Mechanical properties of fly ash modified asphalt treated with crushed waste glasses as fillers for sustainable pavements

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Abstract

This research work investigated the effect of using fly ash as a modifier and utilizing crushed waste glasses (CWG) as fillers to enhance the mechanical properties of Asphalt for a sustainable pavement construction. The cost of pavement constructions is becoming overbearing on the developing countries and the need to develop more sustainable and green methods has become very imperative. With inclusion of waste materials like fly ash and CWG, enhanced and greener pavement is achieved. This is experimented in under laboratory conditions in order to improve the quality of representative asphalt for pavement construction using recycled waste materials. The scope of this research paper was on the investigation of the Marshall stability behaviour of the hot mix asphalt when mixed with recycled wastes. The asphalt, asphalt mixed with fly ash, and asphalt mixed with fly ash and crushed waste glass samples were tested and analysed with the Marshal Stability test, which is a major test for asphalt with admixtures. The results showed that at 15% by weight addition of fly ash in the modified asphalt, and 8% of CWG, the asphalt stability was observed to have increased substantially to 224.2 N/mm^2 compared to the control value of 216 N/mm^2 for stable pavements. The use of fly ash as a modifier in the asphalt road paving industry to mitigate the decrease in performance of the binder material due to exposure to traffic loads, climatic and environmental changes has generally produced favourable results consistent with those achieved by waste polymer modified asphaltic binders. This study demonstrated that incorporating fly ash resulted in improved rheological and performance characteristics while reducing cost and unfavourable environmental impacts.

Keywords: asphalt, fly ash, Marshal stability deformation, pavement, crushed waste glasses

Kulcsszavak: aszfalt, pernye, Marshall stabilitási deformáció, járófelület, zúzott üveghulladék

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1. Introduction

The use of environmentally friendly binders (ash, powder, geopolymer cements, etc.) derived from solid wastes under the influence of alkali activators for binding purposes has been practiced severally [1]. In as much as it is certain that human activity will never cease on the planet, there would always be an equivalent release of solid wastes (industrial, agricultural, household, and municipal, etc.) [1]. Hence, sustaining this technology wouldn't be a problem at all. Among the numerous derivatives of solid waste that have been utilized in various civil engineering works include palm oil fuel ash, fly ash, quarry dust, rice husk ash, coffee husk ash, paper ash, waste tire ash, palm fibre, palm kernel shell ash, snail shell ash, periwinkle shell ash/powder, oyster shell powder, biomass ash, bagasse ash, egg shell ash, sawdust, crushed waste ceramics, crushed waste plastics, crushed waste glasses, bio-peels, biochar, metallurgical slag (ground granulated blast furnace slag), iron ore tailings, palm nut fibre, glass fibres, etc. [1]. Improvement of asphalt pavement performances by means of additives to expand use over a wider range of temperatures and traffic loading has constantly been practiced by engineers. This modification of asphalt is commonly achieved through blending asphalt with manufactured products; such as polymers and some others. The use of fly ash to enhance the performance of asphalt concrete has been demonstrated but had not yet been adopted on a commercial scale [2]. Fly ash is a by-product of coal fired-furnaces at power generation facilities and is the non-combustible particulates removed from the flue gases [3]. The use of ASTM C 618 Class C fly ash has received most of the research focus [3]. It is derived when a subbituminous coal is burnt and it has obvious cementitious and pozzolanic properties. Class F fly ash and other Coal Combustion

Products (CCPs) warrant additional exploration for potential use as an ingredient in asphalt mixtures, especially the synergy between polymer modification and fly ash particles [4, 5]. Fly ash in asphalt bitumen can be considered an effective material in a viscoelastic matrix [1, 2]. Fillers for asphalt pavement applications are defined by AASHTO T190 and AASHTO T307 [6-8] as finely divided minerals, such as rock dust (e.g. granite and limestone), slag dust, hydrated lime, hydraulic cement, fly ash, loess, or other suitable mineral matter. The typical maximum particle size of fillers in asphalt is less than 75 microns. Although fillers, in general, usually represent less than 8% of Hot Mix Asphalt (HMA) by mass, the interactions of fillers with asphalt binder, and/or coarse and fine aggregates, affect the field performance. Furthermore, the use of fly ash in HMA has shown that it does not behave similar to typical fillers [8]. Fly ash has been used extensively in concrete production; however, there are limited applications in which fly ash has been used in asphalt pavements [7, 8]. Pavement engineers are interested in fly ash filler replacement because fly ash usage is important not only for improved performance, but also for economic, environmental and social benefits. Fly ash is an affordable, readily-available local material, and adding fly ash to asphalt mixtures does not require specialized equipment or changes for skilled constructors. Despite these benefits, the application of fly ash in asphalt technology has not yet become commonly accepted.

Glass waste is a viable material, due to its silicate-based composition for asphalt concrete that has been widely used in pavement that offers profound engineering and economic advantages, with a large amount of glass waste from industry forming subject of concern at both national and global levels, glass recycling by way of applications in commercial use in asphalt paving can save energy and decrease environmental waste. Early *glassphalt* projects used high percentages of glass (greater than 25% by weight of the mix) with coarse glass gradations (greater than 12.7 mm (1/2 in)). Current data suggest that the use of high glass percentages and large particles of glass probably contributed to most of the stripping and ravelling problems that were reported during the early test pavement demonstrations of the 1960s and 1970s. This can be attributed to the *"hydrophilic"* nature of glass. The high angularity of cullet, compared with rounded sand, can enhance the stability of asphalt mixes, where properly sized cullet is used. Stabilities comparable and, in many cases, better than those of conventional mixes have been reported, other beneficial characteristics include low absorption, low specific gravity and low thermal conductivity, which reportedly offer enhanced heat retention in mixes with glass. Proper mix design with suitable ingredients will ensure an improvement of the existing performance of roads. Various studies have been conducted to study the properties of mineral filler, especially the material passing 0.075 mm sieve (No. 200) and to evaluate its effect on the performance of asphalt paving mixtures in terms of consistency, void filling, resistance to displacement, water susceptibility, Marshall stability and mix strength. B.W. Ramme et al. and B. Baby *et al.* [9, 10], found that the behaviour of Hot Mix Asphalt (HMA) in different temperature conditions, depending on the variation of the admixture contents and the gradation of the aggregates, is improved in comparison with that of HMA mixtures.

This study aims at exploring the feasibility of using crushed waste glass fillers in improving the mechanical properties of fly ash modified asphalt by the determination of general performance of the stabilized materials through marshal stability testing.

2. Materials and methods

The crushed glass sample was collected from a Glass Industry located within Ogbor-hill environs in Aba, Abia state, while the fly ash was sourced from CIFA Industrial Company Atani Nike, Enugu state. Crushed waste glasses are waste materials derived as scrap loss during glass production and or as waste from mishandling and usage. These are known for their high composition of calcium oxide, silica and aluminates. Also, the fly ash, which is a byproduct of power generation and coal combustion is rich in aluminosilicates contents also. the aluminosilicates composition of the two waste materials constitute their preference as supplementary binders and modifiers due to their ability to enhance pozzolanic reactions. The asphalt was gotten from New Tunnel Asphalt Plant, Along the Isiala-Ngwa axis of the Enugu- Port Harcourt express road all in Nigeria. All the samples were collected at solid state before it was taking to the laboratory. The collected waste glass was crushed using a bulk density load apparatus for about 20 minutes repeatedly until desired particle size was achieved. The crushed glass was made to pass through a stack of BS sieve sizes according to known British test standard procedures with interest in the sieve no 22. The glass particles were made to pass through the sieve until the glass passing becomes finer. This procedure was repeated until the crushed glass wastes were exhausted.

In accordance with standard specifications [6, 7] in order to determine the optimum binder content for the aggregate mix type and traffic intensity otherwise called the Marshall test, about 1200gm of aggregate were blended in the desired proportions, measured and heated in the oven to the mixing temperature, bitumen was added at the mixing temperature to produce viscosity of 170 ± centi-stokes at various percentages and the mixture returned to the oven to be reheated to the compacting temperature (to produce viscosity of 280±30 centi-stokes). The sample was allowed to stand for the few hours to cool and the mass of the sample in air and when submerged is recorded respectively. This was to enable the measurement of density of the specimen, so as to allow calculation of the void properties. The sample is place in lower segment of the breaking head, the upper segment of the breaking head of the specimen is placed in position and the complete assembly is placed in position on the testing machine. The flow meter is placed over one of the posts and is adjusted to read zero, load is applied gently at a rate of 50 mm per minute until the maximum load reading is obtained. The maximum load reading in Newton is observed. At the same instant the flow as recorded on the flow meter in units of mm was also noted.

3. Results and discussion

The general behavior and analysis of the Marshal Stability test can be seen as presented in *Table 1*. The Marshall Stability result of three samples of asphalt was recorded showing the stability values, flow, height or thickness of the asphalt mould and the stability correction value of the samples. Finally, the average stability was determined by calculation as 216 N. This serves as the control MS value for the modified asphalt.

Sample	Stability (N)	Flow (mm)	Height (mm)	Stability correction factor (cf)	Corrected Stability (N)
1	200	0.1	64.5	0.96	192
2	210	0.2	61.5	1.04	218.4
3	218	0.1	60.7	1.09	237.6

Table 1 Marshall Stability result of asphalt
1. táblázat Aszfalt Marshall stabilitási vizsgálatának eredményei

$$\text{Average corrected stability} = \frac{192+218.4+237.6}{3} = 216$$

Fig. 1 presents the results of the three samples that were used to get a suitable corrected stability value for each Asphalt sample mixed with different percentages of Fly ash. It was observed that there was continuous increase in the corrected stability value with respect to increase in the percentage of fly ash sample [11-15]. At 15% fly ash mix, the highest number of corrected stability value was recorded. This substantial improvement was due to the cementing properties of the FA which enhanced carbonation and calcination reaction in the HMA thereby causing strengthening [3, 15-25].

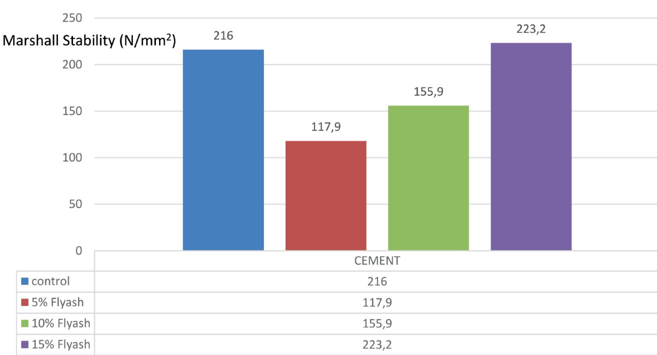

Fig. 1 Marshal stability test result of asphalt mixed with different percentages of fly ash
1. ábra Aszfalt Marshall stabilitási vizsgálatának eredményei különböző arányú pernye hozzáadása mellett

Results of the HMA treated with varying proportions of CWG and modified with 5%, 10% and 15% FA by weight of the mixture are presented in *Table 2* and discussed as follows;

i. it was observed that the result of asphalt mixed with a fixed fly ash percentage of 5 and treated with varying crushed waste glasses percentages showed that there was a reduction in the corrected stability value of the first control sample after crushed waste glass of 2% was added to the asphalt mix but there was increment when 4%, 6% and 8% of crushed waste glasses was added to the mix.

ii. for the asphalt sample mixed with 10% of fly ash and different percentages of crushed waste glass, it was observed that there is a reduction also in the corrected stability value of the first sample after crushed waste glass of 2% was added to the asphalt mix. This was followed by a constant increment at 4%, 6% and 8% of crushed waste glass sample and increased stability values.

iii. For the 15% Fly ash modified HMA and treated with different percentages of crushed waste glass, it was observed that there was a reduction in the corrected stability value for the first sample after crushed waste glass of 2% was added to the mix but there was substantial increment when 4%, 6% and 8% of crushed waste glass sample was added to the HMA mix.

The initial reductions recorded at the start of treatment for the HMA with 2% CWG was due to the reduced cementation due to lack of cementing properties from the CWG [26-30]. But then the recorded increase after the initial treatment was as a result filling pores in the asphalt by the CWG thereby improving the stability again [30-34]. However, the addition of FA maintained a consistent improvement pattern for the HMA stability. This shows that FA is a good modifier for asphalt mixes.

CWG proportion % by wt of HMA mix	MS of FA modified HMA with CWG as fillers		
	Fly Ash proportion % by wt of HMA mix		
	5	10	15
0	105.2	134.5	219.0
2	106.8	149.2	182.4
4	106.7	158.2	193.8
6	108.0	156.7	211.5
8	122.7	161.1	224.2

Table 2 Effect of FA and CWG on the HMA mix
2. táblázat FA és CWG hatása a HMA keveréken

4. Conclusions

Asphalt samples from table one was used as a control mix. This control was derived by getting the average corrected stability value of the three samples done. In view of the above, we observed that the average stability values of both 5% and 10% fly ash mixes were not up to that of the average control stability value; therefore, it had lesser resistance to deformation. At 15% Fly ash content by weight of asphalt cement, a higher resistance to permanent deformation and a higher stability value was observed as compared to the control mix value. Also, it was observed that at 8% waste glass content mixed with different percentages of fly ash modified asphalt, there was increase in the stability values which is a higher resistance to deformation but at 15% fly ash modified asphalt, 8% of waste glass was observed to have a greater average stability value of 224.2 than that of the control mixtures of 216. Hence, it can be concluded that at this percentage we have an optimum modified asphalt that will be able to stand the test of time in terms of durability and also a higher resistance to permanent deformation caused by applied loading. Generally, due to the silicate-based composition of the admixture, it can be accepted that at 8% CWG with 15% fly ash modified asphalt content, a good asphalt mix can be produced for use to achieve a more sustainable pavement construction.

5. Recommendation

After a close and thorough examination and investigation into the mechanical properties of a fly ash modified asphalt using crushed waste glass as filler, it was discovered that the fly ash modified asphalt gave more stability and it is easy to use in road or pavement construction. Therefore, it is recommended that the asphalt samples under investigation should be modified with fly ash due to its high silicate composition, which produces asphalt composite construction material and its quantity should be improved with crushed waste glass so as to meet the criteria for pavement structures that is to be used for highway purposes.

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