Determining Optimum Proportion of Fly Ash as Partial Replacement of Asphalt for Flexible Pavements

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Abstract

Fly ash is a by-product obtained from the combustion of coal. It is a pozzolanic material and has been used as a binder for different types of construction application such as concrete mix, and soil stabilization. However, the studies related to exploring its behaviour when it is used in combination with bitumen are scarcely found. The focus of this research was to determine the optimum proportion of fly ash to be used as partial replacement of bitumen in flexible pavement design. The evaluation is made based on Marshall Stability and flow of Hot Mix Asphalt samples. Specimens were prepared using bitumen with and without fly ash. Varying percentages of fly ash were used as a partial replacement of bitumen. Based on the experimental work carried out during this study, it was observed that flow decreased with the increase in proportion of fly ash. On the other hand, stability was found to be maximum when the proportion of fly ash was at 10% by weight of bitumen. The result has shown that 10% replacement of fly ash with bitumen resulted in the highest stability and acceptable value of flow.

Keywords: Fly ash, hot mix asphalt, Marshall Stability, flow

1. Introduction:

Fly ash is produced as a by-product in power plants and manufacturing industries energized by coal combustion. Properties of fly ash resemble with other cementitious materials, but it is more economical being an industrial by-product. Use of fly ash has been reported to give more strength, and durability than other cementitious materials (Jala and Goyal, 2006). At the same time, its usage in construction projects is deemed environment friendly because its disposal on ground or in water can prove to be hazardous. Primarily, two classes of fly ash are used in civil engineering projects i.e. class C and F. The classification is based upon chemical composition of these types which is a result of their combustion processes. Class F fly ash is most commonly used as a replacement of Portland cement in construction applications because of its high silicon content (Xu, 1997; Oscar, 1999). According to Cooley et al, (2001) & Mistry and Roy (2016); fly ash is also being used in Hot Mix Asphalt (HMA) for many years as mineral filler and has been reported to provide positive results.

However, the review of literature shows that the effect of using fly ash as replacement of bitumen in HMA is further to be investigated. Hence, the objective of this research was set to determine the effects of fly ash, as a replacement of bitumen, on stability and flow of HMA. Class F fly ash has been used in this study because of its more popular application in concrete materials. It has further led to the recommendation about the optimum proportion of fly ash to be used in this regard. The results of this study would be useful for field engineers for optimum design of high-performance asphalt with addition of fly ash. Its importance would increase with the initiation of coal-based power generation projects which would result in ample supply of fly ash.

1.1. Fly Ash in Concrete

Use of fly ash in concrete dates back to six decades. This trend has grown due to the increase in construction activities as well as coal combustion for energy production (Thomas et al, 1999). The use of fly ash has been reported to increase the workability of cement concrete without significantly affecting its strength. Moreover, it has also been found beneficial for increasing the durability of concrete structures (Thomas et al, 1999; Rafieizonooz et al, 2016).

1.2. Fly Ash in Asphalt Pavement a Mineral Filler

Fly ash meets the specifications of mineral filler in HMA which includes its gradation, organic impurities, plasticity and hydrophobic nature. In addition to that, it also reduces the potential for asphalt stripping. A comparison of traditional and fly ash modified HMA was done by Modarres, and Rahmanzadeh (2014). The results of this experimental program showed that the use of fly ash resulted in higher stability and resilient modulus. It also enhanced the water sensitivity of mixes. Results indicated that the fly ash modified HMA exhibited more flexible behavior than the traditional mix.

1.3. Fly Ash in Stabilized Base Course

Fraay et al. (1990) described that stabilized base courses for pavements can be prepared in a cost-effective manner using proportioned mixtures of fly ash, aggregate, and an activator (cement or lime). These mixes are reported to produce strong and durable base course for pavement. These stabilized courses give comparable strength and stability as compared to cement treated aggregate layers at lower cost.

1.4. Fly Ash in Embankment

Kim et al. (2005) conducted an evaluation for use of fly ash in highway embankments. They observed that fly ash embankments give lower maximum dry density and well-defined moisture-density curves. Moreover, they also reported that hydraulic conductivity for fly ash embankments was lower than traditional materials. In terms of mechanical properties, such as shear strength, and compressibility, fly ash embankments were found to be similar to typical sandy soils. Hence, it can be said that use of fly ash can provide higher resistance to moisture while maintaining the same mechanical characteristics as traditional material.

1.5. Fly Ash a Replacement of Bitumen in HMA

Sobolev et al. (2013) investigated the effects of fly ash in HMA and its effects on workability, resistance to cracking and oxidative aging. This research reported that addition of fly ash shows a positive impact on these properties. Another study was conducted by (Vasudevan 2013), which explored the stability of HMA while using different percentages of fly ash (by weight of bitumen) by performing Marshall Test.

He blends asphalt and fly ash at the ratio of 4% and 1%, 4.5% and 2%, 5% and 3%, 5.5% and 4%, 6% and 5% respectively (Vasudevan 2013), concluded that these percentages of fly ash cannot achieve the suitable results for the stability, flow and air voids. But they suggested to increase the percentages of fly ash so that better results may be achieved due to high binding properties.

The above studies indicated the need to do a more comprehensive study for testing the effects of using fly ash in terms of strength of HMA, i.e. stability and flow. The above studies have also recommended the use of fly ash in proportion of 6% or higher as per weight of bitumen with smaller increments. Both these issues have been addressed in this study.

2. MATERIAL AND METHODOLOGY

2.1. Aggregate Gradation

Aggregates used for this research were taken from a single source; i.e. quarries of Hub Chowki. This source is commonly used for acquiring aggregates for construction works in Karachi. The gradation selected for the performance testing is specified by National Highway Authority (NHA) Pakistan for wearing course with maximum aggregate size of 12.5mm. NHA is the prime administrative authority of inter-city highway network of Pakistan. More details about this gradation are shown in Figure. 1 and Table 1.

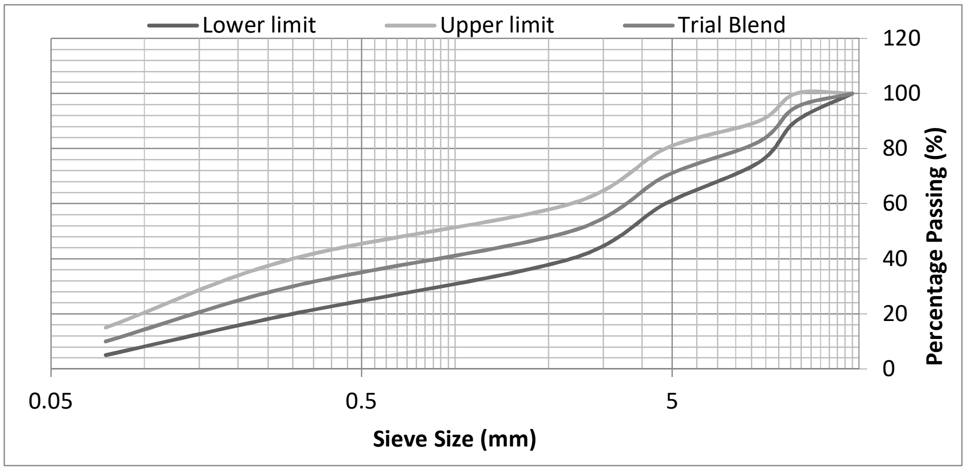

Figure 1. Gradation Chart

Table 1. Gradation

Sieve Sizes mm (inch)	Standard (%age Passing)	Trial Blend (%age Passing)
19 mm (3/4 inch)	100	100
12.5 mm (1/2 inch)	90-100	95
9.5mm (3/8 inch)	75-89	82.5
4.75mm (No.4)	60-80	70
2.36mm (No.8)	40-60	50
0.3mm (No.50)	20-40	30
0.075mm (No.200)	5-15	10
Pan	3-8	5

2.2. Bitumen Tests

Bitumen has been used in engineering projects for many decades. This trend has led to establishment of certain test procedures to evaluate performance characteristics of bitumen. These test procedures also involve empirical rules that have been incorporated through continuous refinement by experts of this field. These tests are mainly concerned with the ductility and grade of asphalt which determines its performance under repeated loading and extreme environmental conditions. The tests for these properties include penetration, softening point and ductility test (Papagiannakis and Masad, 2008). The results of these tests are given in Table 2. They are hereby reported for reference of researchers who intend to do further research on interaction of bitumen quality with fly ash.

Table 2. Bitumen Test Result

Test	Result	Test Procedure
Penetration grade	(60-70 grade achieved)	ASTM D5
Ductility	34.6 cms. Distance of elongate	ASTM D113
Softening point	The average value of softening point of sample was 45^0C	ASTM D36

2.3. Marshall Mix Design

Bruce Marshall of the Mississippi Highway Department developed the basic concepts of the Marshall Mix Design Method around 1939 which were further refined by the U.S. Army. Currently, this method is used in Pakistan for mix design of HMA, although other methods are also available. The Marshall method is aimed at determination of Optimum Bitumen Content (OBC) that gives highest possible density while satisfying the minimum stability and range of flow values.

In this study, specimens having air void ratio closest to standard 4% value were considered to be having the OBC. Then, three (03) specimens containing the OBC at each proportion of fly ash were tested for their stability and flow. According to standard procedure of this method, each compacted specimen is 2.5±0.05inch (63.5±1.27mm) in height and approximately 1200gms in weight. Each parameter is evaluated for at least three identical specimens and the average of these specimens is considered for analysis (White, 1985). Complete procedural details about Marshall Mix Design Method can be found in ASTM standard D1559.

2.4. Air Voids (V_a)

Proportion of air voids is used to find the degree of compactness of HMA sample. Volume of air voids in a sample can be calculated as the difference of bulk specific gravity (G_{mb}) and theoretical maximum specific gravity (G_{mm}) of test specimen.

The test for determination of G_{mb} involves measuring HMA sample's weights under three different conditions, namely; dry, saturated surface dry and submerged in water. Equation 1 can be used to calculate G_{mb} (Hinrichsen and Heggen, 1996; Buchanan, 2000).

$$Bulk\ Specific\ Gravity = G_{mb} = \mathrm{A}/(\mathrm{B} - \mathrm{C}) \quad (1)$$

Where,

A = mass of dry HMA sample (g)
B = mass of saturated surface dry HMA sample (g)
C = mass of HMA sample in water (g)

G_{mm} of a HMA mixture is the maximum possible specific gravity which will be achieved at absolute absence of air voids in the sample. Equation 2 was used to calculate maximum specific gravity. The standard theoretical maximum specific gravity test is defined by the AASHTO standard T 209 and ASTMD 2041.

$$Theoritical\ Maximum\ Specific\ Gravity = G_{mm} = A/(A + D - E) \quad (2)$$

Where,

A = mass of dry HMA sample (g)

D = mass of flask completely filled with water (g)
E = mass of flask filled with HMA sample and water

3. Results and Discussion

3.1. Marshall Stability

Results of the Marshall Stability tests are show in Figure. 2 and Table 3, which shows the average stability of samples at optimum bitumen content. It illustrates that Marshall stability will increase due to increase in bitumen replacement by fly ash from 0 to 10%. Replacement beyond 10% results in reversion of this trend and the Marshall Stability values decrease with an increase in percentage of fly ash. At 10% fly ash, the Marshall Stability value increases by 8% compared to the controlled specimens.

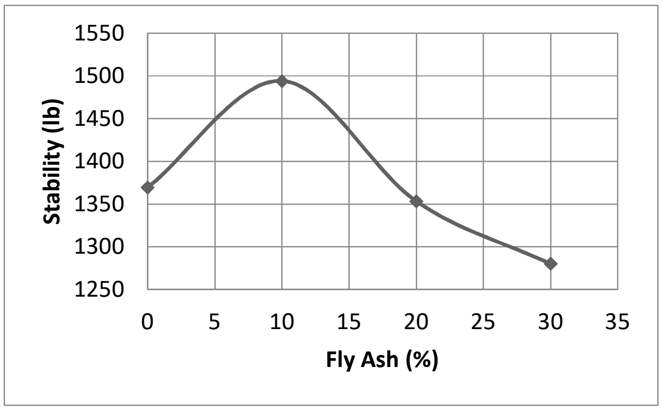

Figure 2. Marshall Stability

3.2. Marshall Flow

Marshall Flow tests were carried out and the results are shown in Table 3 and are graphically presented in Figure 3 for specimens with OBC. From this figure there is an increase in flow values with increase in percentage of fly ash. This means that mixtures with higher fly ash content are more susceptible to rutting. However, the flow value is within acceptable range given by AASHTO at 10% fly ash content (Hınıslıoğlu ans Ağar, 2004).

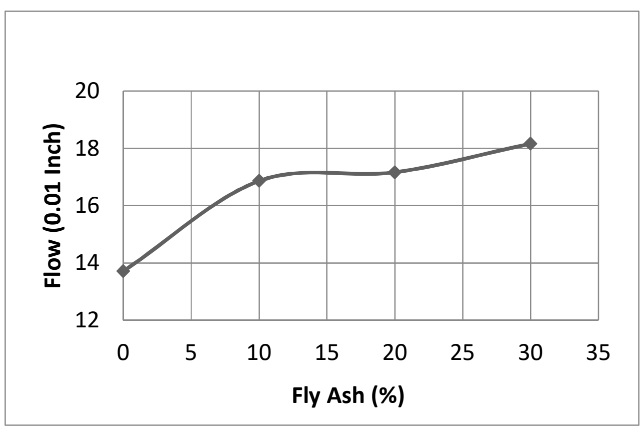

Figure 3. Marshall Flow

3.3. Optimum Bitumen Content (OBC)

The OBC values against different proportion of fly ash as replacement of bitumen are shown in Table 3. It shows that OBC at 10% replacement is almost equal to the control sample. These values decrease significantly as the proportion of fly ash is increased. The possible reason behind this trend could be that fly ash, initially, improves the void ratio in the mixture which provides more stability. On the other hand, it decreases the adhesion within the mix due to its fine particles. Hence, it can be said that 10% replacement of bitumen with fly ash in HMA increases its stability by improving its specific gravity/air voids ratio which is the measure of its compactness. But more than 10% replacement of bitumen the effect of loss of adhesion becomes prominent resulting in reduction of stability. The same reason could be stated for the continuous increase in flow value.

Table 3. Marshall Stability and Flow Test

Fly Ash (%)	OBC (%)	Stability (lb)	Flow (0.01in)
0	5.5	1369.6	13.71
10	5.4	1494.2	16.86
20	4.6	1353.3	17.162
30	4.25	1280.20	18.16

4 Conclusions and Recommendations

This study was aimed at testing stability and flow characteristics of HMA with the proportion of fly ash 0, 10, 20, and 30% with respect to weight of bitumen. Highest stability was achieved when 10% of bitumen was replaced with fly ash. For these specimens, the average increase in stability value was about 8% compared to control specimens. The flow value gradually increases from 0.1371 to 0.1816 inch as the fly ash content is increased from 0 to 30%. However, the flow value at 10% replacement of bitumen is within the recommended specification of AASHTO. Hence, it can be concluded that 10% is the optimum proportion for replacement of bitumen by fly ash for gaining maximum strength of HMA without compromising its durability.

The results of this study provide an optimum mix design of modified asphalt with maximum stability and acceptable flow/rutting resistance. The utilization of such waste material would help in sustainable mix design.

The possible future directions of research in this field may be evaluation of mechanical properties of HMA at 10% replacement of bitumen by fly ash. Moreover, study of interactive effects of grade of asphalt at different proportions of bitumen replacement by fly ash is also another possible avenue to be explored.

5 Acknowledgement

The authors acknowledge the efforts of Muhammad Atif, Agha Mujtaba Jawad, Ahsan Ahmed, Mohsin Ali, and Ali Raza, BE (CE) students of batch 2011-12, NED University in conducting the experimental work. The authors are grateful for the financial support provided by Swedish College of Engineering & Technology Wah Cantt, Pakistan.

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