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To Enhance Bitumen's Quality Using Waste Materials as Modifiers and Scope for Bangladesh's Road: A Review

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A B S T R A C T

The increasing demand for durable and cost-effective road infrastructure in Bangladesh calls for innovative approaches to pavement construction, especially in the context of environmental sustainability and economic constraints. This review explores the potential of utilizing waste materials—such as plastic, rubber, fly ash, and used engine oil—as modifiers to enhance the quality and performance of bitumen, the primary binding agent in road construction. By analyzing global research and case studies, this paper highlights how these waste-derived additives can improve the thermal stability, rutting resistance, fatigue life, and overall longevity of asphalt pavements. Simultaneously, the use of such waste materials offers an eco-friendly solution to Bangladesh's growing solid waste crisis, turning environmental liabilities into infrastructural assets.

The review also examines the suitability and adaptability of these modified bitumen technologies within the socio-economic, climatic, and engineering context of Bangladesh. It discusses implementation challenges, policy gaps, and the scope for integrating such practices into national road development strategies. Through a multidisciplinary lens, this paper advocates for a circular economy approach in road construction—one that blends engineering innovation with environmental responsibility and social impact. Ultimately, this study underscores the promise of waste-modified bitumen as a practical and sustainable pathway to improve Bangladesh's road infrastructure while fostering ecological stewardship.

Keywords: Bituminous pavement; Durability; Solid waste; Incineration; Landfills; Environment.

1. Introduction

Roads are more than mere pathways—they are lifelines of development, linking people to opportunities, markets, healthcare, and education. In Bangladesh, where rapid urbanization and economic expansion are heightening the need for durable and extensive road networks, the quality of construction materials, especially bitumen, plays a key role in ensuring the long-term resilience and safety of transportation infrastructure. However, the typical use of unmodified bitumen often falls short under the strain of heavy traffic loads, increasing temperatures, and monsoonal harm, leading to frequent upkeep, augmented costs, and travel interruptions.

Concurrently, Bangladesh is confronting a growing environmental dilemma: the accumulation of non-biodegradable waste like plastics, discarded rubber, industrial by-products, and used engine oils. These waste streams, if unaddressed, pose serious dangers to human health, aquatic ecosystems, and urban livability. In this dual crisis—one of degrading roads and mounting waste—lies a unique chance for innovation. This research embraces a human-centered approach to explore how waste materials, often viewed as societal burdens, can be transformed into valuable resources for enhancing bitumen quality. Pulling from global studies and regional insights, the review analyzes how these waste-derived modifiers can enhance bitumen's performance characteristics—such as elasticity, thermal resistance, and durability—while simultaneously contributing to environmental sustainability and cost efficiency.

Additionally, the paper assesses the practical scope of implementing these technologies within the socio-economic, climatic, and infrastructural realities of Bangladesh. It considers not just the engineering implications, but also the wider societal impacts—how waste-to-road technologies can support green development, lessen urban pollution, and encourage community involvement in sustainable practices. By joining technical innovation with environmental consciousness and social relevance, this research seeks to reimagine road construction in Bangladesh—not as a linear consumption of resources, but as part of a circular, regenerative process that advantages both people and the planet.

1.1 Scope of The Project

- Identify which waste materials are most effective for modifying bitumen in Bangladesh's hot-humid and flood-prone environment.

- Assess cost-efficiency, durability, and environmental impact compared to conventional materials.
- Explore policy and practical barriers to adopting these technologies in national road projects.
- Provide a framework for integrating community waste management with national infrastructure development.

2. Related Work

The concept of using waste materials in pavements has been done in long time ago. This concept of use waste plastic in Bangladesh in recent 2022. But it turns into costly. It was seen that 9% of plastic gave best results for pavement. Use of plastic in road, it may help in many ways like dispose wastes, good quality road, and pavement service life. The process was use plastic waste directly with the mixing. This result indicates that there was improvement in strength and performances. The results gave a new idea of plastic road.

This paper is divided in two stages. 1) Review previous works 2) Implementation in Bangladesh road sectors. Review previous works is done by look for all kind of works done on bitumen improvement or modifying. Finding their work process, tests procedures, mixing percentages, Optimum content, etc. Thereafter, the application on field tests, their performances, their results etc. After review previous works, find out the best way of implementing for Bangladesh.

Afia Adiba*1, Rafiuzzaman Sadi2 and Riyadul Hashem Riyad3 (2020) The bitumen content, bones and GGBS content were changed in suitable percentage to determine optimum bitumen content and average optimum bone and GGBS content. The design matrix was combined as such that only one parameter was variable and other parameters were fixed. The experiment result was that the stability and flow increased and decreased respectively to a considerable amount. [1]

Akhtar Hossain*, Tasaddik Khan, Jonayed Ahmed and Ashikuzzaman (2018) The mixes are tested to obtain optimum fly ash content. By fixing optimum bitumen content and fly ash content mixes are prepared to observe the effect of water submergence on compacted mixes where compacted mixes are submerged in water for 5, 10, 15 and 20 days. In this study, it is found that 25% fly ash and 75% stone dust by total weight of filler satisfy the mix design criteria for medium traffic condition. So, 25% fly ash by total weight of filler can be used as optimum. [2]

Ghazi G. Al-Khateeb* and Khaled Z. Ramadan (2014) Findings of the study showed that the rubber additive resulted in an increase in each of: the complex shear modulus value, the rutting parameter, the fatigue parameter, and the storage modulus (|G*|, |G*|/sin δ, |G*|sin d, and |G*|cos δ, respectively) of the asphalt binder. In conclusion, the rubber additive improved the rutting resistance as well as the fatigue resistance of the asphalt binder by increasing the complex shear modulus value and the storage modulus, and decreasing the phase angle. [3]

Harun-or-rashid, G, M & Islam, M. M. (2020) This problem can be reduced to a significant extent by using plastics in road construction. Most of constructed roads over here is bituminous road. In the construction of bituminous pavement, plastics, as well as construction debris, are being used in the form of aggregate and filler materials popularly [4]

I. M. Khan, S. Kabir, M. A. Alhussain, Feras F. Almansoor (2016) Low Density and High-Density Polyethylene and Crumb rubber were used as additions to base bitumen (PG 64-10). Complex modulus (G*) and phase angle (δ) obtained from Dynamic Shear Rheometer (DSR) are the basic perimeters used to evaluate the behavior of the binder in respect to rutting and fatigue cracking. It was concluded that Low Density Polyethylene (LDPE), High Density Polyethylene (HDPE), and Crumb Rubber (CR) modified binder showed significant improvement in rheological properties of the binder. [5]

John Mohammad Bhat1, Abhishek Sharma2, Nasir Ali3 (2020) This research we have used low density polythene (LDPE) in form of packets used in packing of various brands of milk. In dry form with aggregate. In this research detailed study is carried to check engineering properties of bituminous concrete. optimum binder content and optimum polythene content is derived using Marshall procedure. The OPC has been found 4%. At this percentage marshal stability value is maximum and marshal flow value is minimum. [6]

Kazami & Govardhana Rao (2015) Author have done test on waste materials of polythene, were he 5 to 11% waste plastic were mixed with bitumen (60⁄70) grade. The studies conclusively showed that the waste plastic materials could be incorporated as a binding agent for the construction of road low density polyethylene (LDPE) to extent of 9% sample was found to be the most effective binder proportion. [7]

M. G. Al-Taher1, Hassan D. Hassanin2, Mokhtar F. Ibrahim3 and A. M. Sawan4 (2018) This study investigates the effect of using silica fume (SF) as an additive to the binder on the behavior of asphalt mixes. The scope of the study includes the investigation of the properties of the asphalt mixes using different percentages of SF (2, 4, 6 and 8% by bitumen weight). Results indicate that, the optimum SF percentage is 6% by weight of bitumen which achieve the best results in Marshall, DC, ITS and WT tests. [8]

M. M. Islam1, M.S. Shirin2, T. R. Tonoy2, S. A. Sweet2 (2021) Among numerous ways of disposal of waste plastics, one can be using it in flexible pavement construction. According to the Bangladesh Waste Database 2014, Dhaka city alone produces 25.44% (5,925.51 tons/day) of waste, of which 8.45% is plastic.

Due to the addition of plastic waste, the ductility always gets affected. But overall, a significant improvement in the properties of bitumen is noticeable. [9]

Nuha S. Mashaan (2022) Along these lines, in this work, nano-silica with a content from 2% to 8% and an increment of 2% was utilized in modifying the bitumen binder. Interestingly, much of the content of nano-silica leads to higher rutting resistance. However, the rutting resistance was affected by the size of the nano-silica coated with the silane coupling agent. [10]

Olumide Moses Ogundipe a*, Emeka Segun Nnochiri b, (2018) The Marshall test results show that the stability increases with increasing glass filler up to 18%, although the values were lower than that of asphalt concrete without waste glass. This implies improved resistance to fatigue for higher waste glass content. Also, the flow increases with increasing glass filler, which implies the resistance to permanent deformation did not improve. [11]

Rumpa Chowdhury (2021) This study examines the effects of using fly ash from medical waste incineration (MWIFA) in the bituminous mixture as mineral filler as an alternative to conventional filler. Marshall samples were prepared with varying filler ratios of 0%, 2%, 4%, 6%, 8%, and 10% to determine optimum bitumen ratios and investigate engineering properties.

The optimum filler contents for MWIFA and SD fillers are found at 5.5% and 9% filler percentages, respectively. The bituminous mixes with 5.5% MWIFA as mineral filler would give better performance in wearing actions, whereas mixes with 9% SD filler will exhibit the same performance. [12]

R. H. Riyad1, A. Amin2, R. Sadi3, M. A. Hasan4, M. K. Bhuiyan5 (2021) Outcome of this research, Air Void Value (for mixing ratio of 4% bitumen,10% bones,10% Fly Ash and 10% GGBS maximum air void is 4.929%) of almost all samples are lower than standard value which means it makes the roadway surface more impermeable. As the filler materials are increased, the value of VMA is decreased (for 5.5% bitumen, 10% bones, 10% Fly Ash and 10% GGBS minimum VMA value is 11.25%). The flow values (for 4.5% bitumen,5% bones,10% Fly Ash and 10% GGBS minimum flow value is 2.99). [13]

Soyal (2015) Author states that addition 1%, 2%, 3%, 4%, 5% by weight of processed plastic for the preparation of modified bitumen. Polythene waste which 4% is showing better performance as compared to other mixes. Marshal stability value increase with 4% polythene waste. [14]

Sepehr Saedi 1, Seref Oruc 2 (2020) The current study investigates the effects of Fiber Reinforce Polymer (FRP) additive on the performance of Stone Mastic Asphalt (SMA) mixtures with SBS and Viatop Premium additives.

The asphalt mixture used in the current study included SBS (Styrene-Butadiene-Styrene) additive modified at the rate of 5% according to the necessary preliminary studies, and some SMA mixture modified by adding FRP (Fiber Reinforced Polymers) additive prepared in dimensions of 5 cm in different proportions (0.3%, 0.5%, 0.7% and 0.9%). The FRP contribution rate that improves the performance characteristics of the SMA mixture to the highest level was found to be 0.7%. [15]

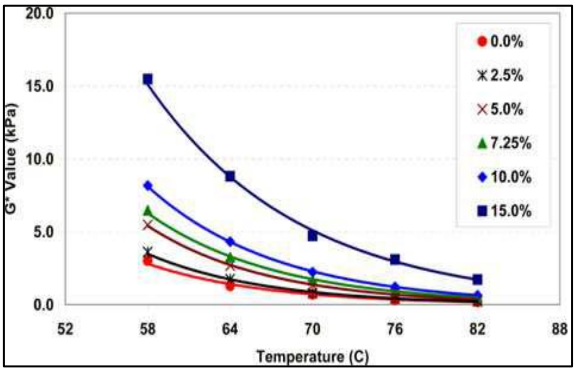
3. Methodology

1. **Literature Search:**
   - Conducted searches on Scopus, ScienceDirect, Google Scholar, and SpringerLink.
   - Used keywords like “bitumen modification,” “waste materials,” and “Bangladesh roads.”
2. **Selection Criteria:**
   - Included studies using waste materials as bitumen modifiers.
   - Considered papers reporting improvements in bitumen properties.
   - Focused on research relevant to Bangladesh’s climate and road conditions.
3. **Data Extraction:**
   - Extracted details on waste types, modifier dosages, testing methods, and performance outcomes.
   - Compared effectiveness of different waste modifiers.
4. **Scope Analysis for Bangladesh:**
   - Reviewed availability of waste materials in Bangladesh.
   - Analyzed current road construction practices and environmental policies.
   - Assessed economic feasibility and practical application in local context.

4. Experimental Results Review

Table 1 Penetration Result [1]

Bones (%)	Penetration Result	GGBS (%)	Penetration Result
5	67.33	5	65
10	63.68	10	64.33
15	63	15	65.68



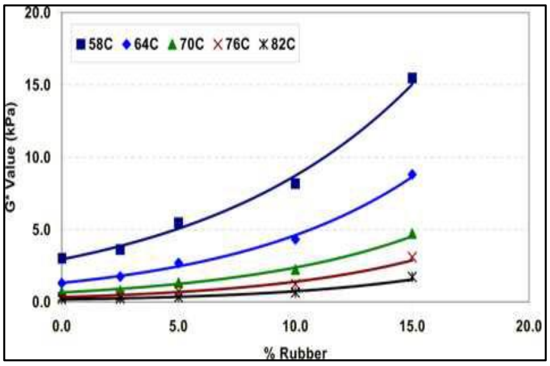


Fig 1 |G*| Value versus Temperature for Rubber- modified Asphalt Binder [3]

Fig 2 Percentage of Rubber versus |G*| Value [3]

In Fig 1 the| G *| value dropped with the increase in temperature with advanced values at advanced rubber chances and lower values at lower rubber chances. The rate of drop in the| G *| value with the increase in temperature was advanced at lower temperatures and advanced rubber chances than the rate at advanced temperatures and lower rubber chances as shown in the same figure.

In Fig. 2 the| G *| value increased with the increase in rubber chance with advanced values at lower temperatures and lower values at advanced temperatures. The rate of increase in the| G *| value with the increase in rubber chance was advanced at advanced rubber chances and lower temperatures than the rate at lower rubber chances and advanced temperatures as shown in this figure.

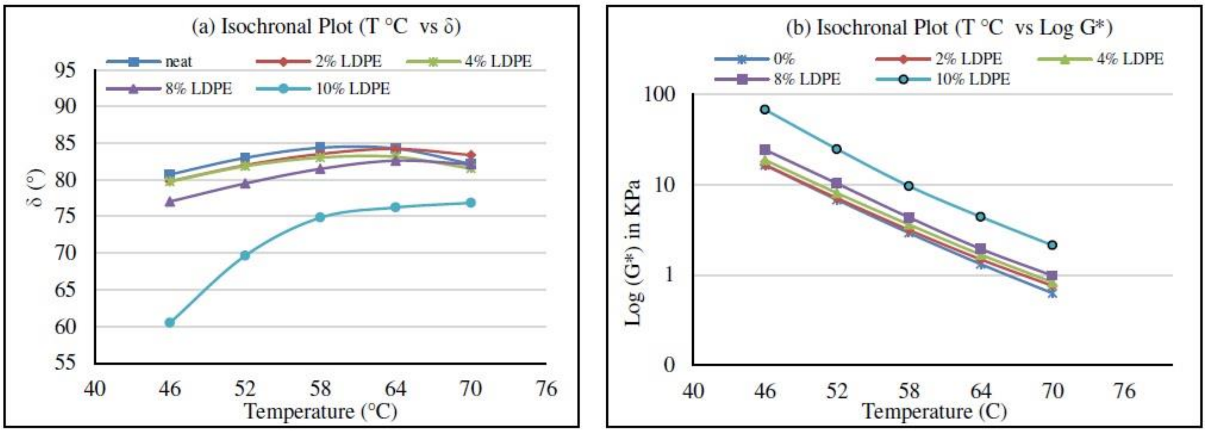


Fig 3 Isochronal plots (a) Relationship between temperature and phase angle and (b) Relationship between temperature and complex modulus for LDPE-MB [5]

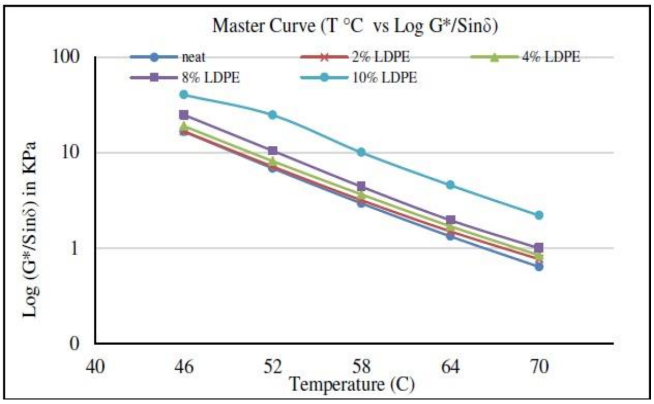


Fig 4 Influence of temperature on rutting perimeter for LDPE-MB [5]

The stage point(δ) has an reverse relationship with the flexibility of the folio, a moo esteem for the stage point shows that the folio is more versatile and less vulnerable to the products of temperature. It was set up from the isochronal plots, seen in figures 3(a) and(b), that as the chance of LDPE increments, the esteem of the stage point diminishes broadly, which shows advancement in the execution of the cover altered with LDPE, in terms of its flexible behaviour.

It was moreover found from the ace bend, seen in Figure 4 that the rutting edge increments with expanding rates of LDPE. At a temperature of 70°C, the flawless cover, 2%, 4% and 6% LDPE-MB do not meet the least prerequisites of Super-Pave, which is G*/Sinδ >1KPa; as it were the 10% LDPE-MB meets the least prerequisites. Be that as it may, at 64°C, the slick folio, as well as all levels of LDPE-MB, meet the prerequisites and there is impressive increment in rutting edge for LDPE-MB particularly at 10% LDPE.

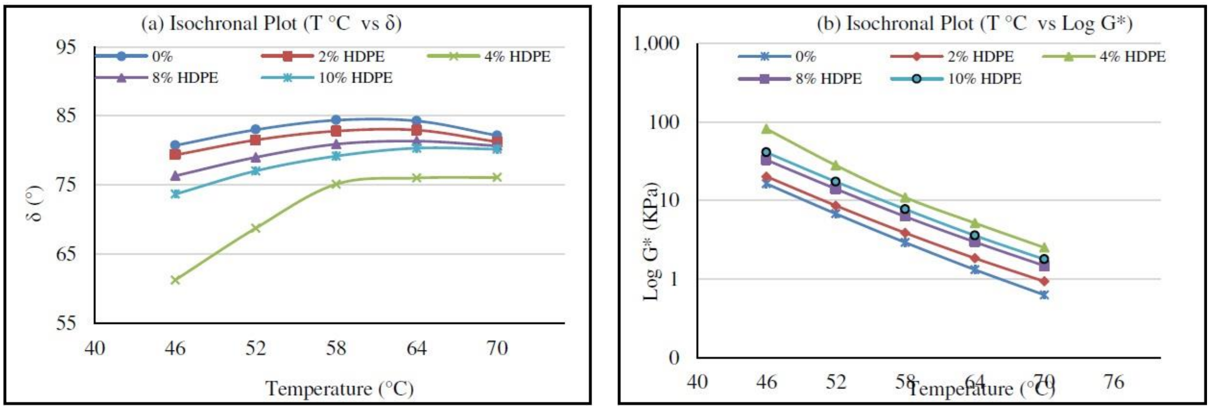


Fig 5 Isochronal plots (a) Relationship between temperature and phase angle and (b) Relationship between temperature and complex modulus for HDPE-MB [5]

It was found from the isochronal plots seen in Figures 5 (a & b), that the 4% HDPE-MB delivered the best comes about in terms of least stage point and most extreme complex modulus values compared to the slick bitumen, as well as the 8% and 10% HDPE-MB. This implies that including HDPE in rates higher than 4% makes the cover more gooey and less flexible.

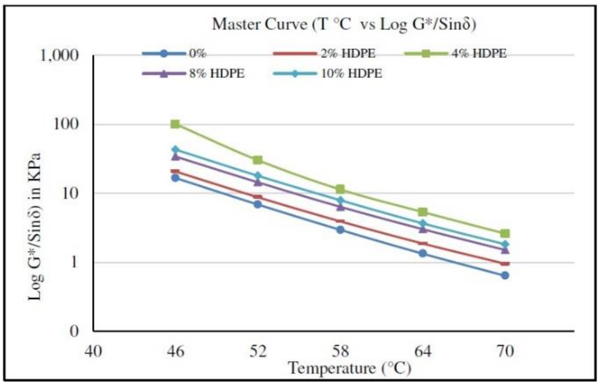
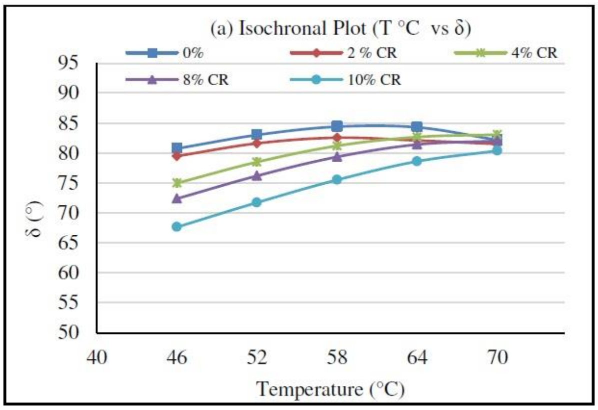


Fig 6 Influence of temperature on rutting perimeter for HDPE-MB [5]

The ace bend, seen in Figure 6, shown that slick bitumen and 2% HDPE-MB do not meet the least prerequisites of Super Pave at a temperature of 70°C. In addition, the 4% HDPE-MB delivered the ideal esteem for rutting border at all temperatures. In this manner, it was found that the expansion of LDPE makes strides the execution of cover against rutting and splitting.



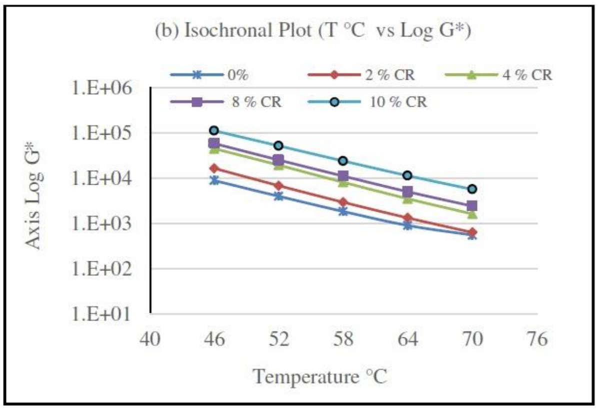


Fig 7 Isochronal plots (a) Relationship between temperature and phase angle and (b) Relationship between temperature and complex modulus for CR-MB [5]

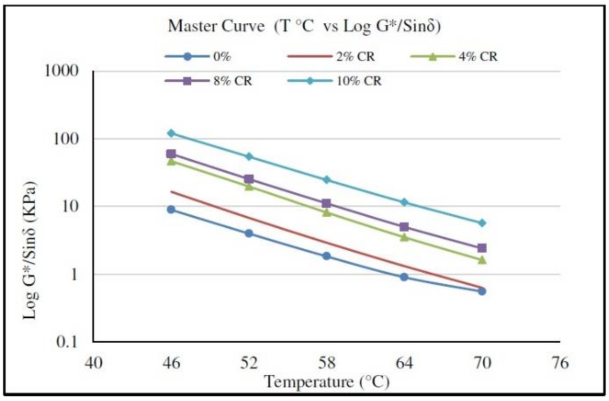


Fig 8 Influence of temperature on rutting perimeter for CR-MB [5]

It was set up from the isochronal plots (Figures 7 a & b) that the 10 CR- MB conveyed the a la mode comes approximately in terms of slightest organize point and most extreme extraordinary complex modulus values at all temperatures. Subsequently, it was set up that the rigidity of the folio supplements astonishingly with the development of piece versatile to indefectible bitumen. moreover, it can be seen from the pro twist (Figure 8) that the indefectible bitumen and the 2 CR- MB do n't meet the slightest musts of Super Pave(G */ Sinδ> 1KPa) at the most lifted temperature of 70 °C. In any case, at temperatures of 64 °C and lower, the CR- MB meets the slightest Super Pave musts. Consequently, it was set up that the extension of CR makes strides the indictment of folio against rutting and cracking.

Table 2 Data for Graph Plotting [6]

Polythene Content (%)	Unit weight (Gmb)	Mean VMA (%)	Mean VA (%)	Mean VFB (%	Mean S (KN)	Mean F (mm)
P0	2.312	16.309	4.976	69.501	13.34	3.766
P1	2.509	17.245	3.87	77.571	13.28	3.833
P2	2.281	18.447	3.096	83.28	13.55	3.4
P3	2.249	20.112	2.58	85.492	14.53	3.3
P4	2.208	22.087	3.17	85.639	16.71	3.4
P5	2.179	23.625	2.946	87.528	14.93	3.4

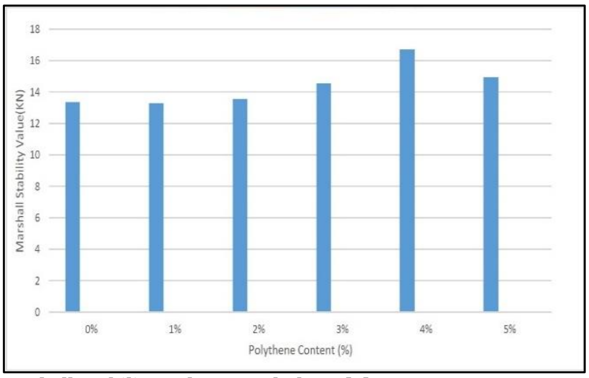


Fig 9 Marshall Stability Value vs. Polythene [6]

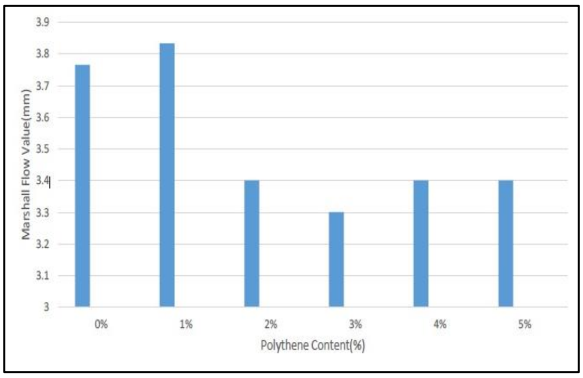


Fig 10 Marshall Flow Value vs. Polythene [6]

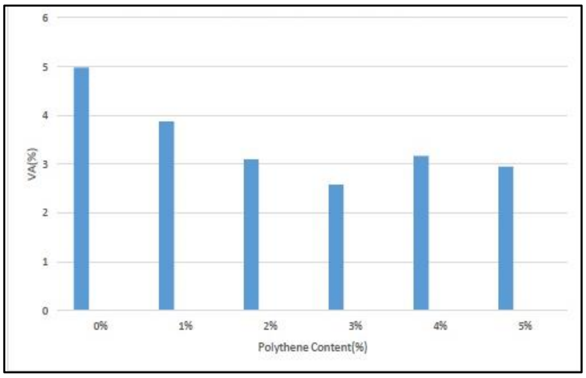


Fig 11 VA vs Polythene Content [6]

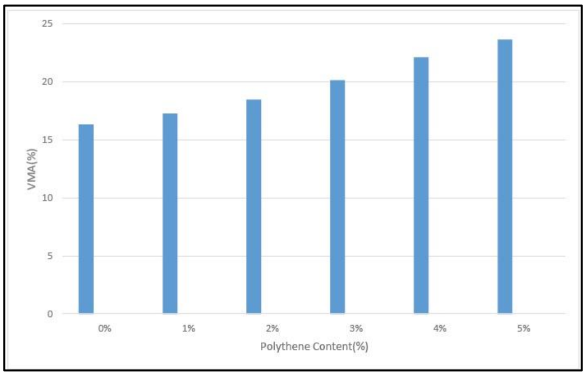


Fig 12 VMA vs. Polythene Content [6]

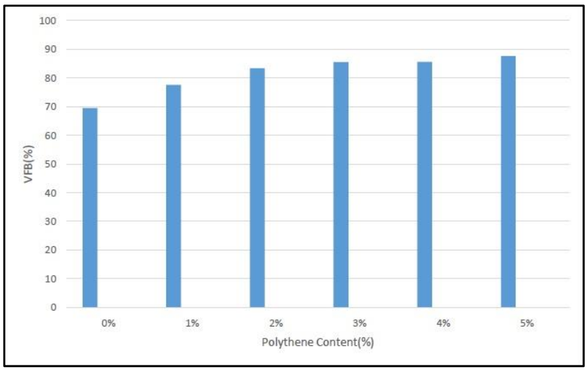


Fig 13 Polythene content VS VFB [6]

From fig 9 to fig 13 the properties of modified BC with polythene we got improvement in the marshal characteristics of mix compared with normal mix as under. Marshal stability values are enhanced up to polythene content of 4% thereafter any increase in polythene decreases the stability. On observing the results marshals' values decreases upon adding further polythene i.e. deformation resistance increases under heavy wheel loads. Parameters like VFB, VMA, VA are within required specifications.

Table 3 Composition of various samples [7]

Sample Type	Plastic (PE)	Bitumen	% of PE
A	2.1g	39.9g	5
B	2.94g	39.06g	7
C	3.78g	38.22g	9
D	4.66g	37.34g	11
E	0.00	42.00g	0

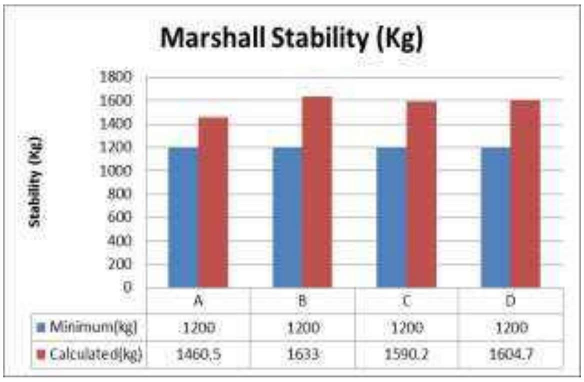


Fig 14 Stability data of various binder combinations [7]

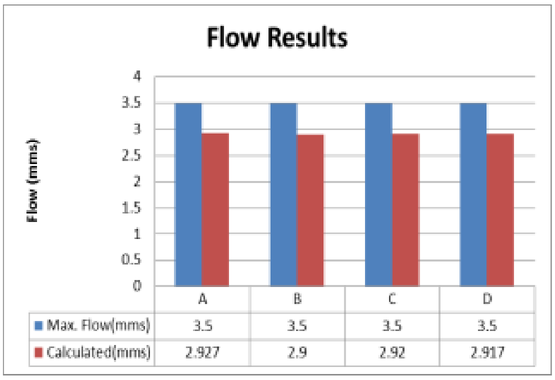


Fig 15 Flow data of various binder combinations [7]

Figures shows the results of Marshall Stability data & Flow data of various combinations by using waste plastic like A=5%, b=7%, C=9%, D=11% 7 E=0%. Results indicates that most suitable binder percentage was C with % of plastic waste

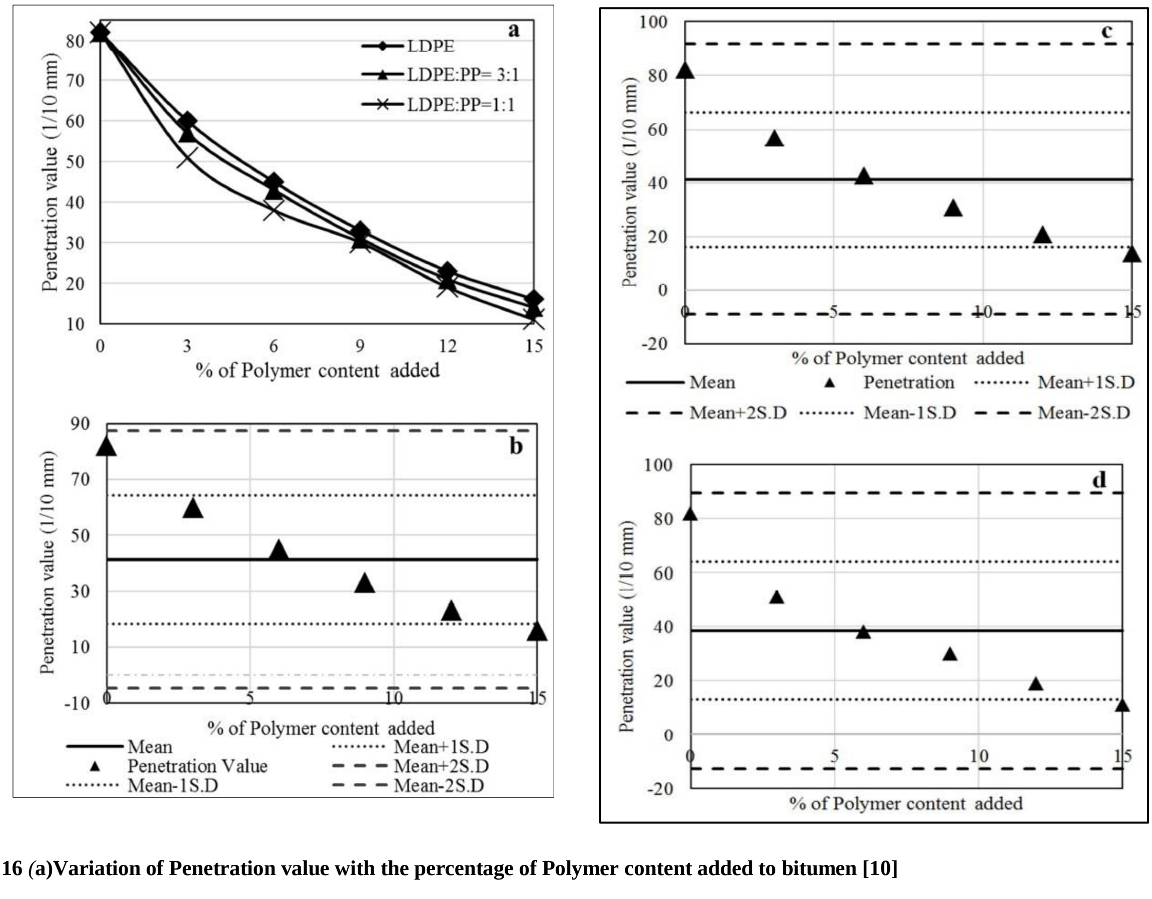


Fig 16 *(***a)Variation of Penetration value with the percentage of Polymer content added to bitumen [10]**

(b) Distribution of penetration value around the mean for LDPE

(c) Distribution of penetration value around the mean for LDPE: PP=3:1

(d) Distribution of penetration value around the mean for LDPE: PP=1:1.

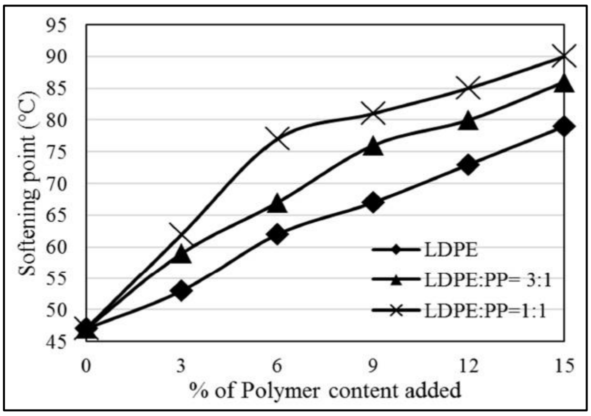


Fig 17 Variation of Softening point [10]

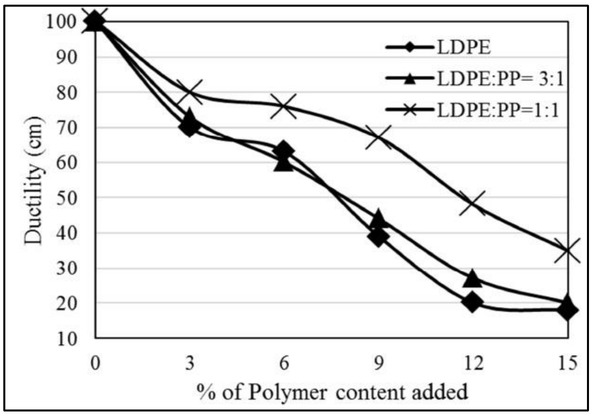


Fig 18 Variation of Ductility [10]

Figure 17 depicts the softening point increases with the increment of polymer content regardless of polymer type. Increment rate is high up to 9% of polymer the it gets slow down a bit. Here the result for LDPE: PP=1:1 is remarkably high. For LDPE: PP=1:1 the softening point increased by 1.91 times of virgin bitumen whereas the result for LDPE: PP=3:1 and LDPE are also phenomenal. Here the highest value of softening point of PMD found is 90°C whereas it's for VB (Virgin bitumen) is 47°C. The result clarifies that the use of mixed plastic polymer results to a satisfactory softening point.

Figure 18 depicts that the ductility decreases with the increase of polymer content at a high rate up to 3% of polymer content. Higher decrease in ductility may make the bitumen unfit for use. So, the selection of optimum polymer content to modify bitumen should be determined on the basis of the result of ductility. From the result it is clear that for LDPE: PP=1:1 the optimum polymer content could be 9% but for LDPE & LDPE: PP=3:1 it should not be more than 6%.

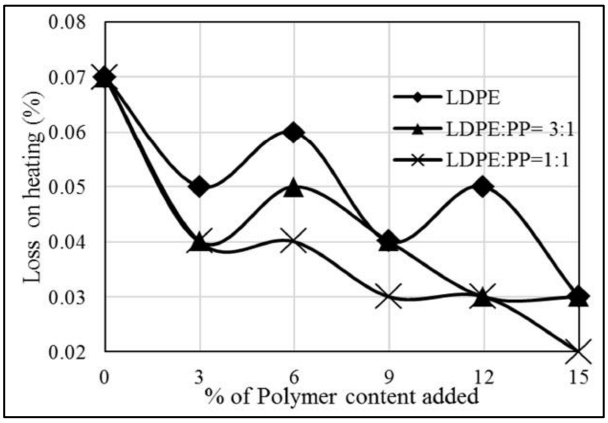


Fig 19 Variation of Loss on heating [10]

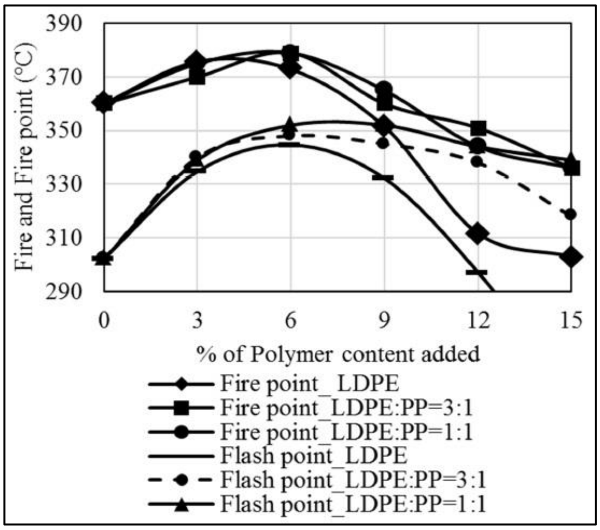


Fig 20 Variation of flash and fire point [10]

The results in Figure 19 portrays that the Losses on heating decrease with the addition of polymer content. But the change is not uniform.

Figure 20 that the flash and fire point increases with the increment of polymer content up to a certain level then decreases. Optimum level of polymer content is around 6%.

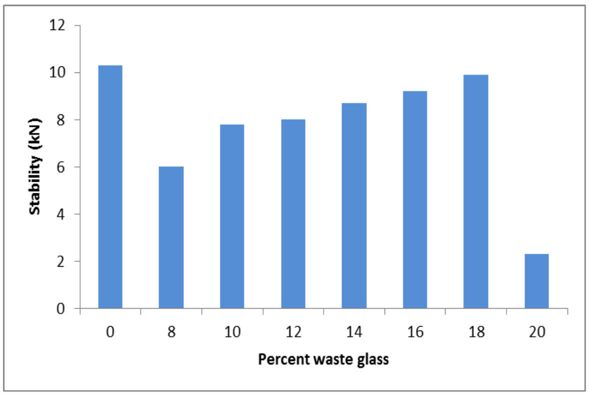


Fig 21 Stability of the asphalt concrete

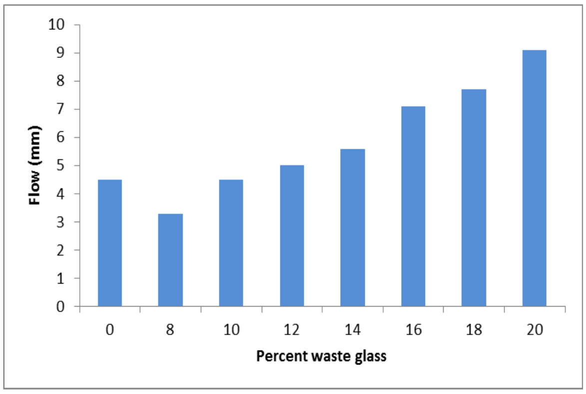


Fig 22 Flow of the asphalt concrete

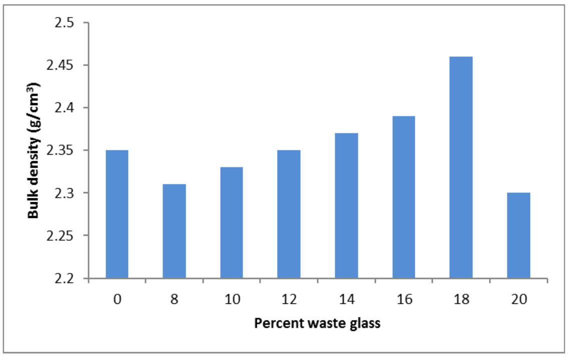


Fig 23 Bulk Density of the asphalt concrete

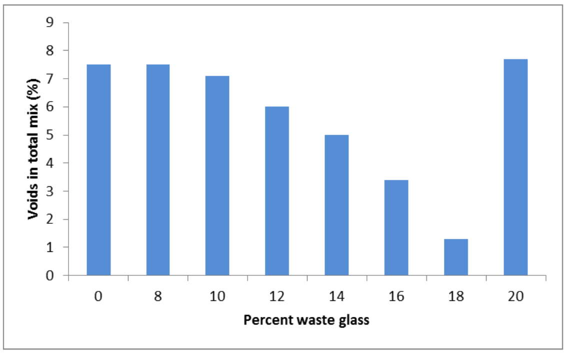


Fig 24 Voids in the total mix of the asphalt concrete

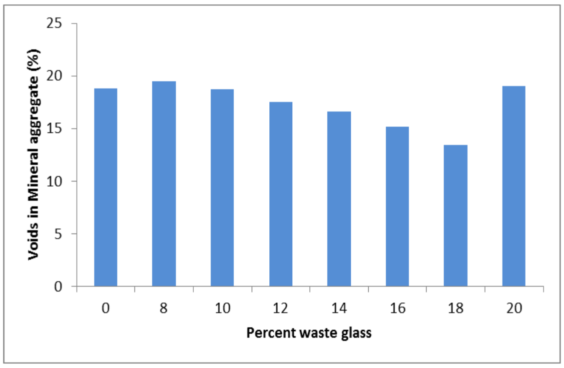


Fig 25 Voids in mineral aggregates for the AC

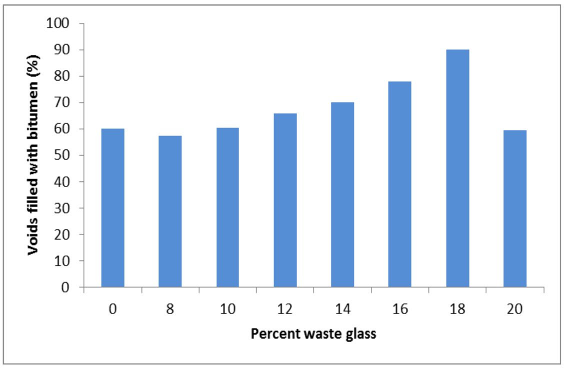


Fig 26 Voids filled with bitumen for the asphalt concrete

Figure 21-26 the mixed results indicate that further studies are required on the glass gradation, the percentage required in the mix, the replacement of aggregates certain sizes or filler completely with the waste glass. The introduction of waste glass in the asphalt concrete is environmentally friendly and it will aid the sustainable management of waste glass. [11]

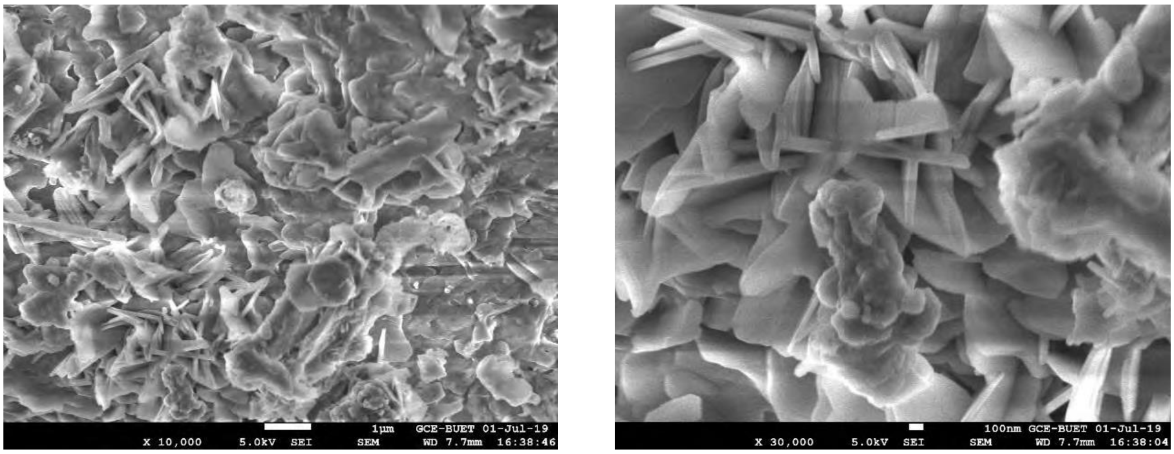


Fig 27 SEM images of fly ash filler from medical waste incineration

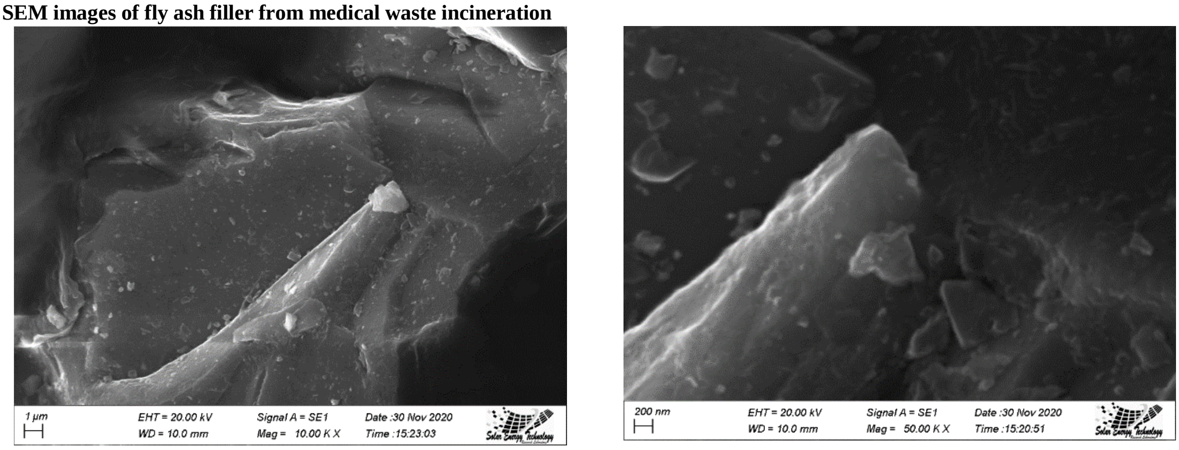
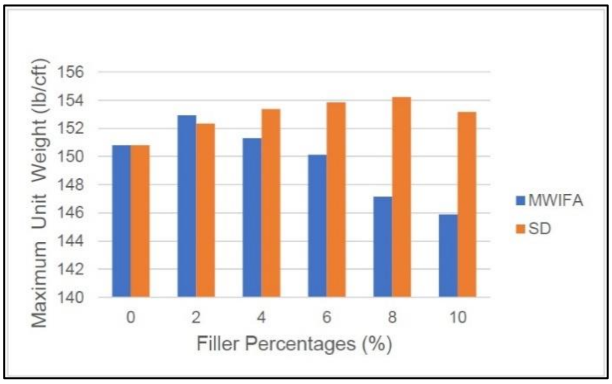


Fig 28 SEM images of stone dust filler



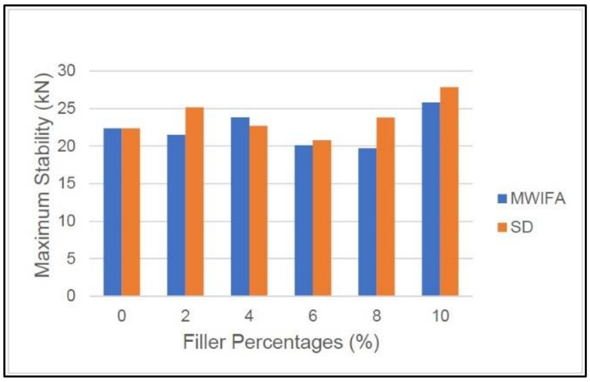


Fig 29 Effect of medical waste incineration fly ash and stone dust fillers on maximum unit weight

Fig 30 Effect of medical waste incineration fly ash and stone dust fillers on maximum Stability

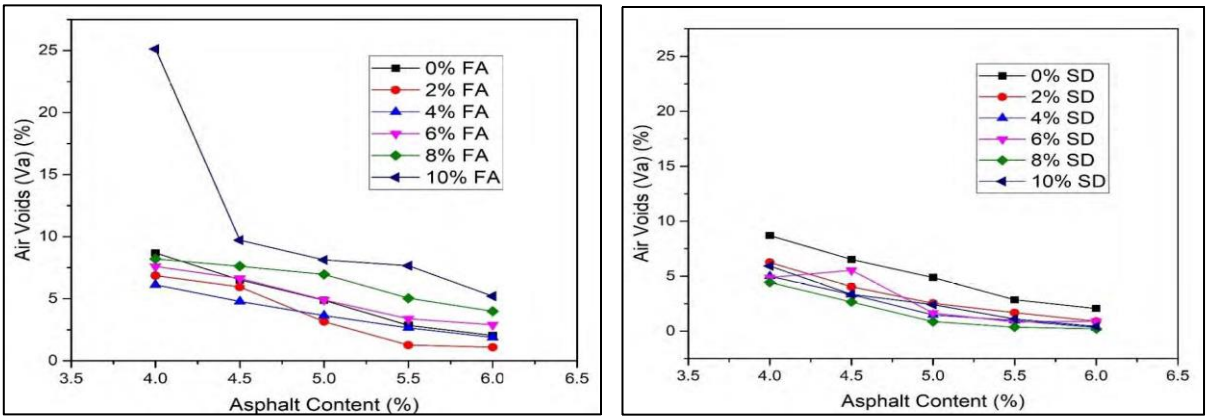


Fig 31 Effect of medical waste incineration fly ash and stone dust fillers on Air Void (Va) % [12]

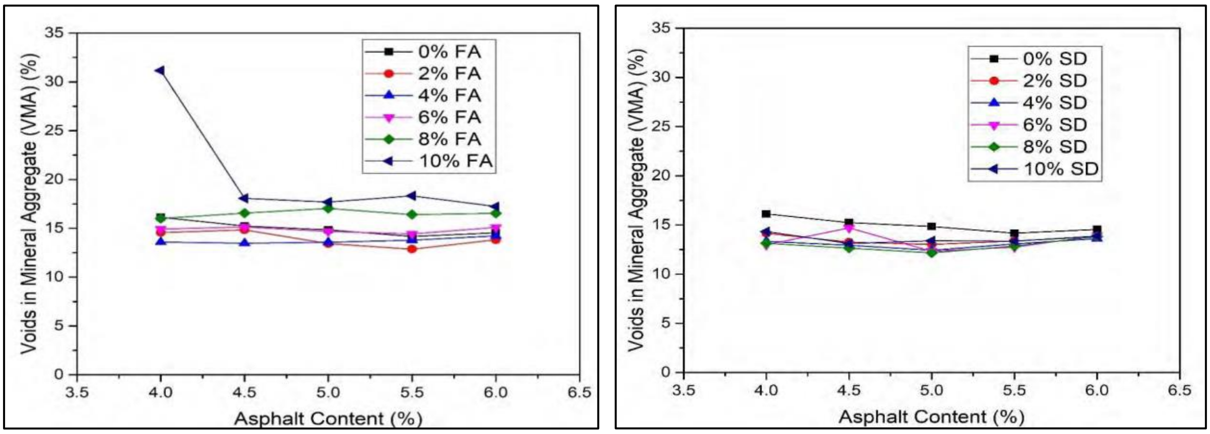


Fig 32 Effect of medical waste incineration fly ash and stone dust fillers on VMA [12]

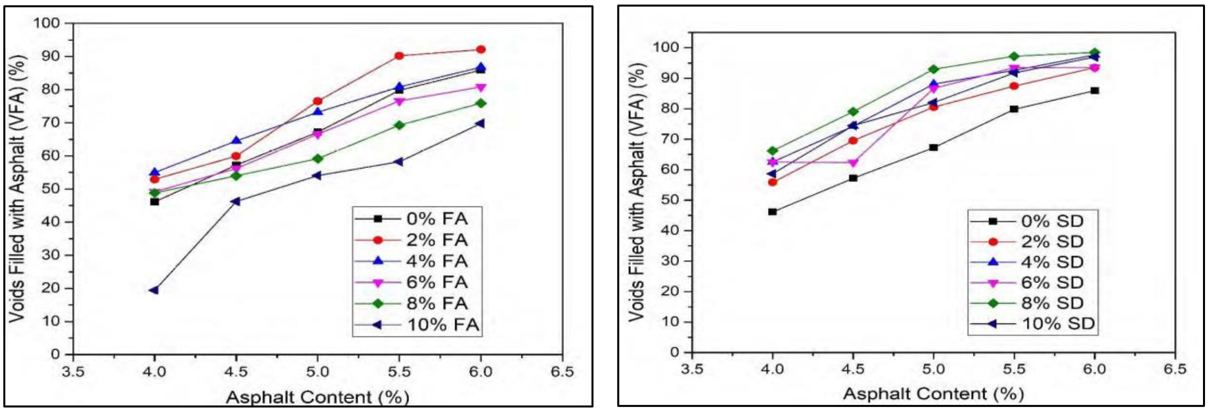


Fig 33 Effect of medical waste incineration fly ash and stone dust fillers on VFA [12]

Figure 31-33 shows: For SD filler, maximum stability decreases up to 6%, then increases up to 10% and shows the highest stability of 27.82 kN at 10%. The highest stability for both fillers is found at 10% filler percentage.

There is no significant difference between mixtures with MWIFA and SD fillers for the Marshall flow parameter.

There is no significant difference between all mixtures for this parameter, but the MWIFA filler shows slightly higher values than the SD filler.

The differences between all mixtures for this parameter are insignificant, but MWIFA filler displays slightly higher VFA values than SD filler.

The higher % of stability loss MWIFA filler shows more moisture resistance than SD filler.

Table 4 Physical Properties of Modified Blend [14]

Physical Properties of Modified Blend properties	P0 0% plastic	P1 1% plastic	P2 2% plastic	P3 3% plastic	P4 4% plastic	P5 5% plastic
Softening Point (ºC)	47.5	50.0	51.4	53.0	55.0	55.9
Penetration Value (mm)	65.0	55.0	50.0	48.5	46.0	44.0
Ductility (cm)	100	100	90	85	78	56
Flash & Fire Point (ºC)	>280	>350	>350	>350	>350	>350

Table 5 Marshall Stability and Marshall Flow Value [14]

Sample	Msv (kn)	Flow(mm)
P0	14.3	2.31
P1	14.2	2.30
P2	14.5	2.28
P3	15.5	2.25
P4	17.7	2.21
P5	15.9	2.18

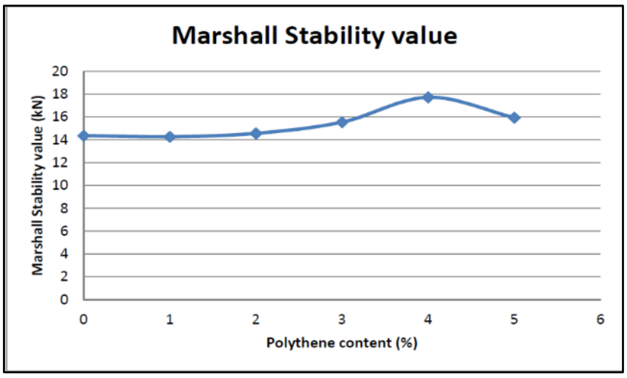


Fig. 34 Msv vs Polyethylene Content [14]

Table 4 shows the values for physical properties of Polythene Modified Bitumen tested through experiment. The effect of polyethylene admixture on the volumetric properties of both modified and conventional bituminous mixes are shown in table 4 & figure 8 below It shows that suitable plastic waste percentage is about 4%

5. Conclusion & Recommendations

After the analysis of below results it'll be observed that waste material could be a modifier for bitumen. It enhances and change the property of the bitumen. Bitumen gain some changes which can helpful now a days when the temperature in the world rising day by day.

Addition of plastic waste to bitumen, it improves the continuity, inflexibility and resistance to wear and tear.

Addition of rubber make the pavement descent resistance, increase water resistance, heat resistance. But it also makes bitumen harden that causes cracks.

Fly ash set up form coal combustion or waste burning. It can use as padding accoutrements of the pavement. Other dust accoutrements like bagasse ash, marble dust, gravestone dust, slipup dust, kiln dust, waste concrete dust, foundry beach can be alternate of regular padding of the pavement. It'll be cost effective depend on their vacuity.

Using waste accoutrements as modifiers is veritably helpful for any country for operation waste accoutrements in different ways without harming public health, water bodies, rainfall, and lands

6. Recommendations

- Adopt Waste-Based Bitumen Modifiers in Road Projects

- Conduct Pilot Projects in Bangladesh
- Develop National Guidelines and Standards
- Promote Research and Innovation
- Ensure Environmental Compliance
- Public Awareness and Stakeholder Training

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