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Utilization of waste crushed glass as aggregate in road construction

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Abstract
Glass is widely used in our daily life, and with the continuously increased consumption, a large amount of waste glass is generated annually. The best way to deal with such waste particles is to recycle and reuse them as raw materials or modifiers. This aims to study the performance of asphalt concrete pavement in which a fraction of aggregate is replaced with waste crushed glass.
In order to meet the objectives a total of 16 samples were prepared by adding crushed glass to the mix with 10%, 15%, and 20% by weight of aggregate meeting the standard Department of Roads (DoR), Indian gradation specifications. The fine aggregates were replaced and same proportion of the glass particles were added. With the increase in glass content the optimum binder content of the mix decreased. The stability values increased upto 15% glass content and decreased when the glass content was further increased to 20%. As per the cost estimate maximum cost saving was possible at 20% glass content.
Despite decrease in Marshall stability value at this glass content, the decreased value was within the specifications and hence the use of this glass content is economically viable.

Keywords: Waste glass cullet, asphaltic concrete, stone dust

Introduction
There are various types of flexible pavement constructed over the country depending upon the traffic volume, durability, design life, maintenance, cost of construction etc. Recently the government has been upgrading the major highways and the feeder roads to the asphalt concrete, so the construction of the asphalt concrete has been widely increased throughout the country. Since the asphalt concrete is more costly than other types of flexible pavement, various factors should be taken into the consideration during the construction work. Glass is considered a potentially promising modifier to asphalt. It is a non-metallic and inorganic material. Glass can be recycled without changing its composition and properties. Glass industry has been part of human history for thousands of years. Glass is widely used in our daily life, and with the continuously increased consumption, a large amount of waste glass is generated annually. The best way to deal with these wastes is to recycle and reuse them as raw materials or modifiers. Asphalt Concrete, also known as bituminous concrete, is a composite material composed of an aggregate framework bound together by bituminous binder with the use of filler materials. It is largely used in paving road surfaces, runways, taxiways and parking lots. The AC shall provide the waterproof surface with good resistance against the deformation, rutting and will provide good smooth surface with good skid resistance. For the good AC it should have sufficient resistance to plastic deformation and cracking when subjected to the expected traffic loading, should have acceptable grading and strength of aggregate with sufficient air voids to avoid bleeding and should be workable for efficient laying and compaction. The properties of AC is mainly influenced by the quality and the strength of the aggregate and the bitumen as it comprises. Asphalt modification can be made at different stages of its usage, from binder production to asphalt pavement production, and can be made by using different modifiers. Glass is considered a potentially promising modifier to asphalt. It is a non-metallic and inorganic material. Glass can be recycled without changing its composition and properties. Glass industry has been part of human history for thousands of years. Glass is widely used in our daily life, and with the continuously increased consumption, a large amount of waste glass is generated annually. The best way to deal with these wastes is to recycle and reuse them as raw materials or modifiers.

Material and Methods

Material Used

Bitumen: Bitumen is used as binders in pavements constructions. Bitumen may be derived from the residue left by the refinery from naturally occurring asphalt. As per definition given by the American Society of Testing Materials bitumen has been defined as ”Mixtures of hydrocarbons of natural or pyrogenous origin, or combination of both, frequently accompanied by their non-metallic derivatives, which may be gaseous, liquid, semi-solid or solid, and which are completely soluble in carbon disulphide!” Bitumen found in natural state known as asphalt contains large quantities of solid mineral matter. When petroleum crude is refined in a refinery, they are separated by fractional distillation in the order of decreasing volatility. On distillation of the residual bituminous residue, straight run bitumen is obtained. This bitumen is known as penetration grade bitumen or steam refined petroleum bitumen.

The grades of bitumen used for pavement construction is known as paving grades and that used for water proofing of structures is known as industrial grades. The grade of straight run bitumen is chosen depending upon the climatic conditions of the region in which surface dressing is to be constructed. In most parts of India 80/100 and 180/200 grade bitumen is used. Bitumen is very important component for paving roads. The quality of bitumen varies in accordance to its source and hence it is necessary to test the properties of bitumen before its use. There are many tests which are conducted to check the quality of bitumen. The bitumen is brought to sufficient fluidity or viscosity before use in pavement construction by any one of the following three methods:

- By heating, in the form of hot bitumen binder.
- By dissolving in light oils, in the form of Cutback Bitumen.
- By dispersing bitumen in water, in the form of Bituminous Emulsion.

Type of bitumen used

We have used VG30 grade bitumen for plastic roads. Because of:

- Good thermal susceptibility.
- Suitable for use in hot and rainy weather conditions instead of bitumen penetration grades.
- The more viscose the bitumen, the fewer the chance of being affected by water.
- VG 30 grade bitumen is also used for plastic roads in India.

Aggregate

Aggregate refers to a granular material used in construction, typically composed of a combination of sand, gravel, crushed stone, or other inert materials. It is one of the essential components of concrete, along with cement and water, and is also used in various other construction applications.

Here are some key points about aggregates

Types of Aggregates: Aggregates can be categorized into two main types

1. **Fine Aggregates:** These are small-sized particles with diameters typically less than 4.75 mm (0.19 inches). Examples include sand, crushed stone fines, and manufactured sand.
2. **Coarse Aggregates:** These are larger-sized particles with diameters ranging from 4.75 mm (0.19 inches) to several inches. Examples include gravel, crushed stone, slag, and recycled concrete.

Glass

Glass is a solid material that is typically transparent, brittle, and amorphous (lacking a crystalline structure). It is primarily composed of silica (silicon dioxide) along with various other additives to achieve desired properties. Glass is produced by heating a mixture of raw materials, such as silica sand, soda ash, and limestone, to a high temperature until it melts and forms a molten liquid. The molten glass is then shaped or cooled to solidify into a rigid and transparent material.

Glass has been used by humans for thousands of years for various applications due to its unique properties. Some of the key characteristics of glass include:

1. **Transparency:** Glass allows light to pass through it, making it useful for windows, lenses, and optical devices.
2. **Hardness and Brittleness:** Glass is rigid and relatively hard, but it is also brittle and can break or shatter under stress.
3. **Heat Resistance:** Glass has good resistance to high temperatures, making it suitable for applications such as cookware, laboratory equipment, and thermal insulation.
4. **Chemical Inertness:** Glass is generally resistant to chemical reactions, making it useful for storage containers, chemical apparatus, and corrosion-resistant surfaces.
5. **Electrical Insulation:** Glass is an excellent insulator of electricity, making it suitable for electrical applications, including insulators and electrically insulating coatings.
6. **Recyclability:** Glass is highly recyclable, and it can be melted down and reused multiple times without a significant loss in quality.

Glass finds applications in various industries, including architecture (windows, doors), automotive (windows, windshields), packaging (bottles, jars), electronics (display screens), optics (lenses, mirrors), and many more.

Glassphalt: Glassphalt is an asphalt mixture that incorporates recycled glass as an aggregate. Crushed or pulverized glass is combined with traditional asphalt binder and used to pave roads. This application provides a sustainable solution for recycling glass waste and offers benefits such as improved skid resistance, reduced rutting, and enhanced reflective properties. Glass products, such as architectural or industrial glass waste, may also be suitable for use in glass asphalt mixtures. These can include glass windows, glass panels, or glass components from various industries.

Selection of Materials

Bitumen

VG-30 bitumen was used during the course of the study.

Penetration at 25 °C 48.33 mm Min 45

Ductility at 25 °C 71.67 cm 40 cm

Softening Point 51 °C Min 47

Flash Point 270 220

Fire Point 320

Aggregates
Specific Gravity of Aggregate 2.71 2.5 to 3
Aggregate Crushing Value Test 43.6% Max 45%
Aggregate Impact Value Test 10.9% Max 24%
Los Angeles Abrasion Value 24.16% Max 30%

Glass Particles
The specific gravity of the glass used in the mix was determined to be the size of the glass particles was selected such that the combined gradation satisfied DoR specifications.

Mix Design
The normal asphalt mix along with the mix with different proportion of glass were designed by Marshall Method. A total of 4 sets of mix design containing samples were prepared during the thesis work. Each set of mix design had 4 samples.

Sample Preparation
A standard Marshall mould of 101.6 mm diameter and 63.5 mm thickness was used in order to prepare the specimens. Appropriate correction factors were used in case of thickness variation of the specimens. The aggregate used in the mix were pre-heated at about 140 °C. Bitumen was added at increments of 0.5%. In case of the mix containing glass particles, different proportions of glass particles were added and the equal proportion of fine aggregates were removed. The mix was then heated to 160 °C and placed in pre-heated mould. The samples were compacted using an automatic compactor by applying 75 blows on either side. The sample was then cooled for some time and extracted using a sample extruder. The extracted sample was then cooled for 24 hours. The thickness and weight measurements of the cooled sample was done.

Test of Specimens
After taking the weight measurements, the specimens were placed in the water bath at 60 °C for 30-40 minutes. Finally, the specimen was placed in Marshall Stability testing machine. The load was applied at the constant deformation of 50mm/min. The maximum load and flow were recorded. The broken specimens were removed and the procedure was repeated again. Two samples were prepared for each proportion of bitumen for a set of mix design.

Result

Table 1: Marshall stability and flow value result

Description	Plain Bitumen	Bitumen 10% Glass	Bitumen 15% Glass	Bitumen 20% Glass
Weight of Core in Air: W1g	1275	1245	1124	1208
Weight of Core in Water: W2g	765	697	639	675
Saturated Surface Dry Core Weight: W3g	1285	1287	1144	1120
Volume of Core: W3-W2 cc	520	590	505	545
Density of Core: W1/W4 g/cc	2.45	2.11	2.22	2.21
Marshall Stability: W6 KN	14.30	16.1	17.3	15.1
Flow Value: W7 mm	3.219	2.39	2.15	4.00

Discussion
Summary of Marshall Stability Test Result
Variation in glass proportions in the mix brought changes in different Marshall Characteristics. The changes in the characteristics are dependent upon the type and gradation of aggregate, type of binder, type of glass used and size of glass used.

Glass Percentage vs Stability
Overall, Marshall stability value of the mix is improved by addition of glass particles. Slight increment was observed at 10% glass whereas significant increment was observed at 15% glass content. The stability value decreased when the glass content was further increased. A maximum increment by 12.60% in stability was recorded at 15% glass. Hence, 15% can be termed as optimum glass content from the stability point of view.

Glass Percentage vs Flow and Voids
The flow values and air voids exhibited a complex relationship. The flow value decreased with the increase in glass content, This caused an increase in air voids. Due to decrease in flow value all the voids in the aggregate framework could not be filled. However, the values were within range and specifications.

Conclusion
In this research article, a number of bitumen and asphalt samples were examined on laboratory tests.
The conclusions are summarized as follows.

1. Crushed glass can be used in asphalt pavement with optimum replacement ratio of 15% by weight of total aggregates.
2. The value of stability for 15% glass modified mixture was higher than the control mixture. Therefore, a significant improvement occurred in the Marshall properties of asphalt concrete mixtures using a crushed glass modifier.
3. All test values are consistent with the specifications limits.
4. The results of this study apply only to the specific gradation and the type of glass that was used.
5. The results showed that the stability and flow values increase with an increase in the bitumen content with or without glass.
6. Other resources of glass or gradations may produce different results.

The maximum increase in stability value was found to be 12.60% at 15% glass content. Flow values decreased at higher glass contents.

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