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Review Article

Crushed Glass as Fine Aggregate in Modified Pavements - A Review

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Abstract

The use of waste and recycled materials in road construction applications has many environmental benefits including cost saving in terms of their disposal, dumping and potential recyclability. Examples of waste materials that could be used include waste glass, broken bricks, recycled crushed brick, construction demolition materials, factory waste roof shingles, reclaimed asphalt shingles, cement kiln dust, etc. The need to manage these materials has led to environmentally friendly actions that promote the reuse and recycling of this type of waste. The use of secondary (recycled) materials instead of primary (virgin) materials helps easing landfill pressures and reducing demand of extraction. This article discusses the feasibility on the use of waste materials especially glass waste in pavements, its advantages, environmental impact and cost effectiveness. This is also one way of getting the road construction industry on track towards sustainable construction practices.

Keywords: Glass waste; Partial replacement; Modified pavements; Fine aggregates.

Introduction

The use of sustainable and cost-effective alternative materials for asphalt mixes in road and airfield pavements have been recently emphasized due to potential depletion of natural aggregate sources and the increasing awareness of environmental issues i.e., green gas emissions, disposals, etc., associated with conventional asphalt materials. For instance, industrial by-products (e.g. steel slag) are gaining adoption worldwide for road construction [1]. The need to modify conventional pavement rises due to high maintenance cost of the highway systems. With the continuously increased consumption, a large amount of waste glass material is generated annually in the world [2]. The present review aims to study the feasibility of performance of pavement asphalt in which a fractional aggregate is replaced with crushed glass. In this paper, some important properties of asphalt mix, various other waste materials used in pavements are being identified. Special emphasis is given to waste glass generated from various sources and this paper aims to present the advantages of using glass in asphalt pavements. Also the present paper discusses the feasibility of partial replacement of aggregates in road pavements using recycled waste materials.

The present reviews works done in partial replacement of aggregates in modified road pavements. This review paper will help in study in the feasibility of reducing the amount of glass waste materials and conservation of the existing raw materials and natural resources. Study on the use of waste crushed glass as a fine aggregate replacement material in different road pavements is presented in this paper.

Construction of Road Pavements

Roads are generally erected up in different layers, consisting of sub-grade, sub-base, base and surface layer and these layers together constitute a pavement. Since the bituminous concrete pavements are more flexible over the cement concrete pavement, bituminous concrete pavements are sometimes called flexible pavements. Bituminous concrete pavements are primarily composed of aggregate and bituminous binder. Aggregates makeup around 95% of Hot Mix Asphalt mixture by weight, whereas binder makeup the remaining 5%. By volume, a typical HMA mixture is about 85% aggregate, 10% asphalt binder, 5% air voids. Bitumen binder sticks the aggregate

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together which means without the bituminous binder HMA would be only crushed stone or gravel.

Bituminous concrete pavements are not a thin covering of bituminous concrete over the soil, but they are engineered structures composed of several different layers. The figure 1 shows typical vertical section of a flexible pavement structure.

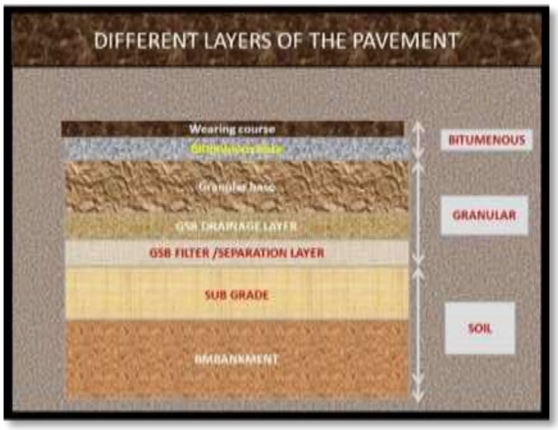

Figure 1. Vertical section of Flexible Pavement Structure

Modified Pavements using Waste Materials as Aggregates

The use of fly ash as a cement replacement to improve recycled aggregate concrete properties. Results indicated that use of 35–50% fly ash (with respect to total cementitious content) of high fineness could improve slump loss behavior in recycled aggregate concretes. Greater proportions of recycled fine aggregates decreased the compressive strength of concrete. However, use of high fineness of fly ash (1.2% retained on a No. 325 sieve) in recycled aggregate concrete could produce greater compressive strength than that of the recycled aggregate concrete alone. The splitting tensile strength of the recycled aggregate concretes containing high fineness of fly ash was 8.2% of its compressive strength, slightly lower than that of the normal aggregate concrete [3].

Glasphalt mixtures performance research on the use of waste glass, slag, tyres, plastic in the recycled solid waste stream in UK roads. Various properties like Martial stability, flow, moisture susceptibility, light reflection characteristics were determined. The research found out that Martial Stability and flow of Glasphalt mixtures decrease a little compared with normal mixture, yet remain active the standards level. Also the TSR and light reflection characteristics were improved for the Glasphalt mixes [4].

The findings of a laboratory investigation of the characterization of recycled crushed brick and an assessment of its performance as a pavement subbase material were compared with the local state road authority specifications in Australia to assess its performance as a pavement subbase material. The experimental program was extensive and included tests such as particle size distribution, modified Proctor compaction, particle density, water absorption, California bearing ratio, Los Angeles abrasion loss, pH, organic content, static triaxial, and repeated load triaxial tests. The repeat load triaxial testing established that crushed brick would perform satisfactorily at a 65% moisture ratio level. At higher moisture ratio levels, shear strength of the crushed brick was found to be reduced beyond the acceptable limits. The results of the repeat load triaxial testing indicate that only recycled crushed brick with a moisture ratio of around 65% is a viable material for usage in pavement subbase applications [5].

The industry perspective of construction and demolition waste recycling based on the results of a survey of the recycling firms in the Sydney area to gauge perception of the current state as well as the future of the industry. The nurturing of a reprocessing and recycling industry in particular is necessary to sustain waste reductions and none is more critical in Sydney than the construction and demolition waste recycling [6]. The replacement of fine aggregates by partially crushed spent fire bricks. Therefore varying percentage of fine aggregates by crushed spent fire bricks with varying percentage of 10%, 15%, 20% & 25% and optimum percentage of replacements is made and strength and workability parameters are studied. The workability of concrete gets decreased with the addition of the crushed spent bricks. From the test results, crushed spent fire bricks replaced for fine aggregates give a maximum strength at 20% when compared to conventional concrete [7].

Waste Glass as Aggregate Replacement in Road Pavements

Glass is a non-metallic material that cannot be disintegrated or burnt. Glass is considered to be an ancient construction material

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with distinctive properties, comparatively simple manufacturing process, higher abrasion resistance, translucent, higher durability, incombustible features, and higher ductility at high temperatures. Glass is an inorganic and non-metallic substance that can neither be decomposed nor incinerated.

The major application of Waste glass (WG) is for the production of new glass. Glass is hydrophobic, brittle, and rich in silicon, with noteworthy physical properties as a composite material. Moreover, the density of glass is less than that of traditional aggregates. They are also less sensitive to moisture. The colors of glass that are manufactured include colorless (flint), green and brown. Green glass can be formed through the addition of a small amount of chromium, white brown (amber) glass contains both chromium and iron. The usage of material wastes in the construction of pavements have aids in not only minimizing the amount of waste materials which requires appropriate disposal but also can offer with construction materials that have major savings over new materials.

The usage of these materials can provide value to what was once a costly disposal problem. Based on previous studies, there are two applications for WG:

- WG can be liquefied and used to yield fresh, virgin, or new glass.
- WG can be used as an alternative war material in products used in the construction industries, such as bricks, blocks, filler materials, building decoration, sound proofing, and adiabatic materials.

Bituminous pavement with glass cullet as aggregate is commonly referred to as ‘Glasphalt’. In recent years, the detection of various environmental and economic benefits could increase the usage of recycled glass in road construction, which made the assessment of the engineering properties of glass and aggregate mixes a necessary. The usages of recycled glass can be varied widely, depending on the specified application.

Glasphalt is most widely used in the structural layers of the pavement below the surfacing layers to avoid the problems that arise when it is used as surfacing bituminous mix (Figure 2). These comprise the lack of skid resistance and reduced bonding of glass cullet to the bitumen in the bituminous mix, which results in stripping and raveling problems.

Figure 2. Glasphalt pavement

The performance of Asphalt concrete where some of the fractional fine aggregate was replaced with crushed glass particles were used to examine the influence of optimal asphalt content, the volume properties and the strength of asphalt concrete when different percentages of crushed glass particles were added to the mix [8]. The research had demonstrated that the recycling and the use of waste glass in asphalt concrete is feasible.

The suitability of using blends of recycled glass and crushed rock as road pavement subbase materials with mixtures of 10 to 50% by mass of recycled glass. The experimental works undertaken in this study includes basic classification tests along with modified compaction, California Bearing Ratio (CBR) and Los Angeles Abrasion tests to assess the suitability of the blends. The research indicates that initially up to 15% “recycled glass with the maximum particle size of 4.75 mm” could be safely added to Class 3 crushed rock. The degree of breakdown occurring in the recycled glass blend is on the limit of what would be acceptable for this material. Depending on the results of future field trials, it may be possible to increase the percentage of recycled glass [9].

The effect of pavement when it is Partially replaced with glass fiber and how ductility and penetration value is varying by adding 1%,2%,3% glass fiber by replacing bitumen .The stability and flow values should be determined for nominal and modified mix by Marshall method by varying percentage of

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fibers. By addition of glass fiber the penetration value increased as compared to the nominal mix. The ductility value decreasing by increasing glass fiber. As glass fiber increases the softening point increases. The optimum binder content for addition of glass fiber is 5.4%. The optimum binder content for the nominal mix is 5.6%. The Maximum Marshall Stability value occurred at 5% of bitumen for 3% of glass fiber is 26.03 KN [10].

The performance of pavement asphalt in which a fractional aggregate is replaced with crushed glass and properties of asphalt mix, including stability, flow, specific gravity and air voids are investigated. The original sample is prepared without adding glass for different percentages of bitumen. Other samples are prepared by adding crushed glass to the mix with 5%, 10%, and 15% by aggregate weight. The results show that the properties of glass-asphalt mixture are improved in comparison with normal asphalt pavement. It is concluded that the use of waste glass in asphalt pavement is desirable [2].

Impact of Recycled Aggregates on Pavements

It is found that leachates from recycled materials in the constructions contain higher concentrations of several constituents than natural water and leachates from conventional materials. However, the rates and extent of constituent leaching were affected by the application methods in various ways. The results of simplified leaching tests did not always reflect the leaching behavior in the field, which highlight the importance of developing assessment methods that allow case specific factors to be taken into account [11]. The environmental impacts of leaching must also be considered in relation to the expected impacts of the default alternative, i.e. landfilling of industrial residues and exploitation of natural resources. Combinations of case-specific assessments and system analyses would be the ideal approaches to evaluate impacts at both local and regional scales.

The experimental studies clearly showed that the use of 34% CKD may bring the pH of sludge above 10, which is enough to stabilize the sludge. Furthermore, the final concentrations of heavy metals were found to be within acceptable international limits [12]. Tests conducted on blocks made using aggregates in the Eastern Province (Type-N) and light-weight pozzollanic aggregates (Type-P) indicated that addition of CKD to cement results in significant gain in strength of the blocks.

The modified asphalt mixture were produced from content concentrate of waste HDPE fillet range 2, 4, 6, 8 and 10% of the weight of asphalt mixture with sieve size from 3.35 mm to 1.18 mm and 4 to 6% is the range of the optimum bitumen content of hot mix asphalt wearing course 14 (ACWI4) with 80/100 of penetration grade of bitumen by referring Standard Specification for Road Works in Malaysia. The performance of the aggregate and bitumen is complying with Specification of Public Work Department 2008 in Malaysia. Therefore, these aggregates and bitumen can be used as asphalt for modified and unmodified sample [13]. Therefore the HDPE modified asphalt with crushed glasses is suitable to use for road pavement in term of economic and environmental aspects.

The Asphalt Institute studied the amount of degradation occurring in a glass-asphalt mixture, and to find whether a glass-asphalt mixture will be resistant to the action of water. Material for testing was obtained by crushing waste glass and sieving it into various size fractions which were combined to obtain the gradations desired. Tests were conducted on the crushed glass to determine various physical properties. Marshall tests were run on specimens at different asphalt contents to see if the Marshall design criteria could be met for the gradation used. Glass was extracted from some of the specimens tested, and sieve analyses of the extracted glass were used to determine the amount of degradation occurring in the glass-asphalt mixtures. Statistical analyses were made to evaluate the significance of the Marshall test results. Static stripping tests and immersion-compression tests were used to determine the water resistance of the mixtures. It is possible to design glass-asphalt mixtures which meet the Marshall design criteria. Extraction data indicates that some degradation does occur during laboratory mixing, compacting, and testing [14].

Mixtures consisting only of glass and asphalt cement show no water resistance; however, the addition of a commercial anti-stripping agent improves water resistance without completely eliminating stripping.

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The laboratory study results, including both bituminous mastics and mixtures tests, to assess the use of glass powder (GP) as possible surrogate to limestone filler in recycled dense-graded asphalt mixtures. To achieve a comprehensive approach, the analysis has been divided into three parts including filler, mastics and mixture characterization. The GP has been completely studied with chemical and physical tests to compare the fundamental characteristics to the commonly used limestone filler. In the second part, rheological tests using the Dynamic Shear Rheometer has been implemented to evaluate fillers interaction with not modified and modified bitumen. Finally, the mechanical properties of the asphalt mixtures containing GP filler were investigated in terms of indirect tensile strength, indirect tensile stiffness modulus and creep characteristics. According to the obtained results, GP filler provided comparable values to limestone filler within both mastic and mixture study [15]. It is noteworthy that from the permanent deformation analysis, both MSCR and RLAT tests confirmed the improvement of rutting resistance with using GP filler.

The development and evaluation of a new asphalt concrete mix that utilizes a sustainable crushed glass as a replacement material of a natural aggregate. The ultimate goal is to produce a cost-effective asphalt wearing course with comparative performance characteristics with a conventional asphalt wearing course (reference mix) commonly used on South African roads. The mix design process of a 9.5 mm nominal maximum wearing course glass asphalt with a design traffic level of 30 million ESALs. Based on the mix design, an optimum binder content of the glass asphalt mix was 5.1%, which is similar to the 5.0% optimum binder content of the reference mix. The results of performance-related tests indicated that the tensile strength and durability properties of the glass asphalt mix are comparable to the reference mix [1]. It was also studied that different proportions of glass beads used for road marking were added into the concrete samples to reduce the temperature gradient through the concrete pavement thickness. It is well known that decreasing the temperature gradient reduces the risk of thermal cracking and increases the service life of concrete pavement [16]. The extent of alkali–silica reaction (ASR) produced with partial replacement of fine aggregate by glass bead was investigated and compressive strength of concrete samples with different proportion of glass bead in their mix designs were measured in this study. Ideal results were obtained with less than 0.850 mm diameter size glass beads were used (19 % by total weight of aggregate) for C30/37 class concrete. Top and bottom surface temperatures of two different C30/37 strength class concrete slabs with and without glass beads were measured. It was identified that, using glass bead in concrete mix design, reduces the temperature differences between top and bottom surfaces of concrete pavement.

The parent recycled aggregates like fine recycled glass (FRG), recycled concrete aggregate (RCA), and waste rock (WR). The recycled glass blend with 20% glass content was found to be the optimum level, where the blended material was workable and also had sufficiently high strength. The field testing results indicated that FRG blends are suitable in pavement subbase applications and is a viable additive when used in limited proportions with other recycled aggregates in pavement subbases [9]. The effect of freeze–thaw (FT) cycles, referred to as environmental effect in this paper, on aggregates stabilized with various stabilizing agents, namely, cement kiln dust (CKD), Class C fly ash (CFA), and fluidized bed ash (FBA). Cylindrical specimens were compacted and cured for 28 days [17]. After curing, specimens were subjected to 0, 8, 16, and 30 FT cycles, and then tested for resilient modulus and values of stabilized specimens decreased with increasing FT cycles up to 30. The reasons for such changes are explained by the increase in moisture content during thawing and the formation of ice lenses within the pores during freezing, causing distortion of the matrix of particles.

Conclusion

The modification of bituminous pavement layers with glass cullet can be used to inhibit rutting phenomena and fatigue cracking. Superior interlocking and greater roughness of glasphalt samples causes an increase in stiffness modulus in samples that include waste glass cullet. Increasing the amount of glass cullet reduces permanent deformation of bituminous samples. As a result of the higher angularity of the glass particles, glasphalt has a higher internal friction angle and better interlocking between constituent

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particles. These characteristics would consequently reduce the final tensile strain in the specimen, due to applied stress, and prevent initial cracking and crack propagation in the specimen.

Conflicts of interest

Authors declare no conflict of interest.

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