

INVESTIGATION INTO POTENTIAL OF FLY ASH OBTAINED FROM COAL-BASED POWER PLANTS TO CONTRIBUTE TO SUSTAINABLE ENVIRONMENT

*M.S.A.M. Anik, M.R. Islam, M.A. Iqbal, K.M.S. Quader

Department of Civil Engineering, Military Institute of Science and Technology, Dhaka, Bangladesh

*Corresponding Author, Received: 3 Dec. 2017, Revised: 13 Dec. 2017, Accepted: 25 Dec. 2017

ABSTRACT: The main objective of this study was to investigate the potential of using fly ash as a mineral filler in asphalt mixtures to reduce the amount of fly ash generated from coal-based power plants in Bangladesh requiring disposal. To achieve this, several mix designs which included fly ash were developed and compared with mixtures using cement as a mineral filler, with mixtures of cement and fly ash with different ratios considered and their performances evaluated. It was found that the design with a bitumen content and fly ash as a mineral filler was within the economical range and, when its Marshall stability and flow values were compared with those of cement, it was found to be satisfactory. Also, the moisture susceptibility of an asphalt mixture with fly ash was checked through immersion-compression tests and compared with that of one with cement as a mineral filler. As it was observed that fly ash generated from coal-fired power plants can reduce the damage caused to asphalt by moisture and is more cost-effective than conventional fillers, it is proposed that using it as a filler material in pavements could reduce the substantial damage suffered by the environment.

Keywords: Fly Ash, Mineral Filler, Recycling, Waste Disposal, Moisture Damage

1. INTRODUCTION

Fly ash (FA) is a naturally occurring by-product of the coal combustion process which the American Coal Ash Association (1993) defines as a fine-grained by-product from the burning of pulverized coal to produce steam and electricity. Approximately five coal fields have been discovered in Bangladesh, with the Barapukuria Thermal Power Plant currently producing 52000 MT of FA. Researchers predict that, by 2018, three more coal-fired power plants will be functional and generate 377,000 MT of FA per year. For a densely populated country such as Bangladesh, this is a massive amount to be disposed of and an alarming environmental issue as, due to the scarcity of land, there are few dumping sites available [1].

FA is used as a mineral filler in asphalt paving mixtures in different parts of the world, as evidenced in numerous studies. Research on the properties of eight different categories of mineral filler materials in Europe determined that the performance of a mixture is not affected by the quality of its filler [2] while higher filler concentrations lead to tougher pavements as they improve the cohesiveness and internal stability of asphalt. However, an excessive volume may deteriorate a mixture by increasing the quantity of asphalt required to coat the aggregates [3]. A study of the viscosity of a FA and bituminous mixture showed that increases in its FA content up to 6% considerably improved its fatigue life [4]. A laboratory study of FA in bituminous mixtures

indicated that it could be used effectively as a filler replacement in a densely graded bituminous wearing course [5]. When FA was used as a mineral filler and anti-stripping agent in bituminous concrete mixtures, the retained strengths of the samples increased as more FA was added and, in most cases, were greater than those with normal fines, and that mixtures using 3% to 6% of FA demonstrated resistance to moisture damage [6]. A study has shown that four types of industrial by-product waste fillers, namely, limestone as a reference filler, ceramic waste dust, coal FA and steel slag dust, intensified the stiffness and fatigue life of a stone mastic asphalt (SMA) mixture [7] and that, while its tensile strength ratio (TSR) increased with increases in the FA content, its fatigue properties did not improve [8].

From the literature discussed above, it is clear that several studies have investigated using FA as a filler in asphalt mixtures. However, in Bangladesh, no research has yet been undertaken to evaluate its potential as a mineral filler in pavements for which cement and stone dust, which are much more expensive, have traditionally been used. Also, coal-based power plants have introduced some environmental and socio-economic challenges, such as groundwater and air pollution, and other health hazards. Therefore, in this study, an effort was made to use FA from coal-based thermal plants in Bangladesh as a mineral filler in pavements and also provide a solution to managing its disposal.

2. METHODOLOGY

2.1 Test Procedure

A methodology that made it possible to compare the performances of FA and a conventional filler material, i.e., cement, was developed, with a 100% cement concentration taken as a control specimen. Samples with mineral fillers of 100% cement, 100% FA and 70% FA/30% cement and 50% FA/50% cement were prepared. Details of the test procedure are shown in Fig. 1. A Marshall mix design and moisture susceptibility test, i.e., immersion-compression test, were conducted for each filler, with photographs of the experiments shown in Fig. 2.

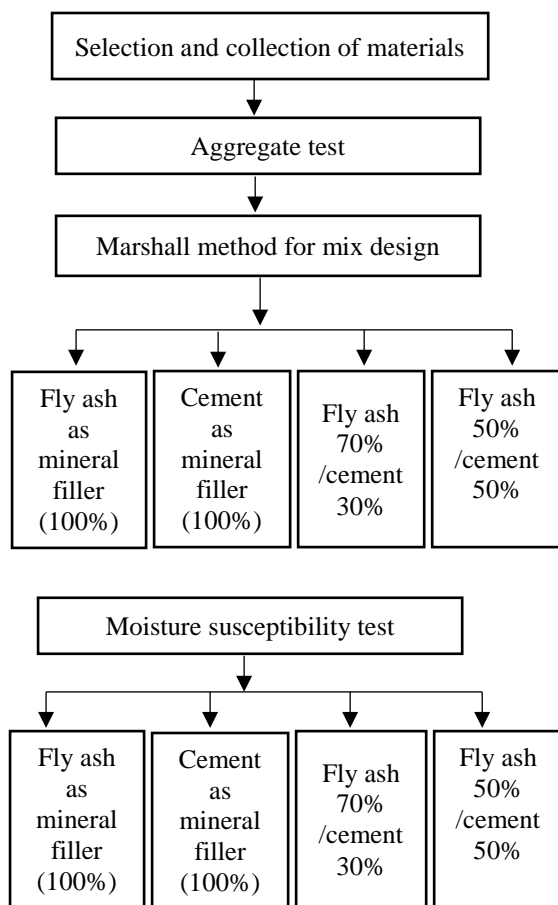


Fig. 1. Flowchart of test procedure

2.1.1 Marshall method for mix design

For the Marshall mix design, the preparation of samples and selection of the optimum bitumen content were conducted according to ASTM D6927 and MS-2, 7th edition (2014) Asphalt Institute [9], respectively. Three Marshall specimens for each combination were compacted based on heavy traffic conditions and the average of their values considered. Before stability and flow testing, the bulk specific

gravity (G_{mb}) of each specimen was calculated according to ASTM D2726.



Fig. 2. Testing procedure

Then, the specimens were placed in a water bath at a controlled temperature of 60°C (140°F) for 40 minutes after which they were removed and placed in the Marshall test apparatus. The maximum load (kN) was recorded as the stability value and the corresponding deformation in a specimen (mm) measured by the flow meter the flow value. For a sample with close to the designed asphalt content, its theoretical maximum specific gravity was determined according to ASTM D2041. The percentages of air voids (V_a) in the specimens were calculated from the G_{mb} and maximum theoretical specific gravity of the mixture. Using the G_{mb} of the specimens, the aggregate percentages of voids in the mineral aggregate (VMA) and those filled with asphalt (VFA) were calculated. The optimum bitumen content for the AC mixture was selected as the median of the air voids (4%), with graphs of the corresponding maximum stability, flow, VFA and VMA values plotted.

2.1.2 Moisture susceptibility test

Moisture damage is one of the primary causes of distress in flexible pavements, with the most common reason for it the intrusion of water which breaks the bond between the aggregates and asphalt, commonly known as stripping, and leads to the

premature collapse of the pavement. The specimens were subjected to the ASTM D 1074 and ASTM D 1075 test procedures [10]. Two sets of cylindrical specimens were made for each test after the optimum bitumen content was finalized: the 1st was immersed in water at 60° C for 24 hours; and the 2nd maintained in an ambient air temperature. The compressive strengths of the specimens in the 2nd group were taken after 12 hours (S₁) and those in the 1st following their removal from the water after 24 hours and maintenance at 25°C for 2 hours (S₂). To evaluate their susceptibility to moisture damage, the index of retained strength (IRS) of each was determined by taking the ratio of S₂ to S₁, which predicts the resistance of asphalt mixtures to moisture damage, as

$$IRS (\%) = \frac{S_1}{S_2} \times 100 \quad (1)$$

Where, S₁ = the compressive strengths of the dry specimens and S₂ = the compressive strengths of the immersed specimens.

3. MATERIALS

3.1 Aggregates

Stone chips and sand were collected from a local source (Madhypara, Sylhet). The proper gradation of aggregates for use in a hot mixed asphalt layer is very important and, in Bangladesh, is the responsibility of the Roads and Highways Department (RHD) which specifies highway materials. To prepare the Marshall mix design, firstly, the aggregates' gradation was checked to determine if it met the RHD's specifications (2011) [11], as shown in Fig. 3. From laboratory testing, the aggregate crushing value (ACV) was found to be 21%, aggregate impact value (AIV) 28%, flakiness index 19, elongation index 21 and Los Angeles abrasion test 26%, all values within the RHD's ranges.

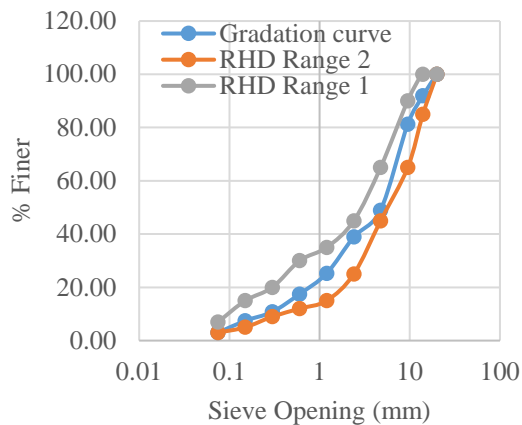


Fig. 3. Aggregate gradation curves for bituminous base course

3.2 Bitumen

For this experiment, penetration-grade bitumen (60/70), which is widely used in various projects in Bangladesh, was collected from the Padma Multipurpose Bridge Project (PMBP) and placed in a sealed container, with its specific gravity tested to be 1.011.

3.3 Fly Ash (FA)

Filler materials consist of particles more than 70% of which must pass through a 0.075 mm sieve (No. 200 sieve), with 100% of the Class F FA reported by [12] collected from the Barapukuria Thermal Power Plant. From the laboratory experiment, it was found that the specific gravity of the bitumen was (25° C) 1.011, penetration value (25° C, 100g, 5 sec) 61, softening point 49.5° C, ductility (25° C) 100 cm, flash & fire points 285° C & 340° C, respectively, solubility (Trichloroethylene) 99.95% and loss on heating (5 hours at 163° C) 0.02%, all values within acceptable ranges according to RHD specifications.

4. RESULTS AND DISCUSSION

4.1 Marshall Test Results

The results of the Marshall tests are presented in Table 1 while Figs. 4, 5, 6, 7 and 8 show the Marshall properties for different filler combinations for the optimum bitumen content. Although the FA and cement specimens performed differently, they all justified the Marshall mix design criteria according to the Asphalt Institute and RHD specifications.

Table 1. Marshall test results

Criteria for mix design	100% cement	100% FA	70% FA/30% cement	50% FA/50% cement	Limit (RHD & AI)
(of mineral filler)					
Air voids	4%	4%	4%	4%	3% - 5%
Design/Optimum bitumen content	5.39%	5.61%	5.55%	5.52%	4.5% - 6.5%
VMA	16	16.41	15.8	15.7	Minimum 14
VFA	68	71.5	73.5	73	65-75
Stability (kN)	13.4	11.2	12	12.4	Minimum 8
Flow (0.25 mm)	3.48	3.40	3.30	3.45	2 - 3.5

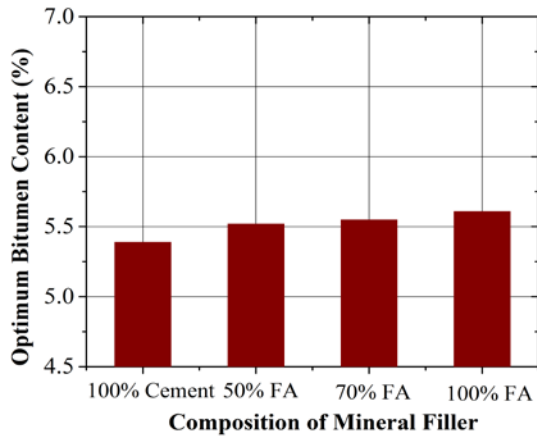


Fig. 4 Variations of optimum bitumen content with different filler concentrations

In Fig. 4, it is clear that using 100% FA as a mineral filler required a 5.61% optimum bitumen content, greater than those for 100% cement (5.39%) and cement-FA combinations (5.55% for 70% FA/30% cement and 5.52% for 50% FA/50% cement). However, these variations were nominal and all within the specified limits. Figs. 5 and 6 show variations of the VFA and VMA with respect to different filler concentrations, with 70% FA/30% cement exhibiting the highest VFA and 100% FA the maximum VMA.

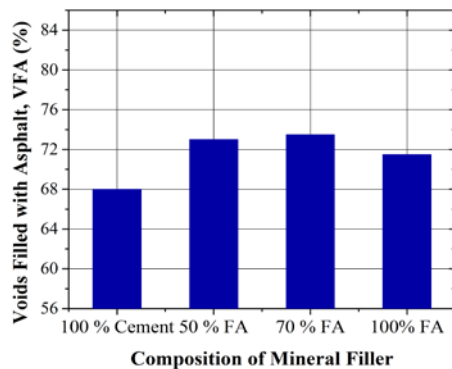


Fig. 5. Variations of VFA with different filler concentrations

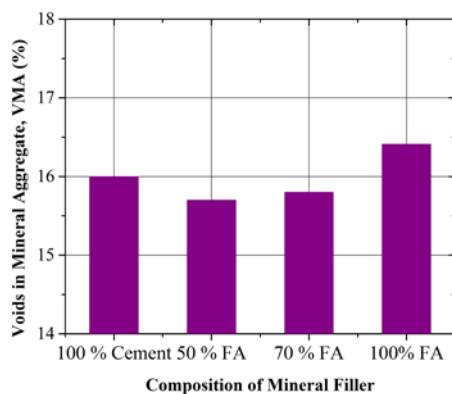


Fig. 6. Variations of VMA with different filler concentrations

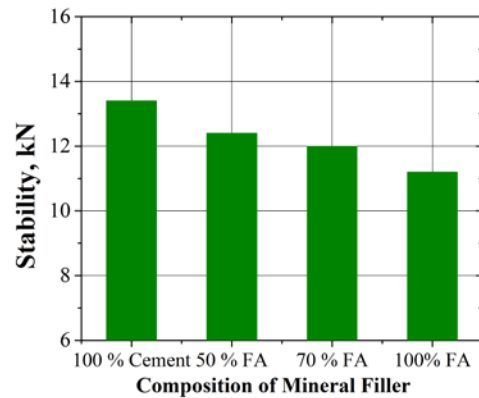


Fig. 7. Variations of stability value with different filler concentrations

The stability value is the maximum loading that can be sustained by an asphalt mixture. At the optimum bitumen content, the highest was shown by the 100% cement followed by the 50% FA/50% cement and 70% FA/30% cement combinations, and 100% FA, as shown in Fig. 7. The FA demonstrated significant stability values within the specified limit, a vital criterion for pavement design. The flow value indicates the degree of vertical deformation when an asphalt mixture is subjected to maximum loading.

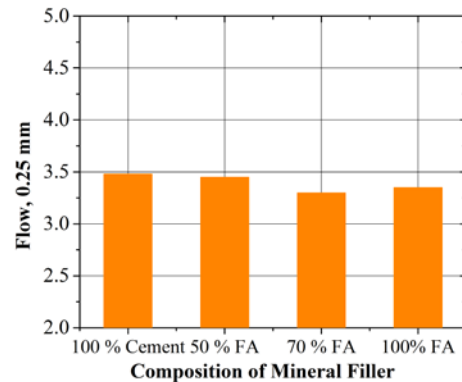


Fig. 8. Variations of flow value with different filler concentrations

In our test, 100% cement demonstrated the maximum flow value of 3.48, the 50% FA/50% cement combination 3.45, and the 100% FA and 70% FA/30% cement combination acceptable flow values within the standard range.

4.2 Index of Retained Strength (IRS)

Ministry of Road Transport and Highways (MORTH) (2013) specified that the minimum prerequisite for the IRS is 75% [13]. As, in all cases, the test results were greater than 75%, as shown in Table 2 and Fig. 9, it can be stated that HMA with FA was less susceptible to water than cement. For

the 70% FA/30% cement combination, the outcome was greater than that for the 100% FA which may have been due to the discrepancy in their air voids. Also, it has been found by different agencies that the results of immersion compression tests vary greatly and usually do not produce the actual results but present a considerable retained stability value which could be incorporated to resist moisture susceptibility.

Table 2. Results of moisture susceptibility tests

Filler	Compressive strength of dry specimen (S ₁ (psi))	Compressive strength of immersed specimen (S ₂ (psi))	Index of retained strength (IRS (%)) = $\frac{S_2}{S_1} \times 100\%$
100% cement	994.98	972.30	0.97
50% FA	918.76	845.26	0.92
70% FA	825.05	840.73	1.01
100% FA	812.60	718.23	0.89

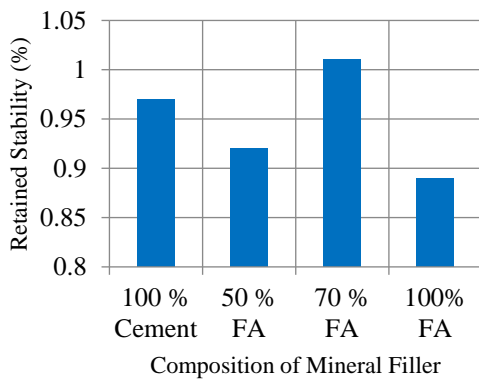


Fig. 9. Variations of retained strength with different filler concentrations

5. COMPARISON OF COSTS

In Bangladesh, cement and stone dust are usually used as filler materials in a pavement. Cement is much more expensive due to its manufacturing process and comprehensive use in construction works while, as stone dust is a by-product of crushing imported stones, its production cost is also relatively high. On the other hand, the abundant amounts of FA generated from thermal power plants that are stockpiled have very limited or no use. Considering the relative market prices of these products, it was found that the cost of filler materials in pavements can be reduced by using an extensive amount of FA. Fig. 10 shows a comparative cost analysis of using cement, FA and stone dust as mineral fillers for the construction of a 1 km road.

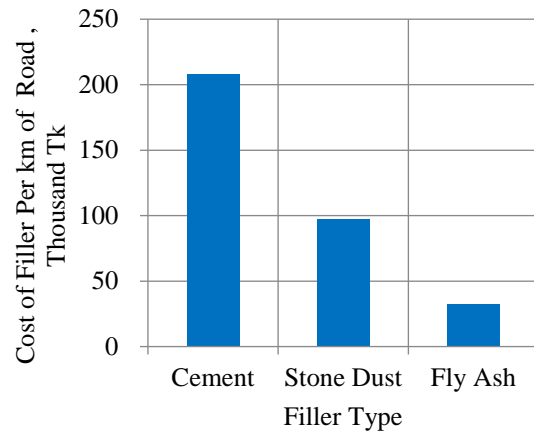


Fig. 10. Comparison of costs

6. CONCLUSIONS

In this study, the potential to use FA, a waste by-product of coal-based thermal power plants, as a filler in asphalt mixtures were investigated. For assessment purposes, a commonly used filler, cement, was considered separately as a control. Based on the results obtained from the Marshall stability and flow, and moisture susceptibility tests performed to explore the suitability of FA as a filler in asphalt paving mixtures, the following deductions can be drawn:

1. The maximum Marshall stability value was obtained when using 100% cement as a filler followed by FA (50% FA/50% cement combinations). However, it was clear that the variations were nominal and at the optimum bitumen content, the mixtures satisfied all the other Marshall criteria.
2. The optimum bitumen content required for FA was relatively higher than that for cement but within the RHD's specified range. Considering the large volume of FA produced as a waste product at places near thermal power plants where other fillers are relatively scarce or expensive, using it as a mineral filler in pavement and/or roadway designs instead of cement and stone dust should be less expensive.
3. Although the compressive strength of the 50% FA/50% cement combination was higher than those of the other mixtures, all demonstrated retained stability levels of more than 70%. This was an indication that those that included FA had very good resistance to moisture-induced damage.
4. The extensive damage caused to the environment by the FA generated from the coal-based industry in Bangladesh can be effectively dealt with by using it as a mineral filler in flexible pavement mixtures which is a viable means of managing its disposal while simultaneously ensuring a safe and clean environment.

7. ACKNOWLEDGMENTS

The authors acknowledge the excellent co-operation and support of all the officials and laboratory staff in the Department of Civil Engineering, MIST, Dhaka, and Special Works Organization (SWO) West during this research work. They also wish to express their gratitude to the Barapukuria Thermal Power Plant, Abdul Monem Ltd and Padma Multipurpose Bridge Project for coordinating the provision of important information and materials for test purposes.

8. REFERENCES

- [1] Tamim M. M., Dhar A., and Hossain M. S., Fly ash in Bangladesh- An Overview. *International Journal of Scientific & Engineering Research*, Vol. 4, 2013, pp. 809-812.
- [2] Mogawer W. S. and Stuart K. D., Effects of mineral fillers on properties of stone matrix asphalt mixtures. *Transportation Research Record: Journal of the Transportation Research Board*, 1996, pp. 1530(1): 86-94.
- [3] Kandhal P. S., Lynn C. Y. and Parker F., Characterization tests for mineral fillers related to performance of asphalt paving mixtures. *Transportation Research Record: Journal of the Transportation Research Board*, 1998, pp. 1638 (1): 101-110.
- [4] Hicks R. G., Santucci L. and Ashchenbrener T., Introduction and Seminar Objectives on Moisture Sensitivity of Asphalt Pavements. *Transportation Research Board National Seminar*, 2003, pp. 3-19.
- [5] Kar D., Panda M., and Giri J. P., Influence of fly-ash as a filler in bituminous mixes. *ARNP Journal of Engineering and Applied Sciences*, Vol. 9(6), 2014, pp. 895-900.
- [6] Rosner J.C., Chehovits J.G., and Morris G.R., Fly ash as a mineral filler and antistripping agent for asphalt concrete. Challenge of change. Conference proceedings, in Proc. 6th Int. Conf. on ash utilization, 1982.
- [7] Muniandy R. and Aburkaba E., The effect of type and particle size of industrial wastes filler on Indirect Tensile Stiffness and Fatigue performance of Stone Mastic Asphalt Mixtures. *Australian Journal of Basic and Applied Sciences*, Vol. 5, 2011, pp. 297-308.
- [8] Aksoy A., Samlioglu K., Tayfur S. and Ozen, H., Effects of various additives on the moisture damage sensitivity of asphalt mixtures. *Construction and Building Materials*, Vol. 4, Issue 1, 2005, pp. 11-18.
- [9] *Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types*, Sixth Edition, 2014.
- [10] Standard Test Method for Effect of Water on Compressive Strength of Compacted, ASTM D 1075. pp. 1074-1075.
<https://doi.org/10.1520/D1075-11.2>
- [11] Standard Tender Documents. General Specifications (Technical Specifications). Roads and Highways Department, The People's Republic of Bangladesh, Section-7, July 2011
- [12] Islam M., Alam M. T. and Islam S., Use of coal burnt fly ash as sustainable construction material. Conf. proceedings, in Proc. 1st Int. Conf. on Civil Infrastructure and Construction Materials (CICM), 2015, pp. 302-310.
- [13] Ministry of Road Transport and Highways (MORTH), Specifications for Road and Bridge Works. Section 500, Fifth Revision, 2013.

Copyright © Int. J. of GEOMATE. All rights reserved, including the making of copies unless permission is obtained from the copyright proprietors.
