CHAPTER 1

INTRODUCTION

1.1 Preamble

India has the second-largest road network in the world which spans over more than 5.6 million km (Figure 1.1). It is responsible for transporting 90% of passenger traffic as well as 64.5% of all goods (IBEF, 2019). Indian road network enabled the transportation sector of the country to contribute about 4.7% in India's GDP, which is very high in comparison to railways that have only contributed to 1% of GDP. Since the dawn of the globalization in 1991, the emphasis is given to enhancing connectivity between different parts of India by systematic maintenance and the further expansion of the existing road network. Under the current government, road construction grew at 30 km per day in 2018-19 compared to 12 km per day in 2014-15 (Economic Survey of India, 2019). Today, Indian road network comprised of various categories of roads such as expressways, national highways, state highways, major district roads, other district roads and rural roads (Figure 1.2).

The present road network is seriously capacity constrained and deficient, which negatively affect the traffic movement. The problem has further worsened due to phenomenal increase in vehicle population along with a substantial increase in axle loads in the last decade. The existing road network also faces challenges with road networks of China and the European Union in terms of trucking logistics. One of the world's largest audit and advisory services companies, KPMG has expressed their concern that the logistics and transportation bottlenecks of Indian road network impede its growth in GDP by 1 to 2% which is equivalent to an annual loss of around

10 million new jobs. Hence, the government of India has initiated several programs including the aspiring National Highway Development Program which comprises of projects such as Golden Quadrilateral, North-South and East-West corridor projects. Government has focused on capacity augmentation by 4-laning and 6-laning of national highways, and improving riding quality.

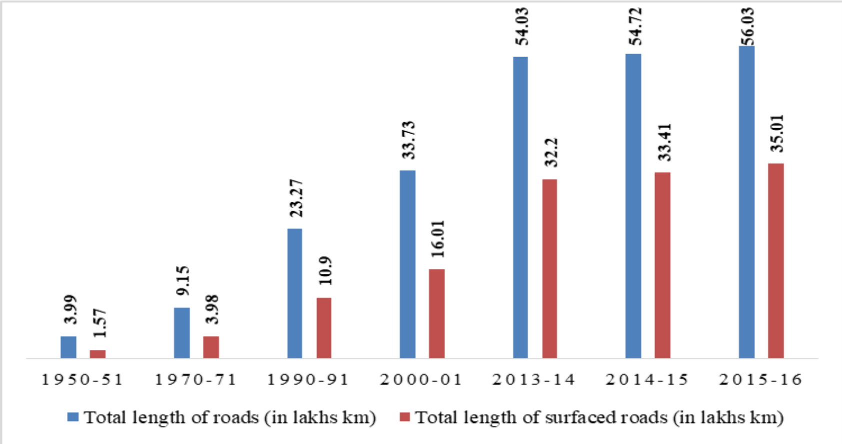

Figure 1.1 Increase in Indian road network throughout the years (IBEF, 2019)

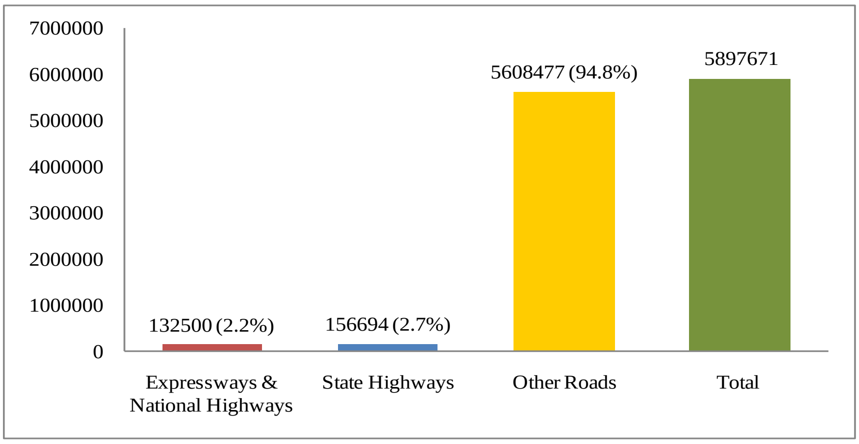

Figure 1.2 Lengths of various categories of roads (in km) and their relative proportion (in parenthesis) (MoRTH, 2019)

The road network of India majorly comprises of flexible pavements and rigid pavements. A typical flexible pavement comprises of bituminous surface course topped over base (granular or cementitious), sub-base (granular) course and subgrade (existing soil). These pavements are termed as “flexible” due to their negligible flexure strength and tendency to undergo deformation by imposed traffic loads. While the rigid pavement has very high flexural rigidity since they comprise of the concrete slab of thickness 5-12 inches as their surface course. A properly constructed flexible pavements offers numerous advantages over rigid pavements such as lower initial cost, faster construction, facility of stage construction, lower noise pollution, higher driver comfort, higher recyclability, and lower green house gas emission (EAPA, 2019). Due to these advantages, around 95% of roads are made up of flexible pavement which utilizes bituminous mixes[1] as their surface, binder and base courses (Huang et al., 2007).

1.2 Problem Statement and Need for the Study

1.2.1 Extensive Demand of Aggregates

Bituminous mixes are conventionally made up of non-renewable natural resources like aggregates and carbon-based bitumen binder. A typical bituminous mix consists of about 93-96% of aggregates and 4-6% of bitumen. In these mixes, the aggregates of various sizes provide strength by forming a rigid structure, while the bituminous binder is responsible for holding the mix together and enhancing its durability. The projected aggregate and bitumen requirements are increasing exponentially every year. In 2013, construction industries produced approximately 92.53 million tonnes of bituminous concrete mixes for pavement construction globally (UN data, 2016). Production of such large quantity of mixes has intrinsic distinctiveness for environmental damage due to continuous exploitation of natural resources, particularly aggregates. Exhaustive mining also causes problems such as vegetation loss, loss of water retaining strata, lowering of groundwater table and disturbance in the existing ecosystem. The unavailability of aggregates is also pronounced due to

[1]Bituminous mix and asphalt mix are synonyms of each other and both terms are used interchangeably in this thesis. Similarly, bitumen and asphalt are used interchangeably.

mining restriction, environmental protection regulation and appreciating land costs. This consequently reduces the availability of aggregates and increases in the cost of bituminous mixes. Price of bituminous concrete increased from the US $68 (1$≈71 INR) per ton in 2004 to the US $104 per ton in 2007 which increased the overall cost of pavement construction (Hasan 2009). Aggregates production is also responsible for half of the total greenhouse gas (GHG) emission in the construction of bituminous and concrete pavements (Inyim et al., 2016).

In India, each km of highway construction consumes around 15,000 tonnes of aggregates (NBM&CW, 2019). Approximate amount of aggregates that will be required for road construction in India from the year 2001 to 2021 is stated in Table 1.1. Large parts of the country such as, West Bengal, Bihar and Gangetic plains of Uttar Pradesh, etc. do not have stone deposits at economical haul distances, which lead to a substantial increase in road construction costs in these areas. It is assumed that for a lead of 200 km requires 180 lakh litre of diesel alone in transportation (NBM&CW, 2019). Such a large amount of diesel consumption led to the emission of harmful pollutants like nitrogen oxides, sulphur dioxides and particulate in the environment which are harmful to the environment and human health. There is an immediate need of alternative materials in place of traditional aggregates to slacken landfill pressures, reducing the demand for extraction and help the road construction industry to move on track towards sustainable construction practices.

Table 1.1 Rough estimate of stone aggregates requirement in 2001-2021 (length of construction taken from Vision Document 2021) (Choudhary, 2008)

Length Proposed (km)	Width of new carriageway (m)	Thickness of new carriageway (m)	Width of an overlay (m)	Thickness of overlay (m)	Quantity of stone required, (million m^3)
Expressways					
10,000	24	0.75	-	-	180
Four-laning/ six-laning of national highways					
35,000	8.50	0.75	8.5	0.10	≈250
Widening to 2 lanes of national highways					
22,000	3.0	0.75	3.5	0.10	≈120
Strengthening weak pavements of national highways					
44,000	-	-	10.00	0.10	≈50
Four/Six laning of state highways					
10,000	8.5	0.75	8.5	0.10	≈75
Widening to 2 lanes of state highways					
95,000	3.0	0.75	3.0	0.10	≈500
Strengthening weak pavements of state highways					
70,000	-	-	10.00	0.10	≈500
Two laning of major district roads					
60,000	3.5	0.50	3.5	0.05	≈120
Strengthening weak pavements of major district roads					
70,000	-	-	3.75	0.15	≈40
Rural roads (new)					
7,00,000	3.75	0.40	-	-	≈1000
Upgrading of rural roads					
10,00,000	-	-	3.75	0.15	≈600

1.2.2 Safe and Efficient Waste Disposal

In the 21st century, the problem of waste generation is becoming increasingly acute due to ever-increasing quantity in industrial, municipal, demolition and other wastes generated despite measures taken at local, regional and national levels. In the year 2002, global solid waste generation was projected to 12.6 billion tones, which is expected to be increased to 19 billion tones by 2025 (Yoshizawa et al., 2004). Today, India alone annually contributes 960 million tonnes of solid waste comprising of by-products generated during industrial, agricultural, mining, municipal and other wastes (Pappu et al., 2007)(Figure 1.3).

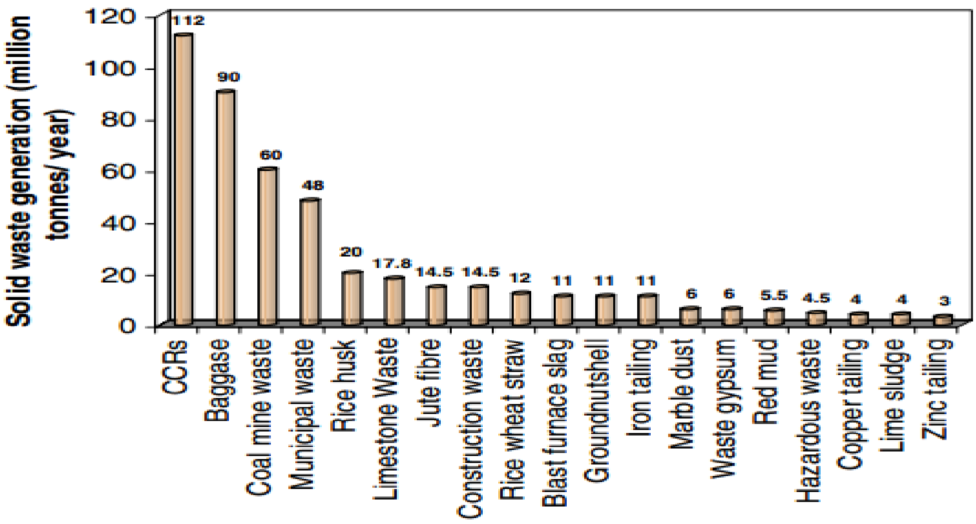

Figure 1.3 Status of solid waste generation in India (Pappu et al., 2007)

This huge quantity of generated wastes constitutes both hazardous and non-hazardous wastes. Exposure of hazardous waste to the environment does lead to serious contamination of soil, air, water, aquatic life, flora, fauna, human health and degrading living conditions. The disposal of these wastes is usually done by landfilling, incineration and by recycling. However, the limited capacity of landfills, air pollution associated with incinerators and limited alternatives for recycling limits the safe disposal of wastes. Not only in India but also European Union countries and other major global economies, the rate of landfills are quite high, meanwhile, rate of recycling is still quite low (Pietzsch et al., 2017). Hence, legislation such as directive 2008/98/EC has been enacted by governments to mandate the recycling of these wastes in various applications. Still, in countries like India, industries just manage to recycle 15–20% of solid wastes in various building components (Pappu et al., 2007). Hence safe management of these huge solid wastes is a major global concern requiring extensive research and development work to find a social, environmentally friendly and techno-economic solution to sustain a greener environment.

1.2.3 Utilization of Waste as Mineral Filler: A Common Solution

Bituminous concrete also popularly known as asphalt concrete is one of the widely used bituminous mixes around the globe (Table 1.2). Utilization of waste materials in bituminous concrete would conserve natural resources for better use in the global economy. So, a more ecologically sustainable and responsible attitude is needed to be adopted for waste minimization and utilization of waste and by-product materials.

Table 1.2 Top bituminous concrete producers around the globe (UN data, 2016)

Country	Net production of bituminous concrete in 2013 (million tonnes)
United State of America	17.57
China	16.27
Russia	5.61
India	4.34
Canada	3.93
Iran	3.53
Japan	3.32
Republic of Korea	3.28
Germany	3.09
Italy and San Marino	2.82
Turkey	2.65
Brazil	2.41
Saudi Arabia	2.22
Singapore	2.02
Spain	1.90
France (including Monaco)	1.75

Mineral filler can be termed as finest part of aggregates and consider as an integral part of the bituminous mix. Fillers are the mineral grains most of which pass through 75μm sieve and represents up to 12% of the aggregates by weight in the entire bituminous mix (MoRTH, 2013). Several studies have observed the significant influence of fillers on the cost (Chandra and Choudhary, 2013; Faheem et al., 2017), constructability (Matos et al., 2014), and performance of bituminous mixes against distresses like permanent deformation (Wang et al., 2011), cracking (Das and Singh, 2018; Kim et al., 2003), ravelling (Zhang et al., 2018), moisture sensitivity (Pasandin et al., 2016), and long-term aging (Gubler et al., 1999; Recasens et al., 2005). Performance of bituminous mixes is ultimately linked to physical and chemical characteristics of chosen filler, its physical-chemical interaction with bitumen and its volumetric concentration in the mix (details will explored in subsequent chapters). Hence the choice of suitable filler is crucial amongst field engineers. Materials such as stone dust, hydrated lime, and cement are being conventionally utilized in bituminous mix composition as fillers since they deliver satisfactory performances in the mix (Lesueur et al., 2013). However, in the past studies, the use of suitable waste materials as alternative fillers has proven to provide a sustainable bulk outlet to wastes without degrading the performance of the mixes (Arabani et al., 2017; Chandra and Choudhary, 2013; Sharma et al., 2010). Hence this study aimed to investigate the appropriateness of industrial waste as filler in bituminous concrete mixes which not only reinstate the economic value of industrial activities and waste processing, but also help pavement industry to move to the path of sustainable construction.

1.3 Details about the Wastes Used in this Study

This study has analyzed the performance of two wastes, dimensional limestone dust and waste glass powder as fillers in bituminous mixes. These wastes are widely available in India and also were limitedly explored as fillers by the past researchers. Available literatures and preliminary studies conducted on them suggested that they display characteristics of good fillers as demanded by Indian specification (discussed in detail in subsequent chapters).

1.3.1 Dimensional Limestone (Kota Stone)

According to ASTM C-119, the term "Dimensional Stone" is used for various types of natural stones that are fabricated to the specific sizes and shapes for structural and ornamental usage as buildings, flooring, paving, cladding, monuments, and statues. In 2012, the worldwide production of dimensional stone is estimated to be about 125 Mt. Dimensional limestone is one of the most consumed dimensional stone since it can take polish similar to marble at a relatively lower cost. Hence its demand in the world market is increasing continuously (Rana et al., 2017). As per USGS, limestone constituted about 45% of total dimensional stone sold in the USA market (Dolley, 2015). Production of dimensional limestone is reported in 28 countries, and India alone contributed to 32% of the world's total dimensional stone output. Rajasthan state is the major producer of limestone and it alone produces 90% of the country's limestone (Rana et al., 2016). Commercially, limestone is marketed by its origin place like Belgian marble, Buxy Limestone, Chassagne limestone, Clipsham Stone, Galala Marble, Indiana limestone, Kansas limestone, Kettone stone, Wisconsin limestone, Tura limestone, etc. In India, it is mostly marketed by the name of its place of origin as Kota stone[2]. It is a type of sedimentary rock composed of calcite with or without magnesium. It can be further classified as industrial grade/cement grade limestone and dimensional limestone. Industrial grade limestone has been used in cement manufacturing as raw material, while dimensional limestone has not been used by cement industries due to lesser CaO and higher impurities in them (Rana et al., 2016).

Manufacturing of limestone is considered a very unsustainable process. The rock mass that is needed to be quarried is usually burdened under the soil or uneconomical

[2]. In this study, the term "limestone" and "Kota stone" are used interchangeably.

rock mass. This overburden is removed using manual, mechanical and blasting techniques. The choice of the technique depends upon the thickness and hardness of overburden rock.

Plate 1.1 (a) Polishing of Kota Stone at Kota city

Plate 1.1 (b) Dump yard of Kota Stone dust at Kota city

Plate 1.1 Generation and dumping of Kota stone dust

The stone is quarried from its mine in the form of blocks which are shaped in the desired sizes using diamond frame saw and/or gang saw. These blocks are subsequently polished to give them smooth and shiny texture. Carbonate stones like limestone and marble are usually polished with 5-8 Frankfurt diamond sector chucks with continuous belt polishers. During the polishing operations, a large amount of cold water is showered on the blades to soak up their dust (Plate 1.1 (a)). The water combined with the dust forms slurry which is drained to the nearby sedimentation tank. In the sedimentation tank, the suspended dust particles in the slurry get settled down at the bottom due to the gravity, while the water is usually recycled back in the cutting and polishing operations. The slurry cakes settled at the bottom of the tank is then dredged up and disposed to the nearby dumping grounds (Plate 1.1 (b)).

Currently, mining and processing of Kota stone generates more than 12 lakh MT of fine dust waste annually. About 4-5 lakh Mt of slurry dust is disposed as landfills, and rest is disposed in an unplanned manner along roadsides, fertile lands, pasture lands, forest areas, in nearby water sources, etc. (Kumar et al., 2018). Unsustainable disposal of this huge amount of produced waste causes a grave threat to the environment and human health. There is a common phenomenon of soil, water, and air contamination which is observed due to unsustainable disposal of slurry around the globe (Algin and Turgut, 2008). The dumped waste occupies huge areas of valuable land near the mines, hinders the flow of storm water and adversely affects the region's landscape. Disposal of this type of dust is affecting 5 to 10 hectares of prime land every year. After dumping, slurry water evaporates or permeates through the ground surface. Along with water, fine slurry particles also penetrate the earth’s surface and choke the pores present in soil strata. Choked pores reduce the water permeability of the soil, thereby reducing the underground water. The fine slurry particles when inhaled can also cause bronchial disorders like silicosis to the nearby inhabitants. A few cases of skin and vision disorders have also been reported. The high concentrations of CaO and MgO in the slurry waste also increase the water hardness and reduce agriculture productivity. The settlement of dust particles in water drains also lead to the hindering of the drainage system which causes rainwater flooding in adjoining agriculture fields which cause high crop losses. Dust particles also cause nuisance and degrade the aesthetics of the area. The sustainable disposal of slurry waste has become a crucial issue for stone industries and government organizations. In the area of Ramganj Mandi, Rajasthan, India, the government has introduced a new policy, according to which mining lease is given to stone industry only if it first procures land for the dumping of waste. However, the newly allotted dumping yards are situated at a distance of 20–30 km, which increased the cost of waste transportation and questioned the economic feasibility of Kota stone mining in the region. Hence sustainable utilization of Kota stone dust as the filler will provide a sustainable bulk outlet to wastes and will reinstate the economic value of mining and waste processing. Kota stone dust has finer nature, a predominance of the calcium-based compound and has low active clay content, hence it could be beneficially utilized as filler in bituminous concrete mixes.

1.3.2 Glass Powder

The manufacturing of glass dates back to as early as 3500 BC in Mesopotamia, Egypt, and northern Syria. Today, glass is one of the primary components in lighting, windows, appliances, solar panels, and fibre optic cables, etc. There are various types of glass which include soda-lime glass, crystal, lead crystal glass, electric glass, and borosilicate glass that are used in different applications. In 2007, global production of glass was estimated to be more than 130 million tonnes (IEA, 2007). This exponential growth in demand for glass also leads to a significant increase in glass waste. USA alone contributed to 10.37 million tonnes of glass waste to the municipal waste stream in 2013 (US EPA, 2015). Waste glass referred as a by-product of crushed bottles, window panes and other glass items obtained from streams of industrial and municipal wastes, which majorly comprise, of sand-sized particles accompanied with a small percentage of silt-sized particles. A good quantity of glass waste is also generated in the form of slurry during the cutting and polishing operations in glass industries which usually got dump in landfills and cause serious damage to the environment. Glass is a non-metallic and inorganic material produced by sintering appropriate raw materials. Being non-metallic and inorganic, glass can be neither cremated nor decomposed by microbial. For this reason, underground burial has been the only possible solution. However, glass bottles are assumed to take around 1 million years for their complete decomposition, thus they consume a significant amount of valuable space for a very long time (Mohajerani et al., 2017). Hence, despite a huge amount of glass waste being generated each year, it has a very low value in the scrap market. In 2018, the net price and trade volume indicators of various wastes are stated as 330 €/tonne (1€≈79INR) and 653,211 tonnes for plastic waste; 145 €/tonne and 3,713,649 tonnes for paper waste; and 57 €/tonne and 429,953 tonnes for glass waste (Eurostat, 2018). Glass has lowest net price amongst all wastes.

Table 1.3 Amount of waste glass and their net percentage of recycling

Country	Rate of recycling (%)	Year	Reference
Canada	68	2009	Ferderico and Chidiac (2009)
Singapore	29	2010	Tan and Du (2013)
Portugal	25	2001	Pereira-de-Oliveira et al. (2012)
Turkey	66	2004	Topcu and Canbaz (2004)
Jordan	0	2004	Park et al. (2004)
Belgium	96	2010	CRI (2019)
Switzerland	94		
Luxembourg	93		
Netherlands	91		
Sweden	91		
Norway	89		
Germany	82		
Italy	74		
France	67		
UK	61		
Spain	57		
USA	33		

Table 1.3 shows the amount of waste glass produced by various countries along with their rate of recycling. It can be observed that the countries that are not part of the European Union have a lower recycling rate of waste glass. India recycles around 45% of glass waste each year, hence there is a need to look for an alternative solution to recycle the large quantities of remaining waste glass (Greensutra, 2019).

Researchers have utilized crushed waste glass and glass cullets as aggregates in sub-base, unbound base, bituminous mixes, cement concrete, and as cementitious material. However, there are very limited studies that have investigated the potential of glass powder as filler in bituminous mixes. A few recent studies have utilized waste crushed glass powder from bottles and window panes etc as fillers in bituminous mixes (Arabani et al., 2017; Saltan et al., 2015). However, to utilize glass waste from aforesaid sources, a large amount of additional energy and cost is consumed to reduce glass into suitable fineness. It must be noted that similar to Kota Stone, a large amount of glass waste is also generated in the form of slurry during the cutting and polishing operations in glass industries which usually dump in open areas and cause serious damage to the environment (Plate 1.2 (a) and (b)). Unlike glass waste from other sources, this form of glass waste is very fine in nature and couldn't be recycled conventionally. Utilization of glass powder from these sources can decrease environmental waste as well as can save energy. However, no detailed study has been made to investigate the recyclability of glass waste from this source. So an attempt was made to assess the usability of glass powder from glass industries as mineral filler by replacing the conventional stone dust filler in the bituminous concrete mix. Few studies have observed problems such as early stripping, poor bituminous adhesion and high ravelling in glass modified bituminous mixes due to low binder absorption by the glass and high silica content in its composition (Wu et al., 2007). So there is a possibility that glass powder used as filler may not form a strong bond with the bitumen in bituminous mix and cause aforesaid problems.

Plate 1.2 (a) Dried glass slurry disposed at dump yards in the Bhopal city

Plate 1.2 (b) Glass slurry disposed along the roadside in Bhopal city

Plate 1.2 Glass slurry generation and disposal

Hydrated lime is one of the commonly used mineral filler and a well-known anti-stripping agent used in bituminous mixes to reduce moisture damage (stripping). Hydrated lime reacts with aggregates to strengthen the bitumen-aggregate bond. Hence the addition of a small amount of hydrated lime with glass powder can reduce the possibility of stripping and can increase the allowable percentage of glass in the mix. Other than that, the addition of hydrated lime in bituminous mix can significantly improve its mechanical properties and resistance to aging (Lesueur et al., 2013). Hence, attempts are made not only to utilize the glass powder alone as alternative filler but also with a limited amount of hydrated lime in the form of glass-lime composite filler.

1.4 Objectives of the Study

This study is aimed at investigating the use of glass powder and Kota stone dust along with glass-lime composite filler in bituminous construction, and their effects over the performance of bituminous mastics and bituminous mixes. The performance of the mastics and mixes prepared with waste fillers were compared with their conventional counterparts prepared with stone dust filler. The primary objectives of this study are listed below.

- Physical, morphological, and chemical characterization of waste and conventional fillers.
- To determine the rheological properties of filler bitumen mastic prepared with different fillers and filler bitumen ratios.
- To determine the effect of type and concentration of these fillers on optimum bitumen content (OBC), Marshall and volumetric properties of the bituminous concrete mix as specified in Indian paving specifications (MoRTH, 2013).
- To evaluate the performance of bituminous concrete mixes prepared with various fillers against various pavement distresses.
- To workout the structural layer thicknesses of bituminous layers made from different mixes and perform comparative economical analysis.
- Propose a novel ranking method based on the laboratory results and decision made by the designer to choose optimum mix.

1.5 Scope of the Study

The present work evaluates the suitability of glass powder and Kota stone dust along with glass - hydrated lime composites as filler in bituminous mixes. All wastes were collected from a single source to maintain consistency in their properties. Similarly, dolomite aggregates from a single quarry and VG 30 bitumen from a single source was used throughout the study. The entire work is divided into six parts as below:

- Physical and chemical analysis of waste and conventional stone dust fillers is done as per relevant test procedures stated in Indian specification as well as that were suggested by other global specifications and relevant literatures. Properties such as particle shape, size, texture, porosity, clay content, mineralogy, chemical composition, pH value, and hydrophilic coefficient were determined.

- Bituminous concrete mixes were designed at four different filler concentration using the Marshall mix design method. Variation of OBC and other Marshall properties of mixes with filler contents were studied.
- Various mastics prepared at filler bitumen ratios corresponding to different mixes, and their rheological was determined with the aid of softening point test and dynamic shear rheometer (DSR) at different temperatures (25ºC and 46-70ºC) and varying frequency range (0.1-100 rad/s).
- The rutting behavior of short-term aged bitumen and mastics was evaluated at 46-70ºC using Superpave rutting parameter and Multiple Stress Creep and Recovery (MSCR) tests. The fatigue behavior of long-term aged mastics was evaluated using Superpave fatigue parameter, Linear Amplitude Sweep (LAS), and MSCR test performed at 25ºC.
- Performance of bituminous concrete mixes in various aspects such as moisture sensitivity, rutting resistance, fatigue resistance, cracking resistance, ravelling resistance, long-term aging resistance, resilient modulus, active and passive adhesion was studied through several standard test methods. The major tests performed are retained Marshall stability analysis, modified Lottman test, Marshall quotient analysis, indirect tensile strength analysis, indirect tensile fatigue test, resilient modulus analysis, Cantabro analysis (wet, dry and aged), mixing time analysis and Texas boiling water test.

- The analysis of structural design thickness of flexible pavements utilizing various mixes as their surface course, for a fixed traffic condition was done according to IRC 37 (2018) specification. The cost analysis of constructing 1 km of 2 lane surface layer course made with various mixes is also done.
- A priority-based novel ranking procedure based on various laboratory results and priority assigned by designer was proposed to choose the most appropriate type and quantity of filler to ensure optimum performance of bituminous mixes. Results of the above tests are analyzed and the possibility of using various fillers in bituminous concrete mixes is discussed.

Majority of the tests were conducted in the Transportation Engineering Laboratory of Civil Engineering Department, IIT (BHU). The characterization tests of mineral fillers like SEM and XRD was conducted in the Central Instrumentation Facility, IIT (BHU). A few filler characterization tests such as Methylene Blue Value analysis and pH analysis was conducted in the Environmental Engineering Laboratory of Civil Engineering Department, IIT (BHU). The fatigue life and resilient modulus analysis were performed in the Pavement Engineering Laboratory of Civil Engineering Department, IIT (Kharagpur) due to the unavailability of the required testing facility at IIT (BHU) or any other nearby research laboratory.

1.6 Structure of the Thesis

The present thesis has been documented in the following chapters

Chapter 1: This chapter provides a general description of the road network in India, availability of natural aggregates and the need for the study. The problem statement is defined and the emphasis is given to the generation of glass and Kota stone waste. The scope and the objectives of the research are defined and the layout of the thesis is stated.

Chapter 2: The comprehensive review of earlier works done to investigate the role of fillers on the performance of bituminous mastics and mixes is stated. Emphasis is given to the various physical and chemical characteristics of fillers and their influence on the performance of bituminous mastics and mixes. Finally, the effect of various widely used waste fillers on the behavior of bituminous mixes is discussed.

Chapter 3: This chapter gives details about the methodology adopted to carry out the experimental work in the present study.

Chapter4: This chapter presents the results obtained from the physical, morphological and chemical characterization of various fillers used in this study as per relevant testing protocols.

Chapter 5: This chapter deals with the designing of bituminous concrete mixes with different fillers (stone dust, glass powder, Kota stone dust, and glass-line composite) added at four different percentages (4, 5.5, 7 and 8.5%). The mixes were designed using Marshall mix design and their respective optimum binder content (OBC) were evaluated. Bituminous concrete mixes incorporating glass-lime composite filler were designed by replacing 2% glass powder at each filler dosage level with hydrated lime and their OBC were evaluated. Various Marshall and volumetric properties of mixes and the effect of type and quantity of filler over them were discussed.

Chapter 6: This chapter explains the various rheological aspects of bituminous mastics. The mastic correspond to each type of mix was prepared at filler bitumen ratio determined with filler content of the bituminous mix and its corresponding OBC. Various rheological parameters of mastics were determined using DSR at different loading frequencies and temperatures. The performance of mastics against rutting, fatigue and long-term ageing was determined as per relevant testing specifications. The relationships between different test results are also determined.

Chapter 7: This chapter examines the performance of bituminous mixes in various aspects such as moisture sensitivity, rutting resistance, fatigue resistance, cracking resistance, ravelling resistance, long-term aging resistance, resilient modulus, active and passive adhesion was studied through several standard test methods. Effect of type of fillers and their quantity on the performance of bituminous concrete mixes are discussed in detail.

Chapter 8: Design of flexible pavements utilizing various bituminous mixes as their surface course for standard traffic conditions is done as per IRC 37 (2018) guidelines. The calculation of cost of construction of surface course for 1 km 2-lanned pavement was also done and comparison between various mixes is made.

Chapter 9: A novel ranking method is proposed to rank various mixes based on their experimental results to ensure optimum performance of mix and priority assigned by the designer on field. The ranking of all sixteen mixes was done according to the suggested method.

Chapter 10: Significant conclusions drawn from this study are given in detail in this chapter. Guidelines for the utilization of stated wastes as filler in bituminous concrete are also given. Recommendations and the future scope of the study are also highlighted.