International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 06 | Jun 2022 www.irjet.net p-ISSN: 2395-0072

Effect of plastic waste particle size on the performance of asphalt concrete

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Abstract – *Plastics are used in various industries for varied purposes. With rapid urbanization this use is continuously increasing, with this increase is important to find sustainable ways to use and discard plastic waste. This study focuses on the impact of plastic waste particle size on the performance of plastic waste modified asphalt bituminous concrete. The various parameters analyzed are, Marshall stability, flow and Marshall Quotient for different percentages of plastic wastes (2,4,6,8 and 10%) . The plastic waste particles were classified into two categories i.e. coarse and fine graded plastic waste and the properties of these were compared to give the results. Through the results of all the parameters it was inferred that using fine graded plastic waste particles leads to overall enhancement in the strength and durability characteristics of the mixtures.*

***Key Words*: Marshall stability, flow, Marshall Quotient(MQ), Fine Graded (FG) and Coarse Graded (CG) plastic particles.**

1. INTRODUCTION:

The use of plastic in road construction is now being done for quite some time. There is sufficient research available on various types of plastics used as modifiers for pavement and their impact on various engineering properties of the bituminous concrete. The various methods used for preparing plastic waste modified asphalt bituminous concrete are as follows:

1.1 Dry process

In the dry process the plastic is used as binder to the bituminous mix. In this process Plastic is mixed with hot aggregate at 170°C which coats the aggregate on which hot bitumen is added to form the plastic bitumen aggergate mixture.

There are four steps in this process:

a) Collection of waste plastic

b) Cleaning and shredding of waste plastic

c) Mixing of shredded waste plastic, Bitumen and aggregate at central mixing plant

d) Laying of bituminous mix

1.2 Wet process

In the wet process plastic is used as a modifier to the bituminous mix. In this process the plastic is mixed to hot bitumen, which is followed by mixing with hot aggregate. This process is not used as widely as the dry process.

2. MATERIALS AND METHODS USED:

2.1 AGGREGATE:

In this study crushed quartz aggregate were used. Various laboratory experiments were performed which include the cleanliness, Grain size distribution, Bulk specific gravity, Los Angeles Abrasion, flakiness and elongation index, impact strength and water absorption were carried out which have been shown in tabular form in table 2.1.

Figure 2.1 Aggregate testing

Test parameters	Test results
Cleanliness (Dust) (%)	3
Bulk Specific gravity (g/cm3)	2.68
% wear by Los Angeles abrasion	10.6
% Soundness loss by Na_2SO_4 solution	3.4
% Soundness loss by $MgSO_4$ solution	3.7
Flakiness & elongation index -20mm -10mm	 27.93 32.13
Impact Strength (%) -20mm -10mm	 4.15 5.91
Water absorption	1.67

Table 2.1 Properties of aggregate

2.2 Bitumen

VG-30 grade bitumen was used in this study. The binder properties were assessed by carrying out flash point, penetration, softening point, solubility, viscosity and specific gravity.

Figure 2.2 Bitumen testing

Test parameters	Test results
Flash point, Cleveland open cup, °C, Min	304
Absolute viscosity at 60°C poises	2855
Kinematic viscosity at 135°C cSt, Min.	392
Penetration at 25°C, 100gm, 5sec, 1/10mm, Min	49
Softening point (R&B), °C, Min	48
Matter Soluble in Trichloroethylene, % by mass, Min.	99.45
Viscosity ratio at 60 °C, Max	1.3
Ductility at 25°C, cm after TFOT min.	75
Specific Gravity gm/cc	0.987

Table 2.2 Properties of bitumen

2.3 Plastic waste :

The plastic waste was obtained and used in this study through the following procedure:

i) The waste plastic was collected from discarded drinking water bottles.

ii)The collected plastic waste was then crushed into finer particles using a specialized crusher.

iii)Plastic waste particles were sieved to check the effects of particle size.

iv)The particles passing through 2.36 mm sieve and retained on 1.18 mm sieve were used as Coarse graded (CG) plastic wastes and the particles passing through sieve 0.595 mm and remaining on sieve 0.295 mm were classified as Fine Graded (FG) plastic waste.

Test parameters	Values
Density (g/cm$^{3)}$	1.35
Moisture absorption (%)	0.2
Melting Point(°C)	240
Tensile strength	850
Coarse graded plastic waste (% passing) -2.36 mm -1.18mm	 100 5
Fine Graded plastic waste (%) - 0.595mm - 0.295 mm	 100 5

Table 2.3 Size distribution of plastic waste used

2.4 Preparation of specimens and mix design:

The bituminous concrete mixtures were prepared through dry process by the following steps:

i) The optimum binder content of the control mixture (without plastic waste) was found to be 4.5% by using the Marshall mix design method.

ii) The aggregates were heated for 4 hours and bitumen were heated for 150°C and 170°C respectively and then mixed for 5 minutes using a lab mixer.

iii)After this plastic waste waste was added and mixed until the aggregate and plastic waste were fully coated with the binder.

This method was used to retain the plastic in its natural state (semi crystalline resin) with minimal changes to its shape and properties.

2.4.1 Marshall stability test :

The prepared mix was poured on cylindrical specimens of 67 mm thickness and 102 mm thickness and were compacted with 75 blows on each side. These mixes were then air dried for 4 hours and finally kept in a water bath at 60°C for 30 minutes prior to Marshall testing. The guidelines of ASTM D6927 2015 were adhered for the testing The following process was followed for Marshall testing:

i) Three specimens of each type of mix were prepared to investigate the effect of repeatability and mean results were computed along with standard deviation.

ii) The maximum load resistance and respective deformation were measured and recorded using a 100 kN load cell and a 50 mm LVDT with a data acquisition system at a constant strain rate of 50.4 mm/min. The results were reported as Marshall's Stability, Flow and Quotient.

3 Results and discussion

3.1 Volumetric properties

The volumetric properties are the most important parameters for evaluating the performance of asphalt bituminous concrete. In this study various properties like air void content (V_a), Voids Filled with Asphalt (VFA), Voids in mineral aggregate (VMA) were analyzed and their variation with different contents of plastic waste were compared to completely understand the performance of plastic waste modified asphalt bituminous concrete.

Mixture	Plastic content % (by weight of bitumen)		Binder Content (%)	Air Voids Content (%)	VMA(%)	VFA(%)
	Coarse Grade	Fine Grade				
Control	0		4.5	4.15	13.29	68.787
CG-2	2		4.5	4.256	13.526	68.550
CG-4	4		4.5	4.362	13.756	68.312
CG-6	6		4.5	4.468	13.985	68.075
CG-8	8		4.5	4.574	14.215	67.837
CG-10	10		4.5	4.68	14.445	67.599
FG-2		2	4.5	4.28	13.547	68.431
FG-4		4	4.5	4.41	13.798	68.077
FG-6		6	4.5	4.54	14.049	67.720
FG-8		8	4.5	4.67	14.299	67.366

Table 3.1 Volumetric properties and proportions of mixtures

The following observations can be made through the results of volumetric properties:

i) The air void content and VMA increases with the increase in plastic waste content. This is because of decrease in binder to fill the voids as it is consumed for coating the plastic waste. Another reason is due to the elastic deformation of plastic waste particles under compaction effort.

ii) The air void content and VMA of combinations containing fine graded plastic waste are higher than those containing coarse plastic waste.

3.2 Marshall stability:

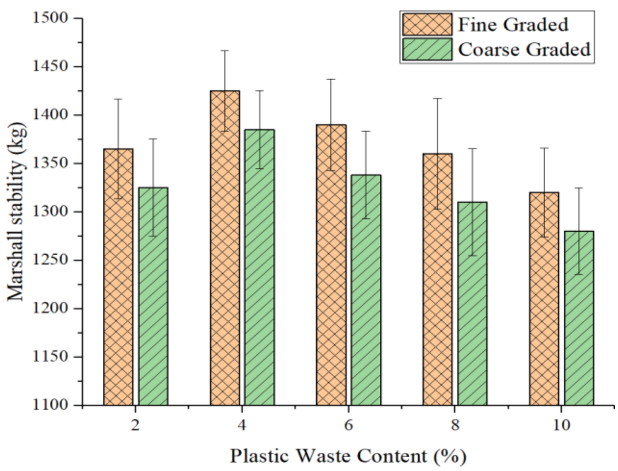

Figure 3.2 Effect of plastic waste on Marshall Stability

The effect of plastic waste on Marshall stability can be summarised as follows :

a) The Marshall Stability (MS) for both fine and coarse graded plastic wastes increases with increase in plastic waste content upto 4% beyond which the MS values start decreasing with increasing plastic content.

b) The plastic waste was added to the mixture at the final stage of mixing the aggregate with the binder, this results in preserving the semi crystalline nature of plastic waste in the mixture and thus we see the increase in MS values.

c) From the results it is clear that the stability of Fine Graded(FG) plastic waste is more than Coarse Graded plastic waste this is due to the shape of the plastic waste particles. The FG plastic waste particles are uniform in shape and are mostly flat which results in low deformation under loading.

d) The FG plastic waste particles can be well distributed in the mixture as compared to the CG plastic waste particles, due to this reason they fill the voids easily and increase the stiffness of the mixture. The FG plastic particles also have low melting point due to which more crystalline part of the plastic remains in the mixture thereby increasing stiffness.

3.3 Flow

Flow is a measure of deformation resistance, and mixtures with a higher flow are more likely to deform under load. Mixtures with a low Marshall flow, on the other hand, are considered to be stiff and prone to cracking. Therefore, minimum and maximum flow are specified for bituminous concrete mixtures.

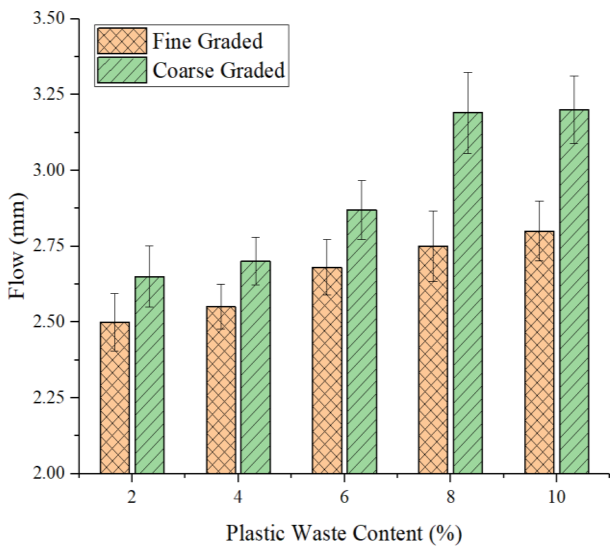

Figure 3.3 Effect of plastic waste on flow

The following results were found on the effect of plastic waste on flow values of the mixtures:

a) Marshall flow is reduced with increasing the plastic waste content of mixtures containing both fine and coarse plastic waste particles up to 4%, after which it begins to increase with increasing the plastic waste percentage of the mixtures.

b) It can be observed that, for any plastic waste content value for the mixtures containing fine plastic waste particles, and the mixtures containing up to 6% of coarse-graded plastic waste particles, the flow is lower than that of the control mixture with 0% of plastic waste content, indicating that inclusion of plastic waste increases the stiffness of the mixtures.

c) From Figure 3.3 it is clear that the flow of fine-graded plastic waste particle mixtures is lower than that of coarse-graded plastic waste particle mixtures.

3.4 Marshall Quotient (MQ)

Marshall Quotient is an indication of a bituminous mixture's resistance to shear stress and permanent deformation.

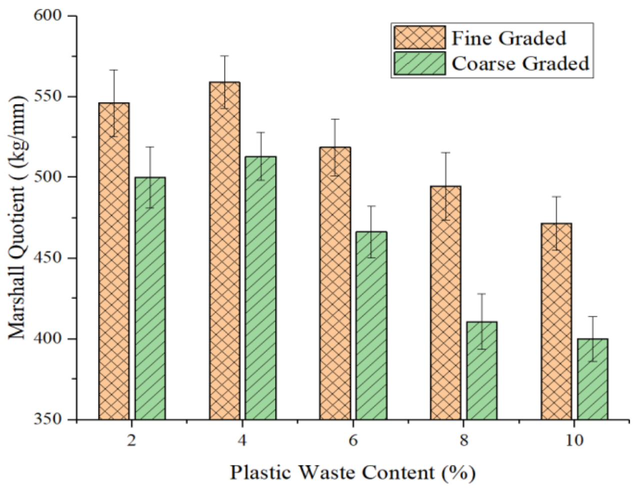

Figure 3.4 Effect of plastic waste on Marshall Quotient

a) The MQ for mixtures containing both fine and coarse graded plastic waste particles increases till 4% plastic waste content after which it starts decreasing with increasing plastic waste content.

b) The MQ for all mixtures except the one containing 10% plastic waste particles is higher than the control mixture .

c) Fine graded plastic waste mixtures have higher MQ as compared to the coarse plastic mixtures and the difference between the two keeps on increasing with increasing the plastic waste content.

4 Conclusion:

In this study, plastic waste particles of different two different sizes were mixed with bituminous concrete and various volumetric and engineering properties of the mixtures were analyzed. The results are as follows:

i)For both fine and coarse graded plastic waste particles, a similar pattern was observed , the Marshall stability and Marshall Quotient of the mixtures increased with increasing the plastic waste content up to 4 %, beyond this limit they start decreasing with increasing plastic waste content.

ii)At 4% plastic content the lowest flow value of mixtures is obtained.

iii) With the increase in plastic waste content the resistance to permanent deformation of bituminous mixtures increases.

iv) Overall, fine graded plastic waste particles are found to be more effective than coarse grained plastic waste particles for improving the properties of the mixtures.

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