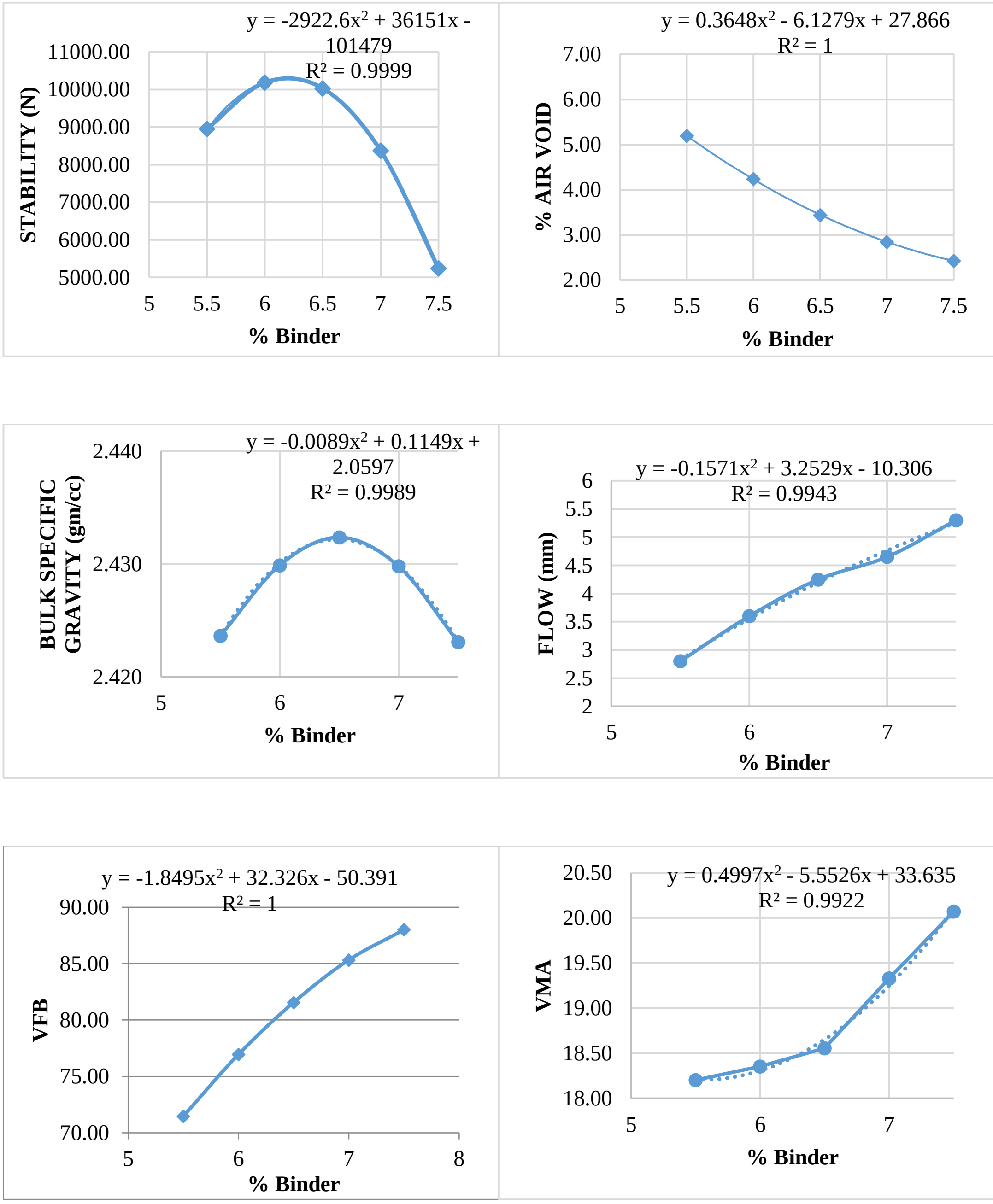

y = -0.017x² + 0.2123x + 1.7583
R² = 0.999
BULK SPECIFIC GRAVITY (gm/cc)
2.440
2.420
2.400
2.380
2.360
5
6
7
% BINDER


y = 0.2429x² - 2.3671x + 9.0043
R² = 0.9981
FLOW (MM)
5.5
5
4.5
4
3.5
3
5.5
6.5
7.5
% BINDER

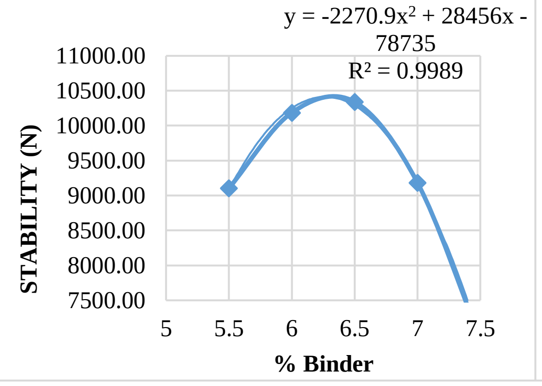

y = -4.0349x² + 59.727x - 138.23
R² = 0.9992
VFB
85.00
80.00
75.00
70.00
65.00
60.00
5
6
7
8
% BINDER

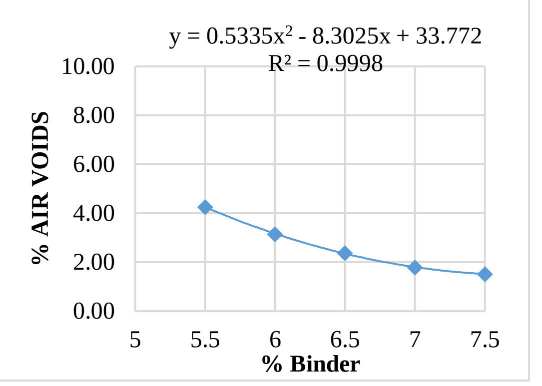

y = 0.4078x² - 3.9656x + 27.657
R² = 0.9929
VMA
21.000
20.500
20.000
19.500
19.000
18.500
18.000
5
6
7
8
% BINDER

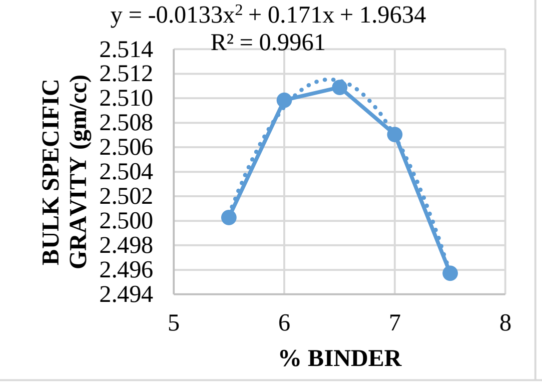
d) 75K-bc

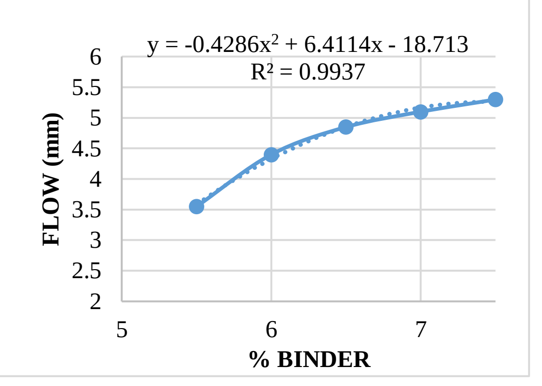

y = -2922.6x² + 36151x - 101479
R² = 0.9999
STABILITY (N)
11000.00
10000.00
9000.00
8000.00
7000.00
6000.00
5000.00
5
5.5
6
6.5
7
7.5
% Binder
y = 0.3648x² - 6.1279x + 27.866
R² = 1
% AIR VOID
7.00
6.00
5.00
4.00
3.00
2.00
5
5.5
6
6.5
7
7.5
% Binder
y = -0.0089x² + 0.1149x + 2.0597
R² = 0.9989
BULK SPECIFIC GRAVITY (gm/cc)
2.440
2.430
2.420
5
6
7
% Binder
y = -0.1571x² + 3.2529x - 10.306
R² = 0.9943
FLOW (mm)
6
5.5
5
4.5
4
3.5
3
2.5
2
5
6
7
% Binder
y = -1.8495x² + 32.326x - 50.391
R² = 1
VFB
90.00
85.00
80.00
75.00
70.00
5
6
7
8
% Binder
y = 0.4997x² - 5.5526x + 33.635
R² = 0.9922
VMA
20.50
20.00
19.50
19.00
18.50
18.00
5
6
7
% Binder

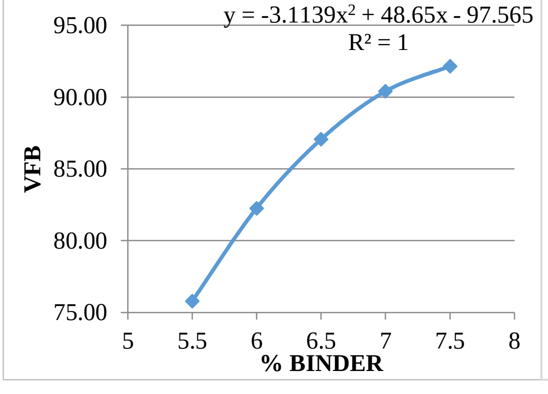
d) 100K-bc

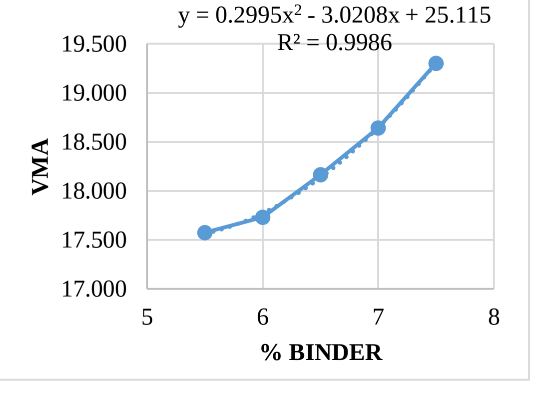

y = -2270.9x² + 28456x - 78735
R² = 0.9989
STABILITY (N)
11000.00
10500.00
10000.00
9500.00
9000.00
8500.00
8000.00
7500.00
5
5.5
6
6.5
7
7.5
% Binder


y = 0.5335x² - 8.3025x + 33.772
R² = 0.9998
% AIR VOIDS
10.00
8.00
6.00
4.00
2.00
0.00
5
5.5
6
6.5
7
7.5
% Binder


y = -0.0133x² + 0.171x + 1.9634
R² = 0.9961
BULK SPECIFIC GRAVITY (gm/cc)
2.514
2.512
2.510
2.508
2.506
2.504
2.502
2.500
2.498
2.496
2.494
5
6
7
8
% BINDER

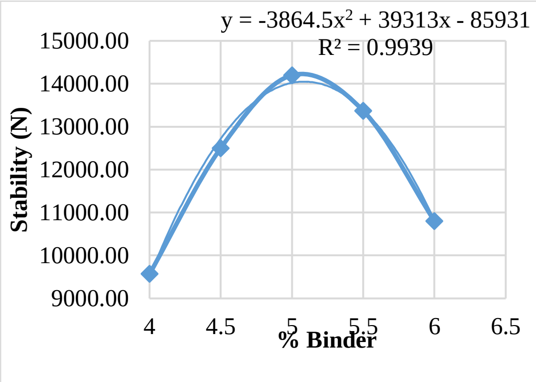

y = -0.4286x² + 6.4114x - 18.713
R² = 0.9937
FLOW (mm)
6
5.5
5
4.5
4
3.5
3
2.5
2
5
6
7
% BINDER

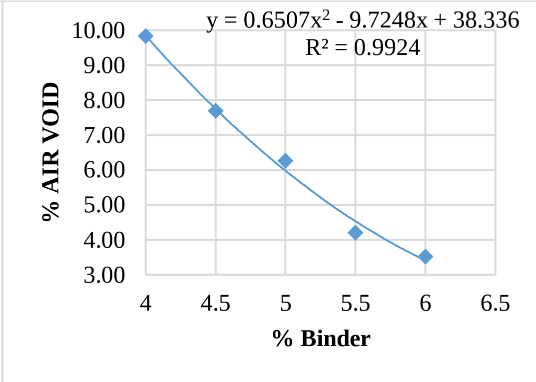

y = -3.1139x² + 48.65x - 97.565
R² = 1
VFB
95.00
90.00
85.00
80.00
75.00
5
5.5
6
6.5
7
7.5
8
% BINDER

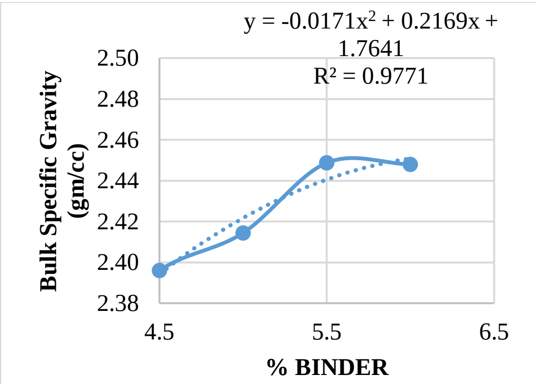

y = 0.2995x² - 3.0208x + 25.115
R² = 0.9986
VMA
19.500
19.000
18.500
18.000
17.500
17.000
5
6
7
8
% BINDER

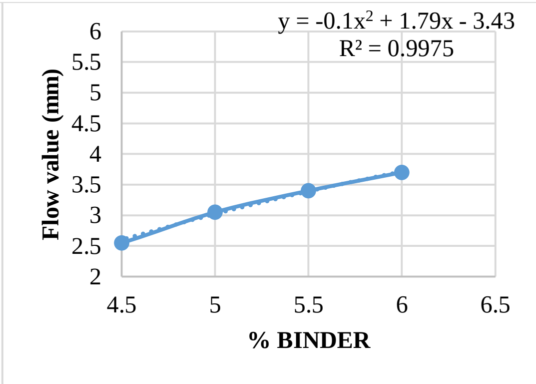
Marshall Test Results of DBM Mixes

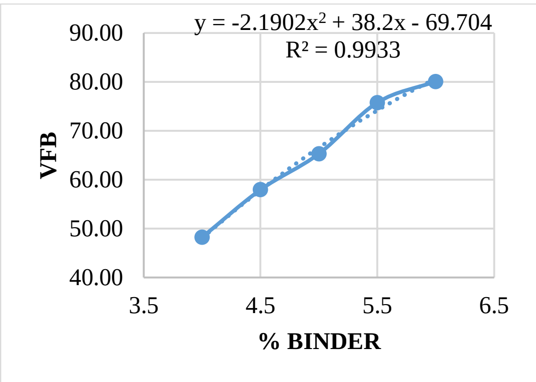
a) C-dbm

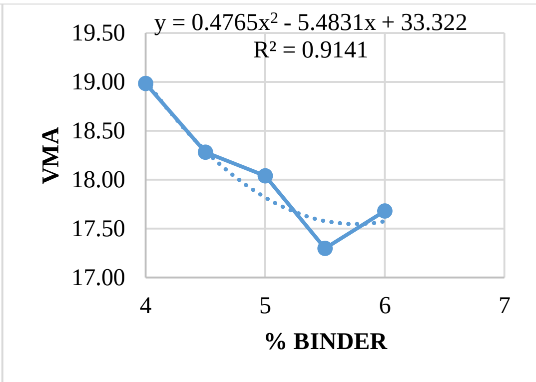




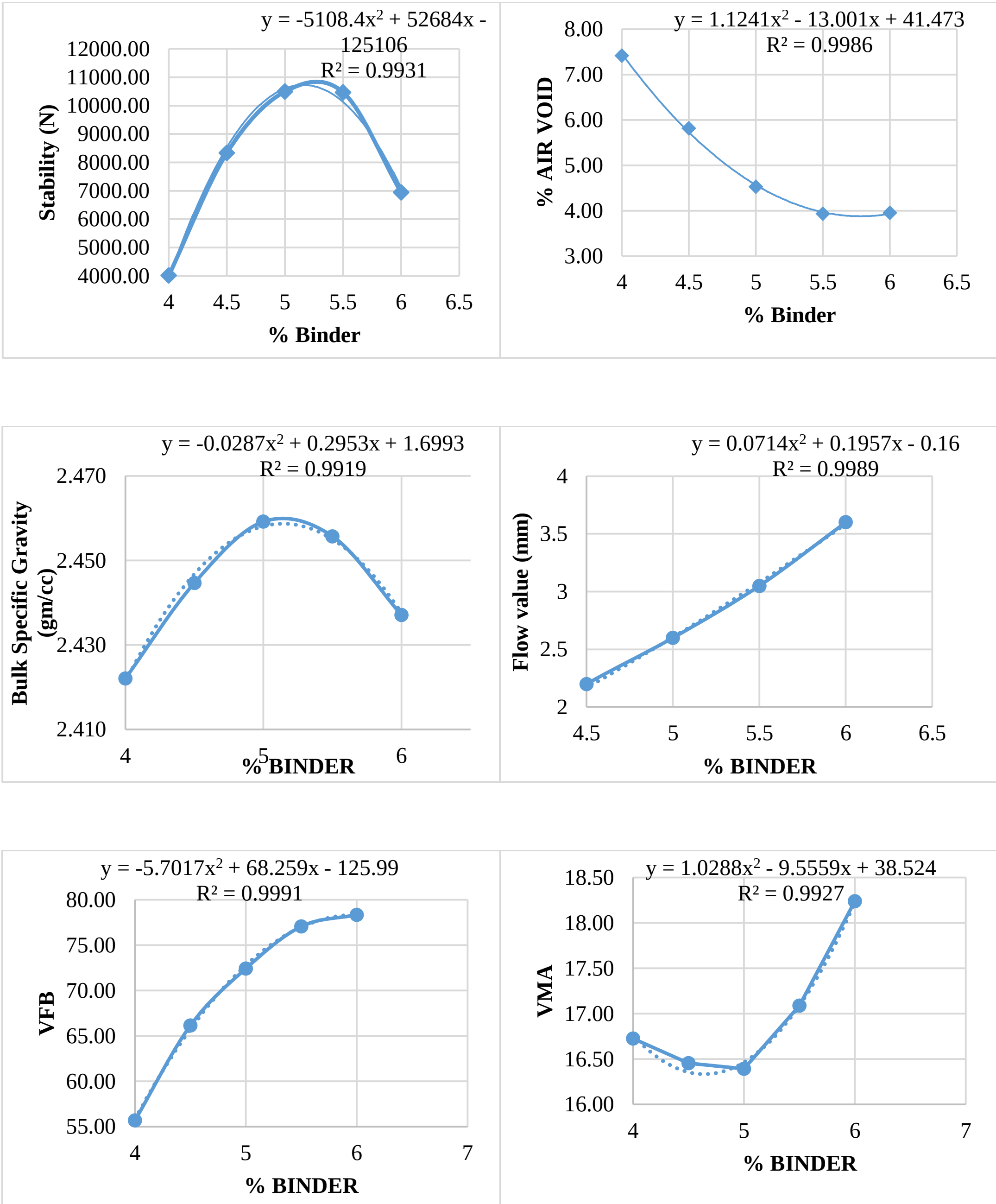




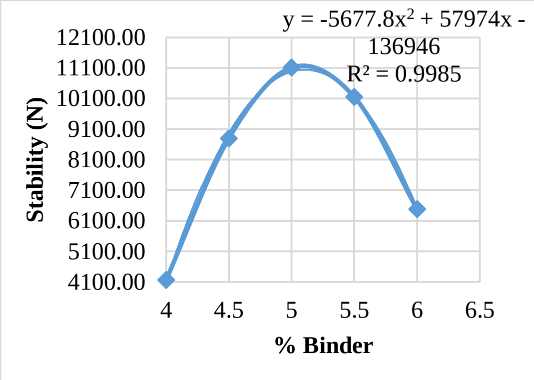


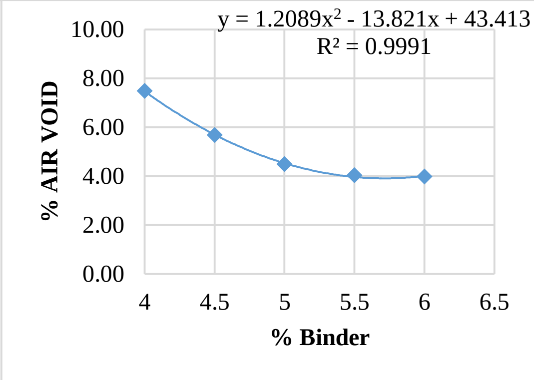


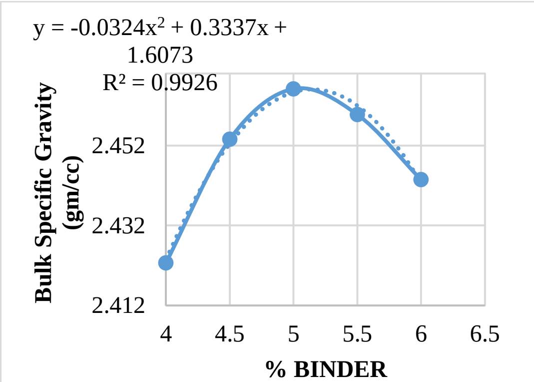
b) 25K-dbm

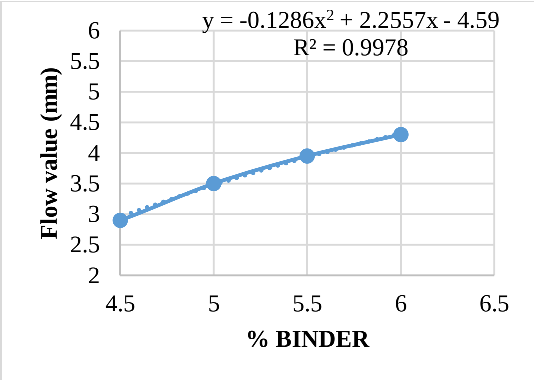

y = -5108.4x² + 52684x - 125106
R² = 0.9931
Stability (N)
12000.00
11000.00
10000.00
9000.00
8000.00
7000.00
6000.00
5000.00
4000.00
4
4.5
5
5.5
6
6.5
% Binder
y = 1.1241x² - 13.001x + 41.473
R² = 0.9986
% AIR VOID
8.00
7.00
6.00
5.00
4.00
3.00
4
4.5
5
5.5
6
6.5
% Binder
y = -0.0287x² + 0.2953x + 1.6993
R² = 0.9919
Bulk Specific Gravity (gm/cc)
2.470
2.450
2.430
2.410
4
5
6
% BINDER
y = 0.0714x² + 0.1957x - 0.16
R² = 0.9989
Flow value (mm)
4
3.5
3
2.5
2
4.5
5
5.5
6
6.5
% BINDER
y = -5.7017x² + 68.259x - 125.99
R² = 0.9991
VFB
80.00
75.00
70.00
65.00
60.00
55.00
4
5
6
7
% BINDER
y = 1.0288x² - 9.5559x + 38.524
R² = 0.9927
VMA
18.50
18.00
17.50
17.00
16.50
16.00
4
5
6
7
% BINDER

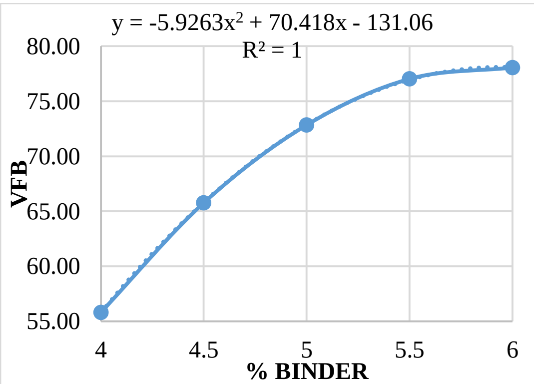
c) 50K-dbm

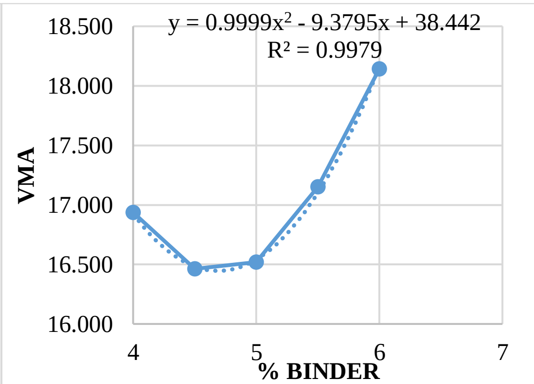

y = -5677.8x² + 57974x - 136946
R² = 0.9985
Stability (N)
12100.00
11100.00
10100.00
9100.00
8100.00
7100.00
6100.00
5100.00
4100.00
4
4.5
5
5.5
6
6.5
% Binder


y = 1.2089x² - 13.821x + 43.413
R² = 0.9991
% AIR VOID
10.00
8.00
6.00
4.00
2.00
0.00
4
4.5
5
5.5
6
6.5
% Binder

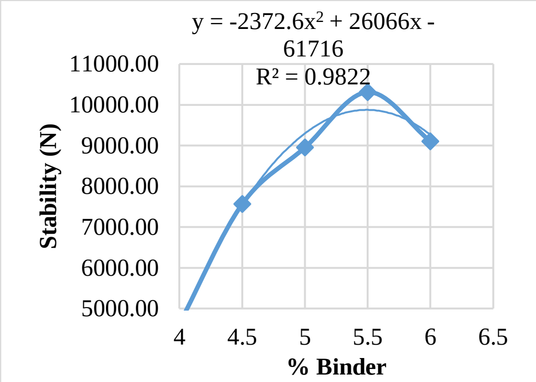

y = -0.0324x² + 0.3337x + 1.6073
R² = 0.9926
Bulk Specific Gravity (gm/cc)
2.452
2.432
2.412
4
4.5
5
5.5
6
6.5
% BINDER

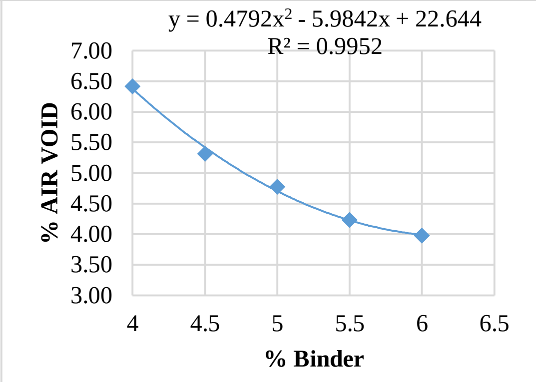

y = -0.1286x² + 2.2557x - 4.59
R² = 0.9978
Flow value (mm)
6
5.5
5
4.5
4
3.5
3
2.5
2
4.5
5
5.5
6
6.5
% BINDER

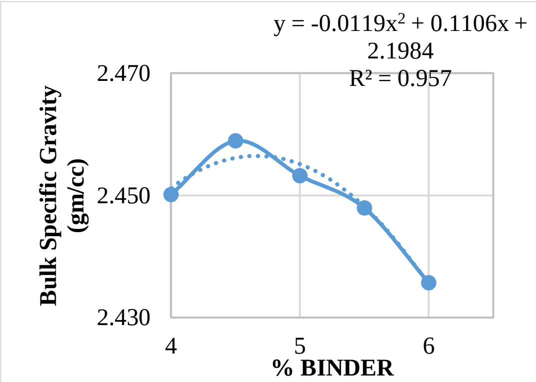

y = -5.9263x² + 70.418x - 131.06
R² = 1
VFB
80.00
75.00
70.00
65.00
60.00
55.00
4
4.5
5
5.5
6
% BINDER

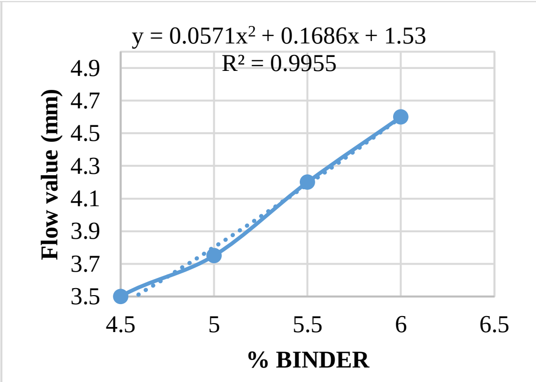

y = 0.9999x² - 9.3795x + 38.442
R² = 0.9979
VMA
18.500
18.000
17.500
17.000
16.500
16.000
4
5
6
7
% BINDER

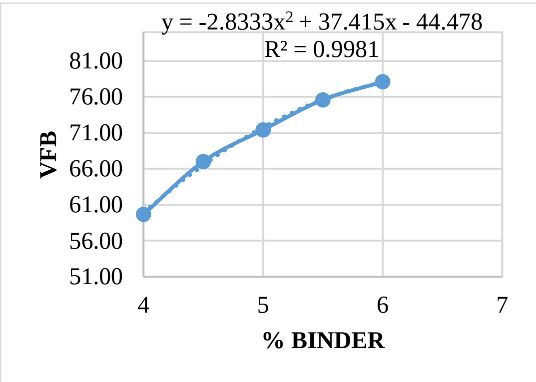
d) 75K-dbm

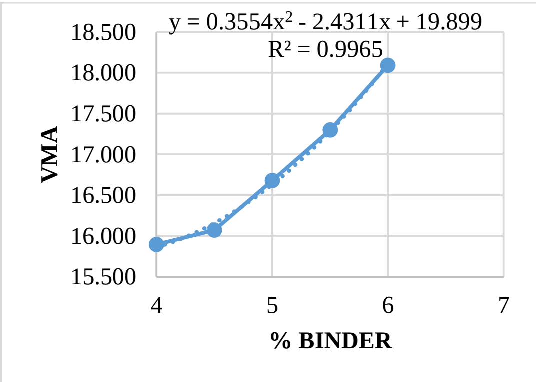

y = -2372.6x² + 26066x - 61716
R² = 0.9822
Stability (N)
11000.00
10000.00
9000.00
8000.00
7000.00
6000.00
5000.00
4
4.5
5
5.5
6
6.5
% Binder


y = 0.4792x² - 5.9842x + 22.644
R² = 0.9952
% AIR VOID
7.00
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
4
4.5
5
5.5
6
6.5
% Binder

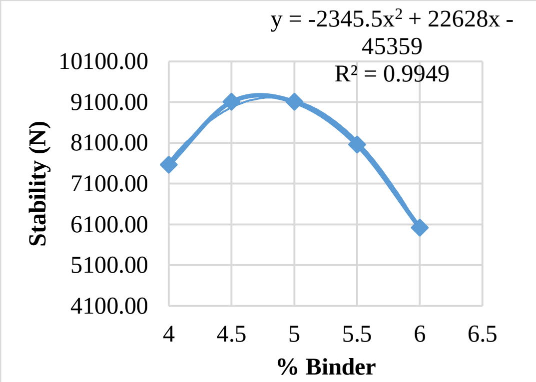

y = -0.0119x² + 0.1106x + 2.1984
R² = 0.957
Bulk Specific Gravity (gm/cc)
2.470
2.450
2.430
4
5
6
% BINDER

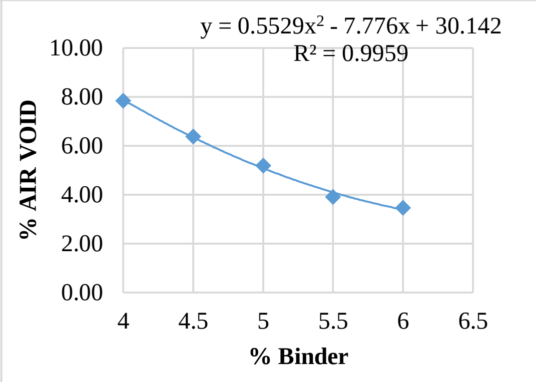

y = 0.0571x² + 0.1686x + 1.53
R² = 0.9955
Flow value (mm)
4.9
4.7
4.5
4.3
4.1
3.9
3.7
3.5
4.5
5
5.5
6
6.5
% BINDER

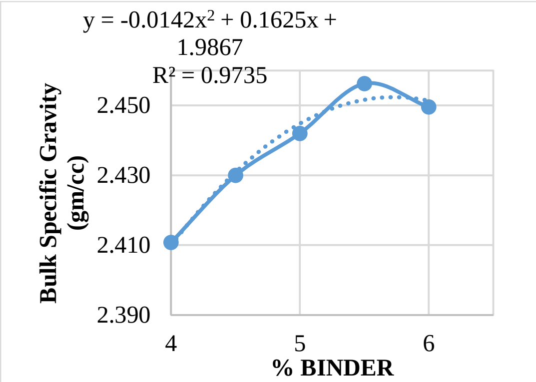

y = -2.8333x² + 37.415x - 44.478
R² = 0.9981
VFB
81.00
76.00
71.00
66.00
61.00
56.00
51.00
4
5
6
7
% BINDER

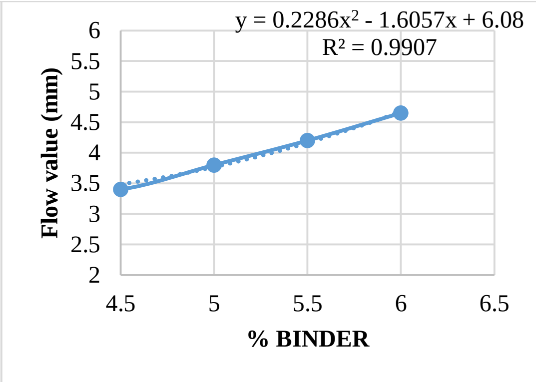

y = 0.3554x² - 2.4311x + 19.899
R² = 0.9965
VMA
18.500
18.000
17.500
17.000
16.500
16.000
15.500
4
5
6
7
% BINDER

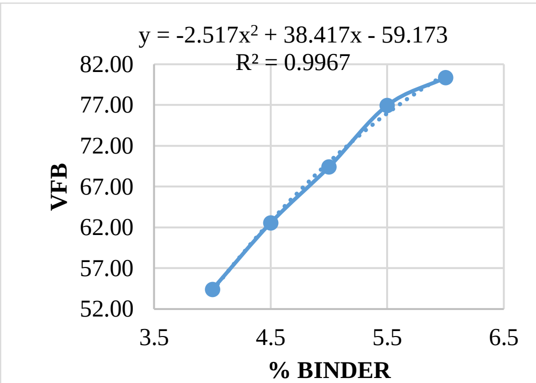
e) 100K-dbm

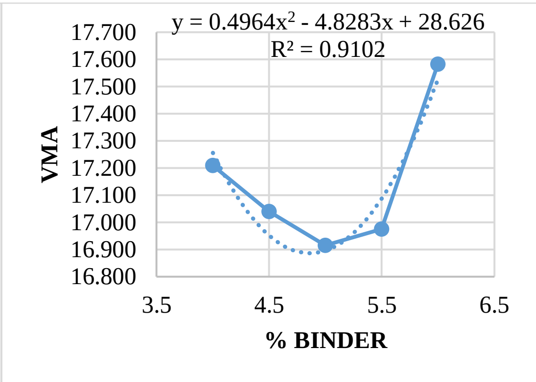

y = -2345.5x² + 22628x - 45359
R² = 0.9949
Stability (N)
10100.00
9100.00
8100.00
7100.00
6100.00
5100.00
4100.00
4
4.5
5
5.5
6
6.5
% Binder


y = 0.5529x² - 7.776x + 30.142
R² = 0.9959
% AIR VOID
10.00
8.00
6.00
4.00
2.00
0.00
4
4.5
5
5.5
6
6.5
% Binder


y = -0.0142x² + 0.1625x + 1.9867
R² = 0.9735
Bulk Specific Gravity (gm/cc)
2.450
2.430
2.410
2.390
4
5
6
% BINDER

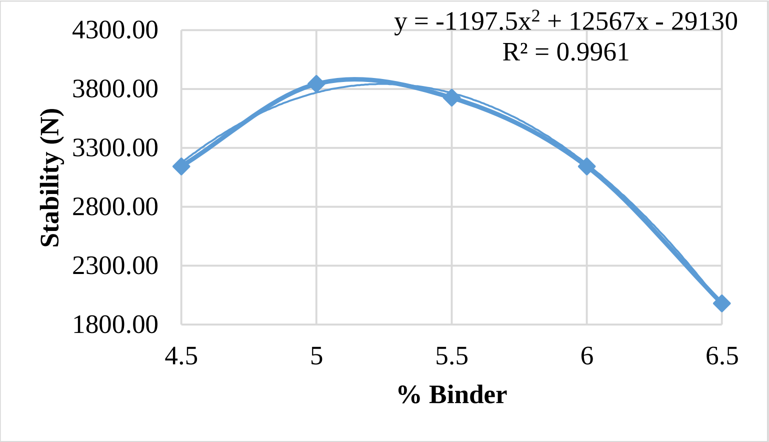

y = 0.2286x² - 1.6057x + 6.08
R² = 0.9907
Flow value (mm)
6
5.5
5
4.5
4
3.5
3
2.5
2
4.5
5
5.5
6
6.5
% BINDER

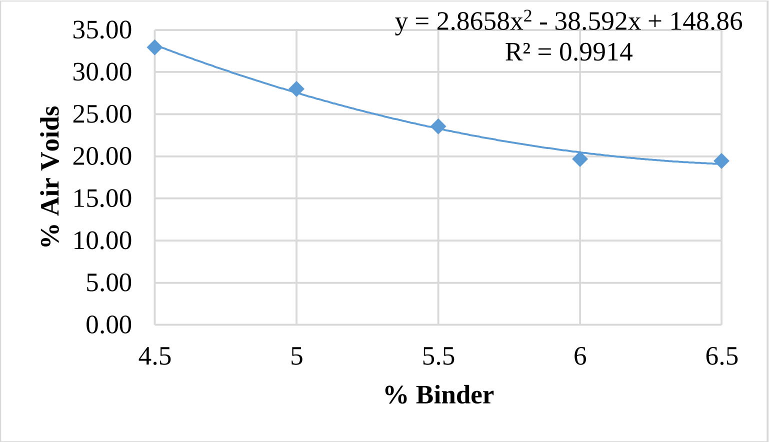

y = -2.517x² + 38.417x - 59.173
R² = 0.9967
VFB
82.00
77.00
72.00
67.00
62.00
57.00
52.00
3.5
4.5
5.5
6.5
% BINDER

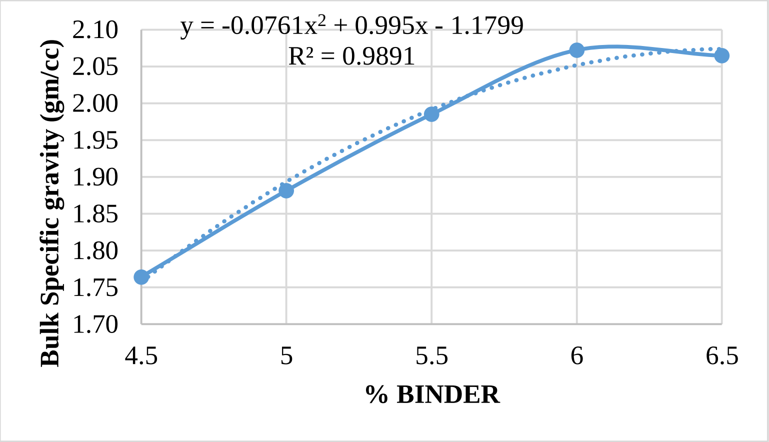

y = 0.4964x² - 4.8283x + 28.626
R² = 0.9102
VMA
17.700
17.600
17.500
17.400
17.300
17.200
17.100
17.000
16.900
16.800
3.5
4.5
5.5
6.5
% BINDER

Marshall Test Results of OGFC mixes

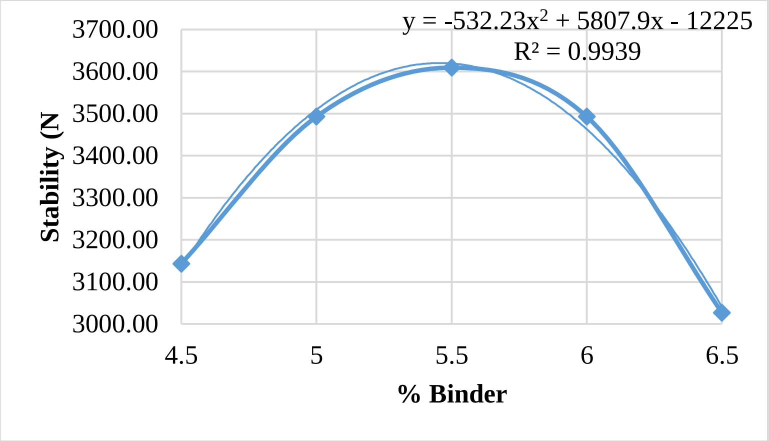
a) C-ogfc

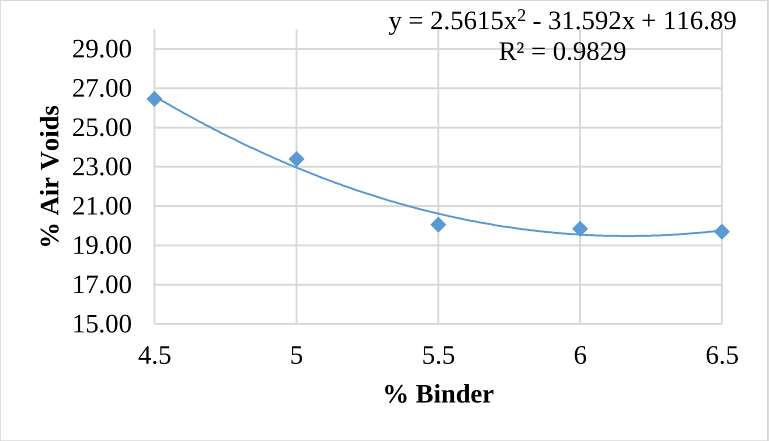


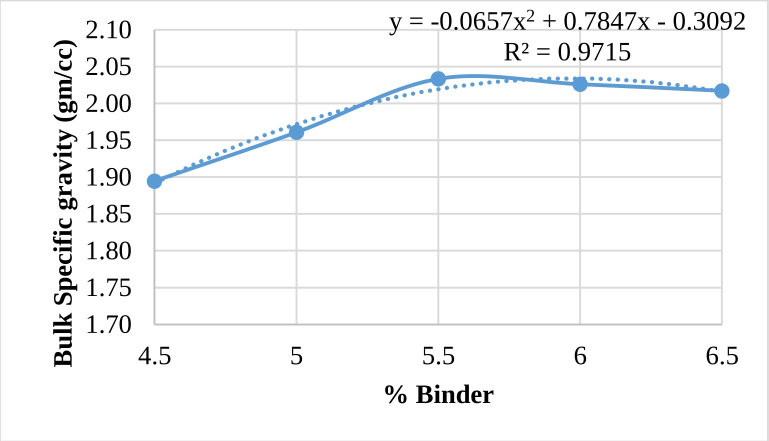




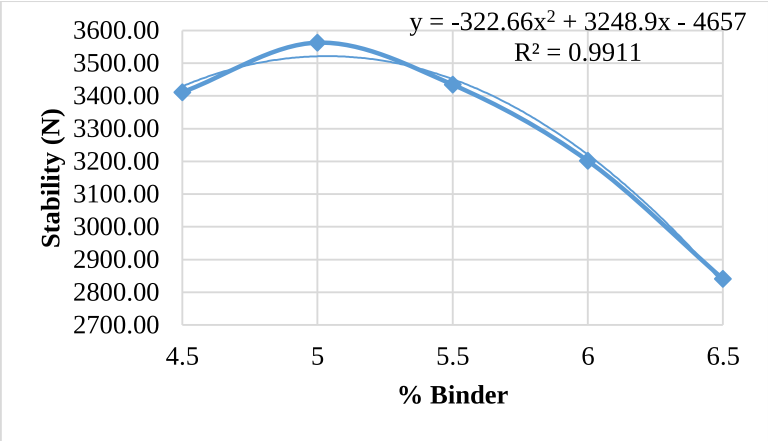
b) 25K-ogfc

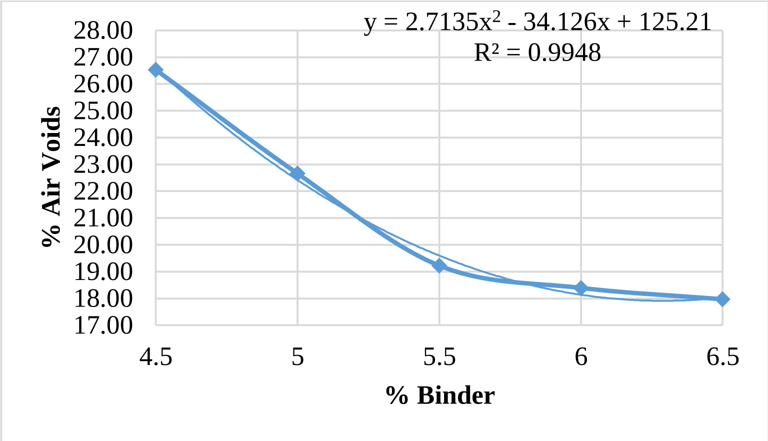

y = -532.23x² + 5807.9x - 12225
R² = 0.9939
Stability (N
3700.00
3600.00
3500.00
3400.00
3300.00
3200.00
3100.00
3000.00
4.5
5
5.5
6
6.5
% Binder

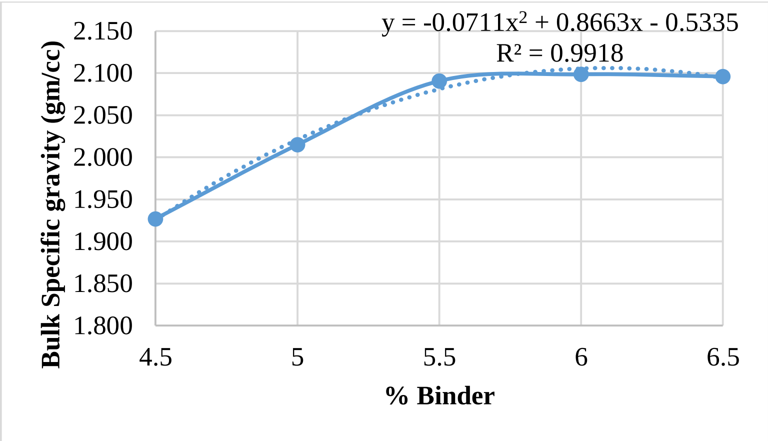

y = 2.5615x² - 31.592x + 116.89
R² = 0.9829
% Air Voids
29.00
27.00
25.00
23.00
21.00
19.00
17.00
15.00
4.5
5
5.5
6
6.5
% Binder


y = -0.0657x² + 0.7847x - 0.3092
R² = 0.9715
Bulk Specific gravity (gm/cc)
2.10
2.05
2.00
1.95
1.90
1.85
1.80
1.75
1.70
4.5
5
5.5
6
6.5
% Binder

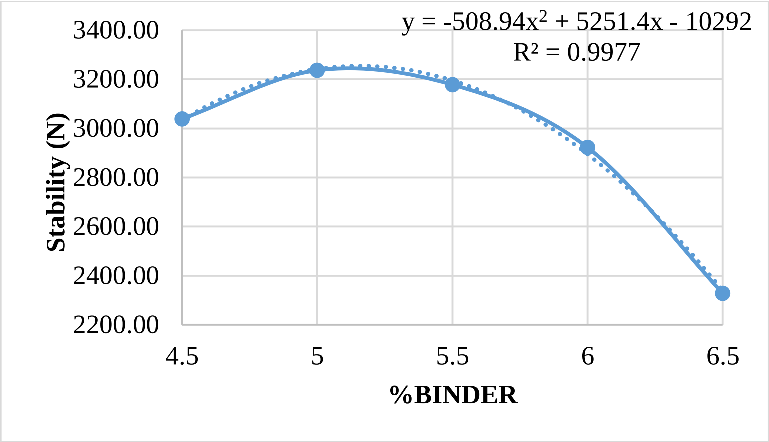
c) 50K-ogfc

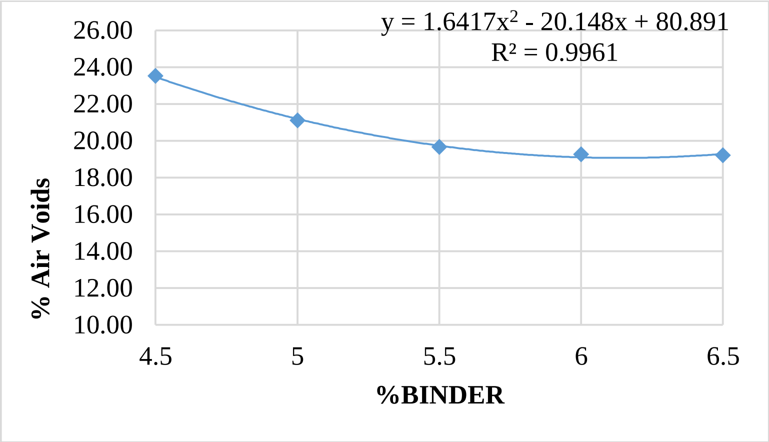

y = -322.66x² + 3248.9x - 4657
R² = 0.9911
Stability (N)
3600.00
3500.00
3400.00
3300.00
3200.00
3100.00
3000.00
2900.00
2800.00
2700.00
4.5
5
5.5
6
6.5
% Binder

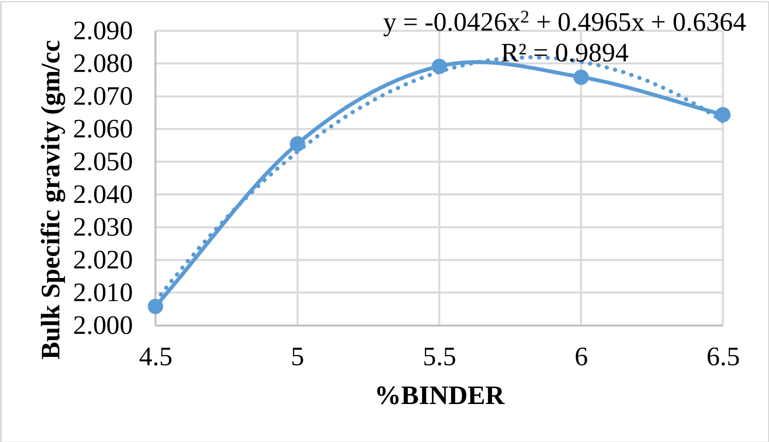

y = 2.7135x² - 34.126x + 125.21
R² = 0.9948
% Air Voids
28.00
27.00
26.00
25.00
24.00
23.00
22.00
21.00
20.00
19.00
18.00
17.00
4.5
5
5.5
6
6.5
% Binder


y = -0.0711x² + 0.8663x - 0.5335
R² = 0.9918
Bulk Specific gravity (gm/cc)
2.150
2.100
2.050
2.000
1.950
1.900
1.850
1.800
4.5
5
5.5
6
6.5
% Binder

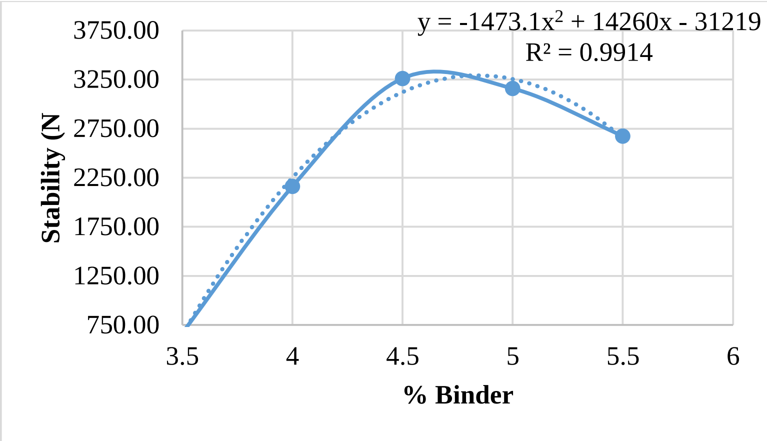
d) 75K-ogfc

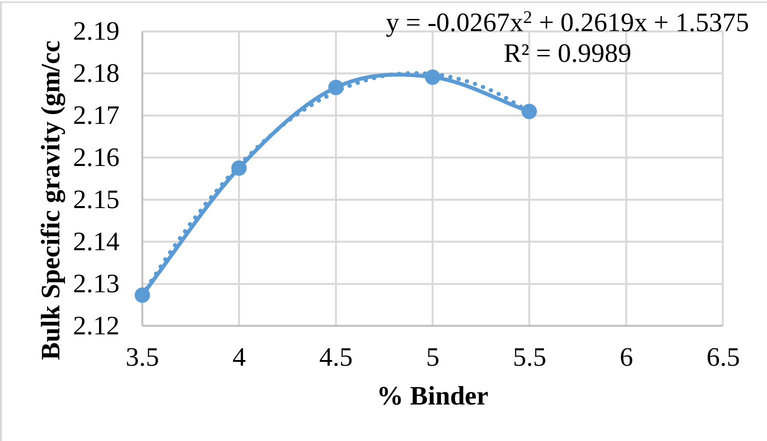

y = -508.94x² + 5251.4x - 10292
R² = 0.9977
Stability (N)
3400.00
3200.00
3000.00
2800.00
2600.00
2400.00
2200.00
4.5
5
5.5
6
6.5
%BINDER

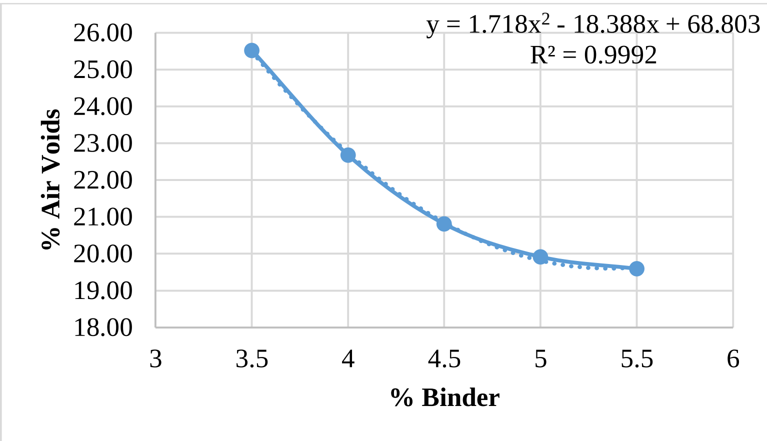

y = 1.6417x² - 20.148x + 80.891
R² = 0.9961
% Air Voids
26.00
24.00
22.00
20.00
18.00
16.00
14.00
12.00
10.00
4.5
5
5.5
6
6.5
%BINDER


y = -0.0426x² + 0.4965x + 0.6364
R² = 0.9894
Bulk Specific gravity (gm/cc
2.090
2.080
2.070
2.060
2.050
2.040
2.030
2.020
2.010
2.000
4.5
5
5.5
6
6.5
%BINDER

e) 100K-ogfc


y = -1473.1x² + 14260x - 31219
R² = 0.9914
Stability (N
3750.00
3250.00
2750.00
2250.00
1750.00
1250.00
750.00
3.5
4
4.5
5
5.5
6
% Binder


y = -0.0267x² + 0.2619x + 1.5375
R² = 0.9989
Bulk Specific gravity (gm/cc
2.19
2.18
2.17
2.16
2.15
2.14
2.13
2.12
3.5
4
4.5
5
5.5
6
6.5
% Binder


y = 1.718x² - 18.388x + 68.803
R² = 0.9992
% Air Voids
26.00
25.00
24.00
23.00
22.00
21.00
20.00
19.00
18.00
3
3.5
4
4.5
5
5.5
6
% Binder

Curriculum Vitae of Author

Name: Pradeep Kumar Gautam

Gender- Male

Birth Date: 29-04-1988

Email: pradeepgtm45@gmail.com , 2014rce9037@mnit.ac.in

Mobile:8107608807

Permanent Address: MIG 503 Ganga Vihar Colony Avas Vikas Roorkee-247667 ; Correspondence Address: Civil Engineering Department, MNIT Jaipur-302017

OBJECTIVE

To pursue higher research, which can help me to develop an expertise in my area of interest and provide a platform to serve society and country.

EDUCATION

Class/Qualification	University / Board	Institute/ School	Year	CGPA/ %
Ph.D. (Transportation Engineering)	Deemed University	Malaviya National Institute of Technology, Jaipur(Rajasthan)	2014-present	7.5
M. TECH. (Water Resource Engineering)	Deemed University	Malaviya National Institute of Technology, Jaipur(Rajasthan)	2012-2014	7.68
B. TECH.	BBDNITM, Lucknow	Gautam Buddh Technical University, Lucknow	2007-2011	65.96
XII Std.	A.I.S.S.C.E	St. Gabriel's Academy Roorkee	2007	67
X Std.	A.I.S.S.E	St. Gabriel's Academy Roorkee	2004	62.4

TECHNICAL SKILLS

Designing and testing of hot mix asphalt.

SEM Analysis of hot mix asphalt.

Dynamic creep and resilient modulus examination of hot mix asphalt. MS Office (MS Word, Excel, Power point).

Auto CAD.

Basic Knowledge of Storm water management model.

TRAINING AND PROJECT WORK

A 45 days summer training at "Construction of school building at Deoband, district Saharanpur." M.Tech dissertation on "Modeling to manage urban storm- A case study of MNIT campus." B.Tech project on "Suggesting alternative route between Zarib Chowki to Mandhana."

PUBLICATIONS

SCI index

[1] P.K. Gautam, P. Kalla, A.S. Jethoo, R. Agrawal, H. S. Chauhan, Sustainable use of waste in flexible pavement: A review, accepted (in print) in Construction and Building Material. Date of acceptance: 9-04-2018 (impact factor 3.169)

[2] P.K. Gautam, P. Kalla, R. Nagar, R. Agrawal, A.S. Jethoo, Laboratory investigations on hot mix asphalt containing mining waste as aggregates, Constr. Build. Mater. 168 (2018) 143– 152. doi:10.1016/j.conbuildmat. 2018.02.115. (impact factor 3.169)

[3] P.K. Gautam, P. Kalla, R. Nagar, A.S. Jethoo, Laboratory investigation on use of quarry waste in open graded friction course, J. Resource Policy. (2018) 0–1. doi:10.1016/j.resourpol.2018.02.009. (impact factor 2.618)

Peer Reviewed International Journals and Conferences

[1] P.Gautam, P.Kalla, A.S. Jethoo, Use of quarry waste as building material: A review at International Conference on Science, Innovation and Management, London, U.K. 7-8th June 2018.

[2] P. Gautam, P. Patidar, P. Kalla, A. S. Jethoo, H. S.C., Use of Kota stone cutting and quarry waste as sub-base material, Interdiscip. Environ. Rev. 18 (2017) 93–100.

[3] P.K. Gautam, P. Kalla, A.S. Jethoo, R. Agarwal, S. Alaria, H. S.C., Evaluation of use of Kota Stone Mining Waste as Fine Aggregate in Bituminous Courses ., Int. J. Eng. Technol. Manag. Appl. Sci. 5 (2017) 834–838. (Impact factor 2.24)

[4] S.C. Harshwardhan, P. Kalla, R. Nagar, P.K. Gautam, Partial Replacement of Cement by Kota Stone Slurry in Mortar, STM Journals. 7 (2017) 8–13.

[5] Vyas, N.K. Gupta, S.K. Gupta, P. Gautam, a. S. Jethoo, Mini/Micro Hydel Power System Design and its Implementation in Rajasthan, Aquat. Procedia. 4 (2015) 1537–1544. doi:10.1016/j.aqpro.2015.02.199.

[6] P.K. Gautam, A.S. Jethoo, S. Shrivastava, S.K. Gupta, Sustainability In Civil Construction and The Role of Civil Engineers, Int. J. Eng. Technol. Manag. Appl. Sci. 3 (2015) 2013–2015. (impact factor 2.24)

[7] S.K. Gupta, A.S. Jethoo, J. Tyagi, N.K. Gupta, P.K. Gautam, Application of Hydrological Models in Water resources : A Review, Int. J. Comput. Math. Sci.4(2015)94–100.

Peer Reviewed National Conferences

[1] P.K. Gautam, P. Kalla, A.S. Jethoo, S.C. Harshwardhan, Dimensional Stone Waste Characterization in Rajasthan and Suggesting their possible Remedies, Int. J. Emerg. Technol. 8 (2017)40–42.

REVIEWER

- Construction and Building Materials.
- Journal of Rehabilitation in Civil Engineering

TEACHING INTEREST

- Highway Engineering.
- Construction of Low-Cost Roads and use of alternative materials in Low and heavy volume traffic roads.
- Sustainable Materials and Construction
- Water Resource Engineering.
- Concrete Technology
- Soil Mechanics
- Environment Engineering
- Hydraulics Engineering
- Fluid Mechanics
- PERT-CPM
- Railway Engineering
- Strength of Materials
- Structure Engineering

RESEARCH INTEREST

- Performance analysis of pavement containing waste materials.
- Sustainable development.
- Sustainable use of waste as construction and building materials.
- Low cost building materials.

SEMINARS/CONFERENCES/COURSES/WORKSHOP ATTENDED

- GIAN Course on "Building resilient and sustainable road structure" from 12-23 Dec 2016 at IIT Madras.
- National Conference on "Urban Environmental Management in India: Problems and Prospects" held on 13-14th February 2017 at MNIT Jaipur.
- One week short term course on "Mathematical Modeling, MATLAB Programing and their application in engineering Sciences" held during January 19-23, 2015 at MNIT Jaipur.
- International Conference on "Emerging Trends of Engineering, Science, Management and its Application" held on March 01, 2015 at JNU, NewDelhi.

EXTRA-CURRICULAR ACTIVITIES

- Second in T-shirt designing competition on occasion of National unity day celebration event, 2017.
- Secured third position in bodybuilding competition at Malaviya SportFest-2012, 2017.
- Member of Jodhana photography Association, Jodhpur, Rajasthan.
- Organizing committee member in Co-NIT's Meet held at MNIT Jaipur in October2015
- Organizing committee member for "Gainful utilization of mining waste" summit, sponsored by Centre of Development of Stones, held at MNIT Jaipur.

HOBBIES

- Participated in other co-curricular activities as volunteer and as participants.
- Drawing, Sketching.
- Photography
- Chalk carving
- Weightlifting