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A Study of Effect of Filler Contents and Filler Types in Marshall Stability and Flow Value in Asphalt Concrete

Niraj Bohara [a], Gautam Bir Singh Tamrakar [b]

[a, b] *Department of Civil Engineering, Pulchowk Campus, IOE, TU, Nepal*
Corresponding Email: [a] boharanj@gmail.com, [b] gbstamrakar@hotmail.com

Abstract
Filler produces mix of higher stiffness and improves performance against rutting distress. However, different fillers behave differently and produce different property asphalt concrete. To compare different behaviour of different fillers, 18 numbers of Marshall specimens are prepared consisting of varying filler contents of fly ash as filler with additional two sets of specimens with cement and stone dust as filler . The comparison is performed at only 6% bitumen content.

Fly ash at 9% showed highest stability and least flow value when compared to other content. Highest stability of 17.2 kN and least flow value of 3.41mm is observed at 9% fly ash content. With increase in the filler content, void gets filled and results an increase in stability and a decrease in flow value. Mix with fly ash performs better than the mix with cement and stone dust in terms of Marshall stability and flow value. The cost analysis is performed in context of Nepal based on the mix property and unit cost of paving asphalt concrete for different fillers. The unit cost of paving asphalt concrete with stone dust (5% by weight) is minimum whereas with cement is maximum. The minimum unit cost of paving of Rs. 18,275.56 is obtained for 7% fly ash containing asphalt concrete when compared to other fly ash containing mix during analysis. The cost of paving 7% fly ash containing asphalt concrete seems to be reasonably economical for producing highly stiffer mix.

Keywords
Fly ash – Cement–Stone dust–Marshall Stability–Flow value–Cost in Nepal

1. Introduction

The asphalt concrete consists of two kinds of materials namely coarser and granular aggregates; and binder. The mixture of bitumen and filler is called asphalt mastic. These asphalt mastics are responsible for providing the mixes of sufficient viscosity so that it facilitates coating, easy paving and compaction for more durable mixes.[1]. Fillers are thus the finer material (finer than 75μ, as per ASTM D242 [2] minimum of 70% passes through No. 200 sieve) when with the bitumen acts as binder and together fill the voids present in the mixes to produce denser, water resistant (entrance to the water) [3] and durable asphalt concrete. More importance is given to the gradation of aggregate or the optimum bitumen content of the mixes, whereas the filler content is neglected in the mix design procedure. However, to aid to the fact of the importance of the filler contents in the mix, several studies have been made with different types of filler and its content with respect to the change in the physical characteristics of asphalt concrete.

1.1 Fly Ash and its use

[2] ASTM-D242, Standard Specification for Mineral Filler for Bituminous Paving Mixtures, has identified rock dust, fly ash, hydrated lime, hydraulic cement, loess, slag dust as the mineral filler. Presently in Nepal, only stone dust is used as a mineral filler where the content of the filler is taken as to only satisfy the gradation requirement of aggregate put forth by Standard Specification for Road and Bridge Works [4]. However, the standard does not recognize the fly ash as the filler material, a coal combustion by-product which is fine in nature produced during combustion of pulverized coal in electric or steam generating plants. It has been now and then used in a numerous study and real life projects in asphalt concrete. It is a matter of interest to know the extent of benefits brought by the

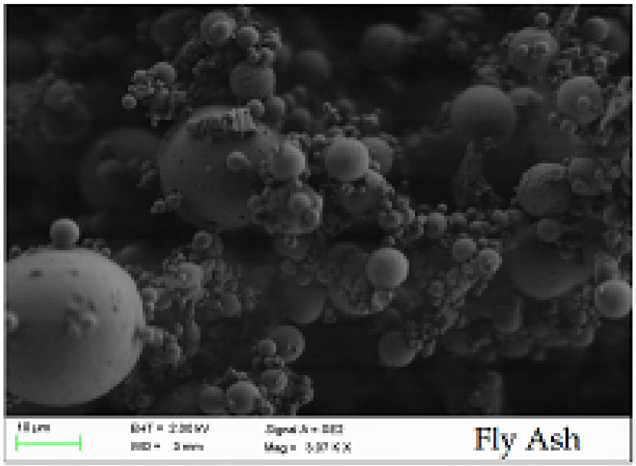

Figure 1: SEM photograph of fly ash [1]

use of fly ash in the asphalt concrete in Nepal in terms of performance and cost.

Fly ash seems to fulfill all the physical requirements of mineral fillers. With the use of low specific gravity fly ash (with a range of 2.0 to 2.6) lesser than other typical mineral fillers (range from 2.6 to 2.8), the requirement of fly ash as the filler will be low by percentage by weight to gain similar performance to the other filler asphalt concrete.[5]. With the addition of the filler in the bitumen, the viscosity of the binder is reduced. This may mislead the mixing temperature and compaction temperature simply obtained from the study of bitumen. Since, the temperature is required to maintain specific viscosity of the mastic to flow and mix through. However, for the case of fly ash it is different. Fly ash is characterized by its spherical particles as shown in the Figure 1. This allows the mastic to not lose its viscosity in a considerable amount and thus confirming to the temperature for mixing and compaction.[1]

1.2 Study Objectives

The major objective of the study is to compare different filler and different filler content at a bitumen content with respect to Marshall stability and flow value. The study also covers cost analysis of different fillers mix in context of Nepal.

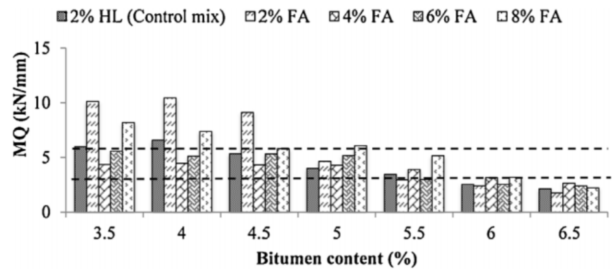

Figure 2: Variation of Marshall quotient with respect to filler content and bitumen content [6]

2. Literature Review

Prior to the selection of study area, different literatures related to the study of fillers in asphalt concrete were reviewed and analyzed. Literatures suggested that asphalt concrete is greatly influenced by the presence of fillers and its physical properties.

2.1 Behaviors Under Different Fillers

Raja Mistry and Tapas Kumar Roy performed experiment on the effect of the fillers; fly ash and hydrated lime and got some interesting results with respect to Marshall Quotient. The experiment showed that different fillers (fly ash and hydrated lime) behaved differently even with the same quantity of fillers and bitumen content (% by weight). The graph in the Figure 2 is extracted from the same research paper and shows the differences in Marshall quotient of mixes.[6]

Another study was performed by Didier Lesueur et al on the impact of the filler on the asphalt mix. They performed tests where the impact by the increase of the filler content on the asphalt mix in terms of complex modulus was studied. Two fillers were studied namely hydrated lime and limestone filler. The complex modulus was found to have a well defined peak with respect to the filler content. Peak was observed at filler content of 4 % by weight for hydrated lime filler and at 10 % by weight for limestone filler as shown from the Figure 3. [7]

Amir Modarres on a [8] paper presented comparison between fillers; limestone, coal waste product and coal waste ash with their constant filler proportion (7% by weight of total aggregate) in asphalt concrete. A total of 6 types of samples were prepared with different fillers.

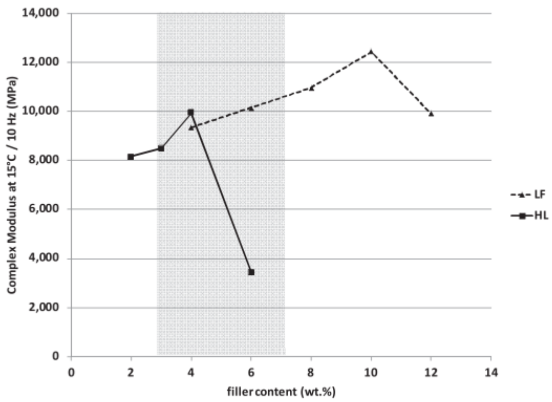

Figure 3: Variation of complex modulus with respect to filler content where LF is limestone filler and HL is hydrated lime[7]

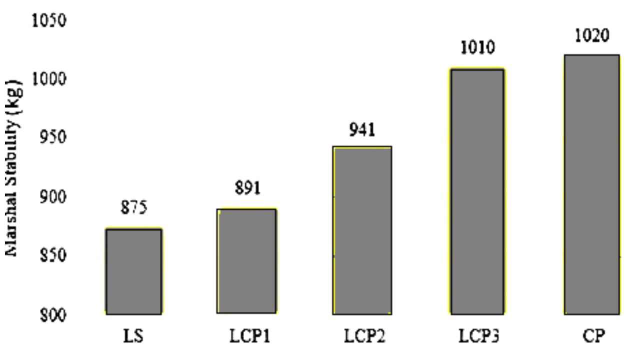

Figure 4: The graph showing Marshall stability of different mix[8]

Six filler combinations were prepared namely 100% limestone (LS); 75% coal waste powder, 25% limestone (LCP1); 50% coal waste powder, 50% limestone (LCP2); 25% coal waste powder, 75% limestone (LCP3); 100% coal waste powder (CP) and 100% coal waste ash (CA). The Marshal stability test showed an increase in the stability with the incorporation of coal waste powder as shown from graph in Figure 4. The Table 1 suggested the Marshall stability for coal ash to be the highest among the mix.

Table 1: Differences between Marshall stability of different mix[8]

Property(Unit)	LS	CP	CA
Marshall stability (kg)	875	1020	1260
Marshall flow (mm)	3.13	3.00	2.5

2.2 Coal Fly Ash and Its Use

The primary components of coal fly ash are silicon dioxide, aluminum oxide, iron oxide, and calcium oxide.

Coal fly ash is characterised by its spherical particles. The shape allows it to act more as a tiny roller that directly affects the compaction. It there by decreases the friction in the mastic and increasing packing with a lower void mineral aggregate.[9]. The result of the study also suggested the better performance nature of asphalt mixture with respect to moisture susceptibility, strength, stiffness and stripping resistance of mix with cement and/or fly ash.

The filler content for maximum stability was found to be 6% by weight for the fly ash as the filler. With more increase in the content, the Marshall stability decreases giving a peak for a filler content. The OBC (Optimum Bitumen Content) for optimum filler content for fly ash seems to be lower when compared to the OBC of the control mix (hydrated lime as the filler) [6]. In another study, a maximum stability was observed for 5% of fly ash content when compared to the 7% content of limestone filler. A 1923 kg stability was observed at 5% OBC for fly ash filler as compared to the stability of 1527 kg of sample of limestone filler at 5.5% OBC, a nature where fly ash reductes binder amount in mix(possible asphalt extender).[10] However, result obtained on [11] paper suggested the performance order of cement filler, stone dust and fly ash filler with respect to Marshall stability, where first in the order denotes highest.

In 1988, a study was undertaken to evaluate the use of ”ponded fly ash” as a component in a stabilized aggregate base course. Ponded fly ash is the fly ash portion of coal ash waste previously sluiced into a disposal pond. Laboratory investigations determined that the optimum mix was a composite of 84-percent dense-graded aggregate, 11-percent ponded fly ash, and 5-percent hydrated lime. A 230 m (755 ft) long, 20 cm (8 in) thick test section was constructed and overlaid with an asphalt base, binder, and surface course. After three years of service, the experimental section is outperforming the conventional section; the amount of rutting is significantly lower in the experimental section than in the control section. Aside from minor reflective cracking associated with base shrinkage base, the experimental section has performed excellently. [12].

The study takes its shape with the study of different literature that provided evidences of the positive effects brought in due to introduction of the fly ash as the filler. The study incorporates the effect of fly ash and compares it with asphalt concrete with cement and stone dust fillers.

3. Methodology

The comparison of different mix is performed with the help of Marshall properties. So, the methodology of the study involves Marshall specimen preparation, Marshall tests and properties and cost analysis. This is followed by appropriate conclusion to the use of fillers in asphalt concrete to meet the objective of the study.

3.1 Sample Preparation

3.1.1 Selection of Aggregate

Three sets of aggregates were selected to fulfill the requirement of Standard Specification for Road and Bridge Works, 2073. The coarse aggregate ($A1$), fine aggregate (A_2 & A_3) are proportioned such that aggregate satisfies grading requirements. The gradation of the selected aggregate is shown in Figure 5. Coarse aggregates properties confirming to the requirements is shown in Table 2.

Table 2: Physical tests for Aggregate 1

Test	Limiting Value	Result	Standard
Los Angeles Abrasion Test	Maximum 30%	30%	IS 2386 Part IV
Aggregate Impact Test	Maximum 24%	19%	
Aggregate Crushing Value Test		21%	

Specific gravity tests for aggregates and their respective proportions can be summed up as:
Aggregate 1 – 2.74 - 50%
Aggregate 2 – 2.70 - 32%
Aggregate 3 – 2.59 - 18%

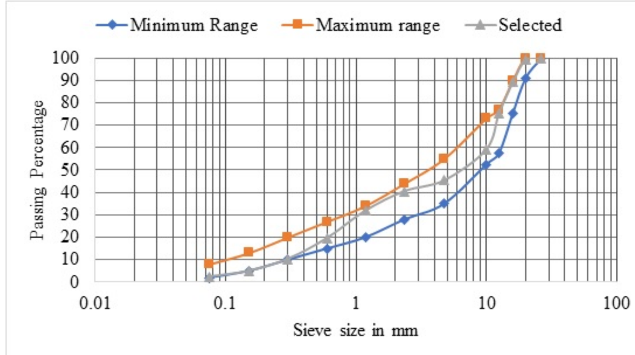

Figure 5: Limiting grading curve and selected gradation

3.1.2 Selection of Bitumen

Property of bitumen collected from nearest local supplier is shown below in Table3. As per the known sets of properties, the bitumen is identified as VG-10 grade bitumen.

Table 3: Standard tests for the characteristics of bitumen

S.N	Characteristics	Method of Test	Value
i	Penetration at 25^{o}C, 100 g, 5 s, 0.1 mm, Min	IS 1203	100
ii	Absolute viscosity at 60^{o}C, Poises	IS 1206 part 2	825.8
iii	Softening point (R & B)^{o}C,	IS 1205	40.5
iv	Ductility at 25^{o}C, cm	IS 1208	>100
v	Specific gravity	IS 1202	1.002

Bitumen test data chart is used to find out the compaction and mixing temperature as shown in the Figure 6 for corresponding viscosity of 170 ± 20 cP and 280 ± 30 cP of the binders for mixing and compaction. [13]

3.1.3 Selection of Filler

Three different filler materials were selected. Fly ash was collected from the Butwol Cement factory, Bhairahawa. Similarly, cement was collected from local hardware

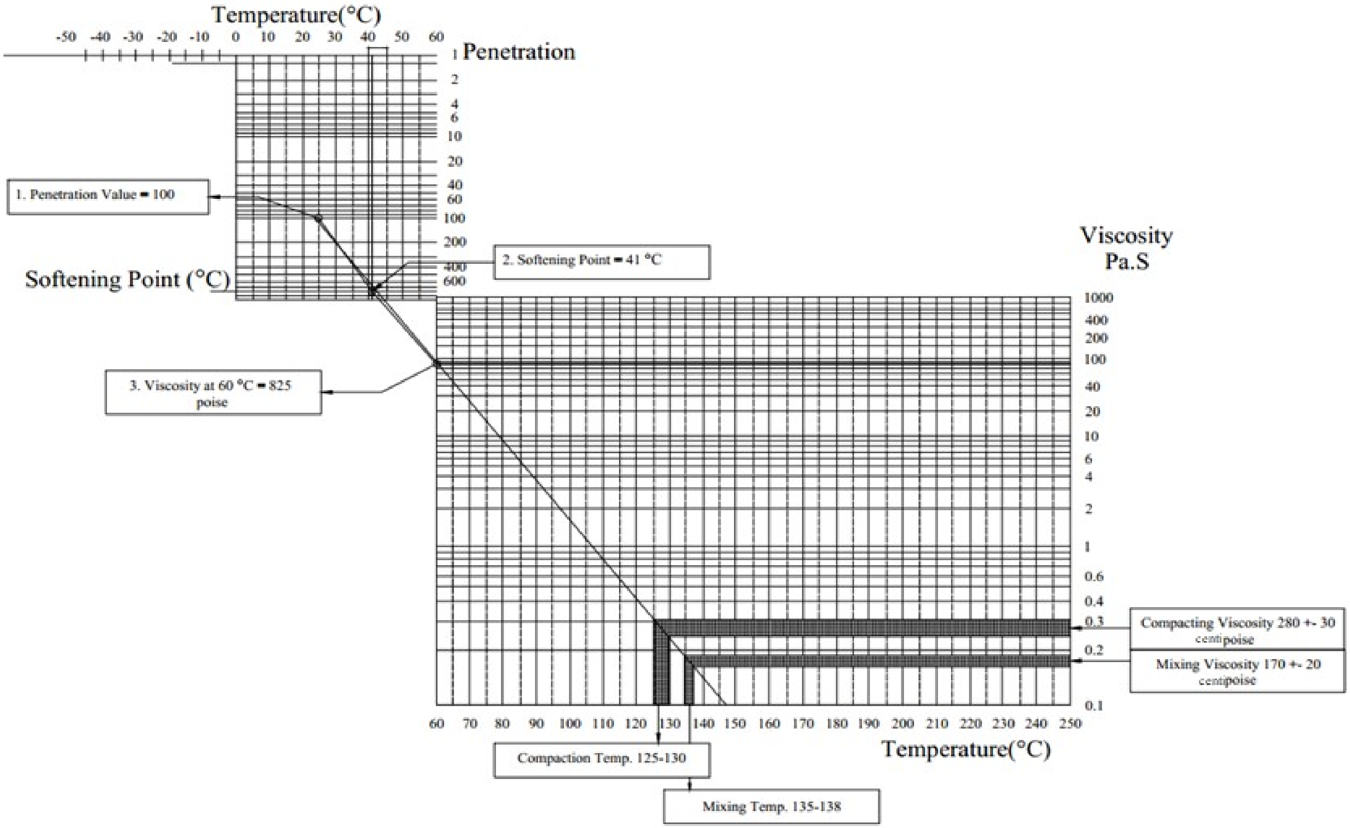

Figure 6: Bitumen Test Data Chart showing mixing and compaction temperature

Table 4: Sieve analysis result of fly ash

Sieve size (mm)	Percentage passing
0.3	100%
0.15	97%
0.075	83%

store. Cement used was Pozzolana Portland Cement (PPC). As for stone dust, crushed stone dust sieved from 75μ sieve was used.

Sieve analysis of collected fly ash yielded following results as in Table 4.

Specific gravity of filler materials are provided below:
Fly Ash - 2.15
Cement - 2.95
Stone dust - 2.63
As seen, fly ash has the least specific gravity compared to other filler materials and has a prominent greyish colour which can be seen in Figure 7.

Figure 7: Fly ash with its natural greyish color

3.1.4 Mix Preparation

Marshall specimens with total weight of the mix, bitumen, filler and aggregates, have been prepared confirming to standard specified by (ASTM - D6926)[14] for specimen preparation. For the control mix a filler content of 5% by weight of aggregate and a bitumen content of 6% was prepared with cement and stone dust as filler. To study the effect of fly ash content, samples were prepared with 3%, 5% ,7% and 9% by weight of mix.

The obtained mixing temperature of 140^{o}C is lesser than required for efficient coating of aggregates and hence temperature 160^{o}C was used. Samples were given 75 number of blows on both sides as specified by standard specification for road and bridge work (SSRBW), 2073 (DoR, 2016)[4]. Three numbers of specimen for each proportion of the filler and bitumen content were prepared to validate the Marshall test results produced for samples (ASTM - D6927)[15]. Figure 8 and Figure 9 shows samples with cement, stone dust and fly ash as filler.

Figure 8: Samples with cement and stone dust as filler; darker black colour

Figure 9: Samples with fly ash as filler; greyish colour in the surface

3.2 Marshall test

Marshall tests were performed with respect to (ASTM - D6927)[15], standard test method for Marshall stability and flow of bituminous mixtures. The results of the experiments are expressed in terms of following terms:

1. Marshall stability – kN
2. Flow value – in mm
3. Percentage of air voids – %
4. Voids in Mineral Aggregate (VMA) – %
5. Voids Filled with Bitumen (VFB) – %
6. Unit weight of specimen (G) – gm/cm^3

The test setup is as shown in the Figure 10

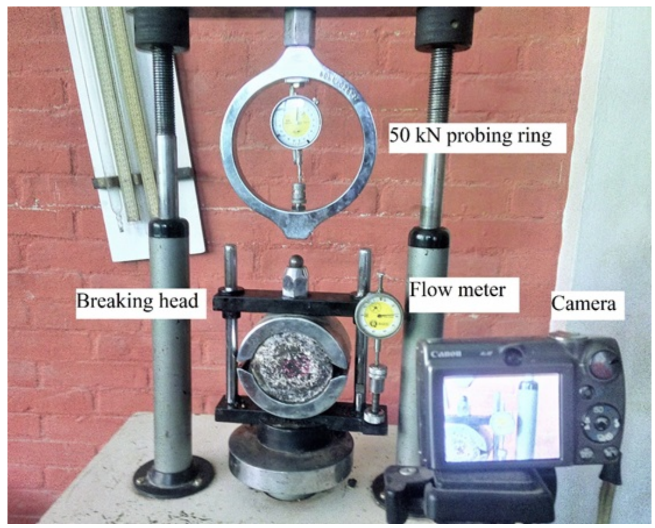

Figure 10: Marshall stability test setup in Kantipur Engineering College, Dhapakhel

The test is followed by analysis of the samples result and comparison with respect to Marshall properties and providing proper recommendation for the use of fillers in Asphalt concrete.

3.3 Cost Analysis

As fly ash is not produced in Nepal, it is exported from India in most of the cement factory of Nepal. The unit cost of fly ash is calculated as the unit cost of buying from India, unit cost of exporting (custom duty)[section 26 of list of custom, tariff] and freight charge. The unit rate of cement, bitumen, diesel, skilled, unskilled manpower, aggregate are collected from District Rate

Table 5: Marshall properties at different fly ash content and different fillers

Fillers/percentage by weight	Marshall Stability (kN)	Flow Value (mm)	Unit weight (gm/cc)	Percentage of air void	VMA	VFB
3% FA	12.45	5.60	2.297	5.69%	19.43%	70.73%
5% FA	16.20	4.90	2.279	6.01%	19.37%	69.58%
7% FA	16.82	4.03	2.262	6.30%	19.80%	68.26%
9% FA	17.20	3.41	2.265	5.81%	19.33%	69.98%
5% Stone dust	14.71	5.33	2.316	5.41%	19.38%	72.23%
5% Cement	13.39	5.43	2.309	6.26%	19.71%	69.37%

Table 6: Quantity of different material required for different mix

Fillers		Unit Weight	Wt of Fly Ash	Wt of bitumen	Aggregate (weight and volume)				
		kg/m^3	kg	kg	A1	A2	A3	To. Wt	Vol. m^3
FA	3%	2296.67	64.77	137.80	1047.05	670.11	376.94	2094.10	1.27
FA	5%	2279.33	107.13	136.76	1017.72	651.34	366.38	2035.44	1.23
FA	7%	2261.67	148.82	135.70	988.57	632.69	355.89	1977.15	1.20
FA	9%	2264.67	191.59	135.88	968.60	619.90	348.70	1937.20	1.17
Stonedust	5%	2316	108.85	138.96	1034.09	661.82	372.27	2068.19	1.25
Cement	5%	2309.33	108.54	138.56	1031.12	659.92	371.20	2062.23	1.25

of Kathmandu, 2016/17 whereas, the unit cost of hiring rate of heavy equipment is collected from Department of Heavy Equipment Hiring Rate Table. The quantity of manpower and heavy equipments required for unit paving of asphalt concrete is taken as per the norms of Department of Road for paving and laying asphalt concrete.

With the help of unit weight property of asphalt concrete of different mix with different fillers, the quantity of different materials; aggregate, fillers, and bitumen is calculated followed by calculation of cost of paving a cubic meter of asphalt concrete is presented. The quantity of materials are increased by 10% considering possible losses. Since, the durability analysis for fly ash and cement containing mix is not performed, the cost comparison is presented only on the basis of the cost of paving but not full life cycle cost analysis.

4. Results and Discussion

The result of study has been divided into two sections; Marshall properties and cost analysis; to present idea of physical properties of different mix and to present their respective cost effectiveness in context to Nepal.

4.1 Marshall Properties

The summary of the results obtained for different mix has been presented in Table 5 and Figure 11 for 6% bitumen content. It shows that with the increase in fly ash content Marshall stability increases. Similarly, the mix flexibility or deformation at maximum load condition, flow value, decreases with the increase in fly ash content. A maximum Marshall stability of 17.2 kN and alternately minimum flow value of 3.41 mm is observed at 9% fly ash content.

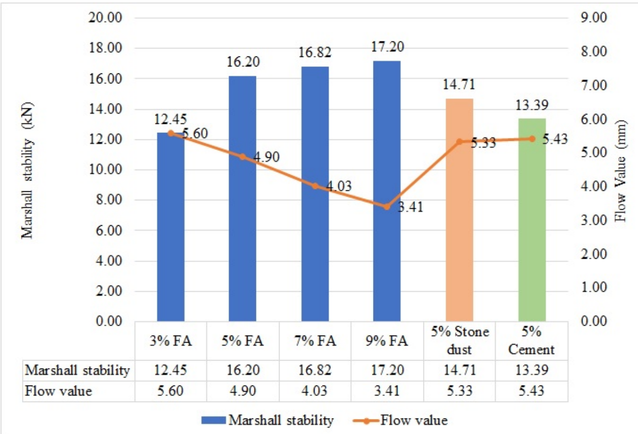

Figure 11: Variation of Marshall stability and flow value for different fly ash content and different fillers

Percentage of air voids shows a complex behavior for different fly ash content mix. Lower filler content mix shows least air void content. It is because of larger influence of bitumen in lower filler content in producing more plastic mix that provides higher flexibility(flow value) and correspondingly lower air voids. However, for 7% fly ash content mix, air voids is higher as compared to 5% and 9% fly ash content mix. As explained earlier, for lower filler content, influence of bitumen is higher producing lesser void mix. Though, for higher filler content, the influence of bitumen is low and hence, higher fly ash content plays more influencing role in filling voids and producing lower air voids at the same bitumen content.

With presence of fly ash in the mix, Marshall stability increases when it is compared to the mix containing stone dust and cement. It is also observed that, mix with fly ash at 5% content has least flow value if compared to mix with stone dust and cement (control mix). This proves that, entrainment of fly ash in asphalt concrete increases the rutting resistance (from Marshall stability) and stiffness (deformation/flow value)of the mix.

4.2 Cost Analysis

The Table 6 and Table 7 respectively shows the quantity of materials and the cost of different materials used in the asphalt concrete with different amount of fillers and different fillers. The cost has been further divided into sub headings as Manpower, Aggregate, Filler, Bitumen, Other materials and Heavy equipments. The major cost of the paving asphalt concrete herein Nepal is covered by Bitumen whereas the cost of the filler (as of our interest) is highest for cement fillers and lowest for stonedust fillers.

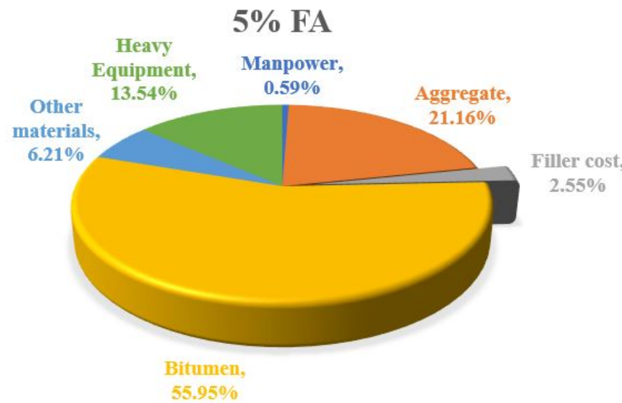

Figure 12: Cost contribution in different sub-heading for producing 1m^3 asphalt concrete with 3% Fly ash

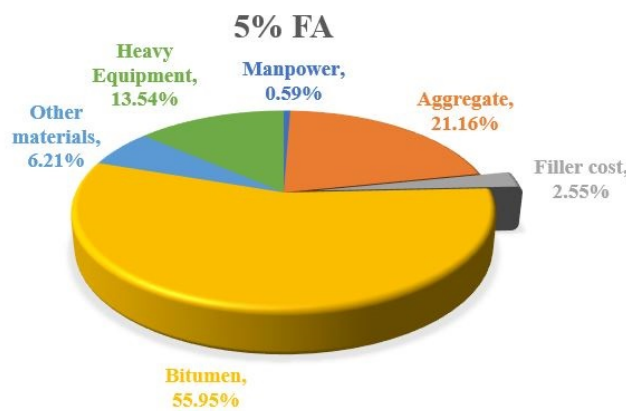

Figure 13: Cost contribution in different sub-heading for producing 1m^3 asphalt concrete with 5% Fly ash

The unit cost of cement is taken as Rs. 15.94 per kg, aggregate Rs. 2,851.46 per m^3, bitumen Rs 68.00 per kg and fly ash Rs.3.93 per kg (based on custom duty, freight charge and cost).

The cost of paving for 7% fly ash is the least among asphalt concrete with fly ash as filler. The cost of paving 1m^3 asphalt concrete for 7% fly ash as filler is Rs. 18,275.56. Whereas the least cost of paving a unit of asphalt concrete is Rs. 18,243.60 for 5% stone dust as

Table 7: Cost of paving unit m^3 asphalt concrete with different fillers

Fillers / Materials	3% Fly Ash	5% Fly Ash	7% Fly Ash	9% Fly Ash	5% Stonedust	5% Cement
Manpower	107.60	107.60	107.60	107.60	107.60	107.60
Aggregate	3,980.83	3,869.32	3,758.50	3,682.55	3,931.57	3,920.25
Filler cost	280.14	466.16	649.72	828.47	200.84	1,730.11
Bitumen	10,307.44	10,229.65	10,150.36	10,163.82	10,394.21	10,364.29
Other materials	1,134.43	1,134.43	1,134.43	1,134.43	1,134.43	1,134.43
Heavy Equipment	2,474.96	2,474.96	2,474.96	2,474.96	2,474.96	2,474.96
Total cost, in Rs	**18,285.39**	**18,282.11**	**18,275.56**	**18,391.83**	**18,243.60**	**19,731.63**

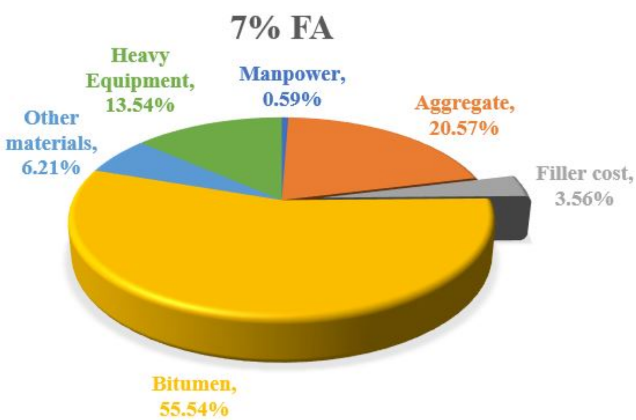

Figure 14: Cost contribution in different sub-heading for producing 1m^3 asphalt concrete with 7% Fly ash

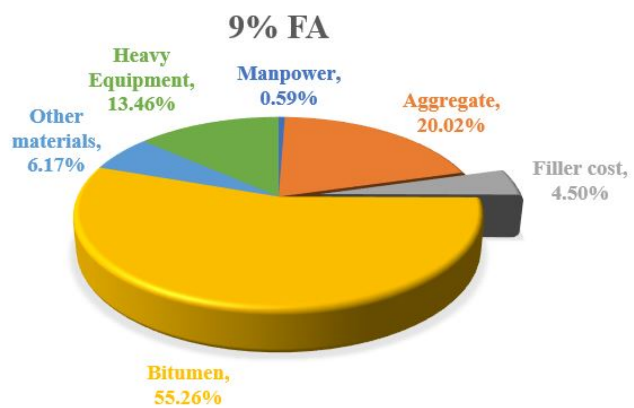

Figure 15: Cost contribution in different sub-heading for producing 1m^3 asphalt concrete with 9% Fly ash

fillers. With cement as fillers in asphalt concrete, due to the higher cost of cement per kg, the cost of paving 1m^3 asphalt concrete become higher and stands highest at Rs.19,731.63.

Figure 16: Cost contribution in different sub-heading for producing 1m^3 asphalt concrete with 5% stone dust

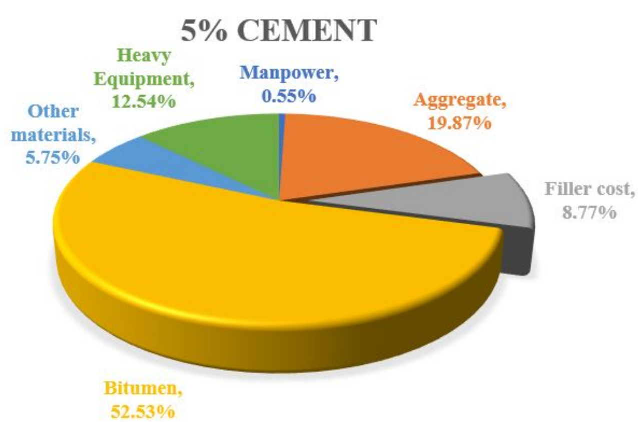

Figure 17: Cost contribution in different sub-heading for producing 1m^3 asphalt concrete with 5% cement

Figure 12,13,14,15,16,17 represents the proportionate cost contribution under different subheadings for production of a unit asphalt concrete. It shows that a least contribution of 0.59% is made by manpower in cost of asphalt concrete followed by fillers; stonedust and fly ash. A highest of around 55% cost contribution is made by bitumen followed by heavy equipment. The cost contribution of the stone dust in paving is least whereas maximum for cement fillers with 1.1% and 8.77% respectively. The cost contribution of the fly ash as the filler is nearly half of its proportion by weight (of the total mineral aggregate) i.e., 1.53%, 2.56%, 3.56% and 4.5% respectively for 3%,5%,7% and 9% fly ash content.

5. Conclusion

The work is conducted to study the effect of filler contents in mix of asphalt concrete along with the cost of unit paving of asphalt concrete. Marshall test is used to compare the properties of different mix. As for fillers, cement, stone dust and fly ash is used for comparison. The study concluded with following points as:

- With increase in fly ash content, Marshall stability increases and corresponding flow value decreases. This proves the stiffening effect due to fillers.
- When compared to the mix containing cement and stone dust as fillers, mix of fly ash usually more than 5% by weight of total mix behaves superior with respect to Marshall stability and flow value.
- Despite with higher amount of voids in mix of fly ash when compared to mix with stone dust, mix with fly ash shows higher stability. This supports the theory of chemical effects of fly ash in asphalt concrete that was put forward by Bautista et al. [16]
- Since, the cost of asphalt concrete with fly ash as the filler is less than that of cement as filler, fly ash is a better option economically to increase stiffness of mix herein Nepal.
- If we consider increasing stiffness and selecting a best economical mix, it would be recommended to use asphalt concrete with 7% fly ash fillers in the mix by total weight of aggregate in the mix.

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