Experimental Analysis of Polymer-Coated Aggregate in Comparison to Ordinary Road Material

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ABSTRACT: *Worldwide the broad usage of plastic has resulted in the massive production of plastic pollution, which is incinerated, and put in landfills and oceans. The technique of coating road aggregate with plastic has a good potential to deal with this global issue. The unique physical, mechanical and thermal properties of polymer offer effective binding, less moisture retention, and less susceptibility to void formation. This research will ultimately reflect plastic waste management and road enhancement. The main purpose of this experimental study is to predict and highlight the effect of varying plastic composition coating on an aggregate and select the best-performing sample. For this study, samples of polymer-coated aggregates of different ratios are created, and further tested for their enhancement in properties. To create polymer-coated aggregate, we have used recycled aggregates, Grade 70 bitumen, and polyethylene bags from waste. To coat the aggregates used the "dry-mix process". The effectiveness of the coating with varying plastic compositions was measured using seven different tests. It was hypothesized that incorporating plastic would enhance the properties of aggregate and increase the durability and workability of road materials. The test results supported the hypothesis. Standard ranges were used to perform a comparative study between polymer-coated aggregate and conventional aggregate. Nearly all tests' plastic compositions>8% and less than 15% have shown good results, but the optimum value for all tests is achieved by a sample with 12% plastic coating. Although this study supports that plastic incorporation is a better idea to enhance the longevity of roads, more research is required to explore the underlying mechanism of plastic coating and its long-term outcomes.*

KEYWORDS: *Polymer coated aggregate; Road material; Waste plastic; Bitumen; Moisture absorbed; Polyethylene.*

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INTRODUCTION

Different strategies are developed to lower the rate of plastic pollution, such as regulating production and consumption, increasing the demand for recycled plastics, and utilizing waste plastic to create new products. Even though plastic is a useful product, its waste and resulting contamination have made its disposal an issue. One insightful approach to wiping out plastic from climate is to follow the 3R's expertise to reduce, reuse and recycle. Concerning plastic waste, many techniques like pyrolysis, recycling, and reusing have been thought of as wise techniques for waste management. But in the past decade, plastic waste, if incorporated into road construction, has proved to be a viable option for minimizing plastic waste [1, 2].

Plastic waste generated by different sectors can be a convenient raw material for road pavements shows studies. The temperature range for softening of plastic is usually between [110 °C – 140 °C], and no toxicity occurs when burnt at these temperatures softened plastics tend to form a film over the aggregate when laid over hot aggregate. The obtained polymer-coated aggregate seems to be a better pavement material, reveals the study. So in this research, use a polymer to create bricks of polymer-coated aggregates of different polymer ratios by weight and test their durability, strength, and mechanical properties like hardness, toughness crushing strength impact, and abrasion to predict their reliability for use [3, 4].

The first issue this study will tackle will be of managing plastic waste. Today observe that plastic is being utilized in every single thing we use. Its versatility has resulted in increased demand for plastic production, which has, in turn, caused massive plastic waste products, which have now been entitled as a global problem. Due to global climatic changes, plastic things separate into more micro pieces, and increasingly more plastic is coasting into the sea. And thus, the amount of plastic in water and the climate is expanding quickly, more specifically, microplastics. [4, 5]. Although at first it was thought that plastic pollution was a problem limited to oceans only, as in early times, plastic dumping in oceans was common, it is now evident that plastic is everywhere, including in the water, we drink, and the air we breathe. The waste plastic disposed of in oceans is deadly, harming marine life. An alarming quantity of plastic has been observed on the seashore shown in Fig. 1 (a). It indicates how much of the waste is already present in the ocean.

The second issue of significant concern in this study is the disintegration of roads. The environmental effects like heavy rain or high temperature can affect asphalt that may cause raveling cracking or other deformation inroads are shown in Fig. 1 (b). Also due to extra traffic loading deterioration of roads has been observed significantly. Deterioration of roads can increase safety concerns, and operability of road and affects the ease of travel. The most notable defects in the road encountered daily are potholes, cracks, and deformation in smooth paved roads, as shown in Fig. 1 (c). Road construction materials play a vital role in road deformation [5, 6].

In a world where the need for versatile material which deals with such issues is necessary, this idea of turning waste into a useful material will prove to be a great step towards waste management and road enhancement [7, 8]. Previously researchers have worked on modifying bitumen to improve its properties to offer better binding and resistance to impacts and crushing. Still, in this research, we have worked on modifying aggregates only, keeping the bitumen composition constant. The major objectives of this research are; to make use of waste plastic and abstain from dumping and incineration, which causes pollution. Recycling plastic waste by reusing it in a useful manner, coating it over the surface of aggregate, which is further used in road construction materials. To study the strength characterizations of Polymer-Coated Aggregate (PCA) itself and also with bitumen.

This research expects improvements in the following area once PCA is utilized successfully; plastic waste management, deformation of roads, cost-effectiveness, eco-friendly pavements, and reduction in toxicity. Strength will be enhanced enough to bear heavy loads without bleeding. Hardness will be high to bear abrasive effects. Toughness will increase to resist the damage caused by vehicle jumps. Affinity with water will reduce since voids will decrease with increasing plastic content. Durable enough to bear climatic changes and effects as binding will increase with the incorporation of plastic. The points are hypothetical statements that can only be proved using testing and correlating research data and analysis. PCA can be cost-effective if the polymer is used to enhance the binding properties. Lesser cost of raw materials as waste is being used. The polymer will be used as an alternative

Fig. 1: (a) Plastic waste on the seashore (b) Rutting of the road due to heavy load (c) Pothole formations on the road.

Fig. 2. Raw materials for PCA preparation.

to an anti-stripping agent. We believe such techniques will attract stakeholders from the global market. Doing pavements with recycled materials helps reduce the costs of using new construction materials and rehabilitation projects. Recycling waste material leads to an increase in the design life of pavements, fuel savings from smooth roads, and reduction of road damage. But this method is new in Pakistan; however, it will be a marvelous achievement to implement all the plastic waste in fixing roads [9, 10,14].

Raw materials and products

The production of polymer-coated aggregate is based mainly on three raw materials: waste plastic, bitumen, and aggregate which are easily and cheaply available, as shown in Fig. 2.

Plastics can be molded and shaped into anything from car bodies and washing-up bowls to sanitary wares and toothbrushes. Scientists have been searching for innovative ways to dispose of plastic without polluting the environment. According to modern research, 30 million tons of solid waste are produced, of which 9% are plastics. Every year, around 80 lac metric tons of plastic is found in the oceans, which is harming marine life, is deadly, and disturbing the food chain [11, 12]. Aggregates are coarse particles that are utilized in the industrial sector, mainly for construction. It is available in different forms like gravel, sand, and stones. New studies in science and design have made a few discoveries that will make aggregate much more valuable for people in the future. With more studies and continuous research regarding the enhancement of aggregates, its significance will keep on increasing. Bitumen is adherent in nature, black, and possesses a higher viscosity. There are several types and grades of bitumen. Mainly bitumen is used in road construction, where it is combined with aggregate in certain percentages to form bitumen concrete or Hot Mix Asphalt (HMA). It is assessed that the current world utilization of bitumen is roughly 102 million tons each year, and it's expected to increase if further bitumen applications are studied [13, 14].

There are two processes available for PCA creation, and these are the dry process and the wet process. In the wet process, the plastic is turned into waste powder or very fine particles and is mixed with bitumen, which makes the bitumen a Modified bitumen mix. For this project, we used the dry process as the project is concerned with improving the performance of aggregates in road laying. The dry process for the production of PCA is to coat the melted plastic over the aggregate and then add heated bitumen over it. [15, 16].

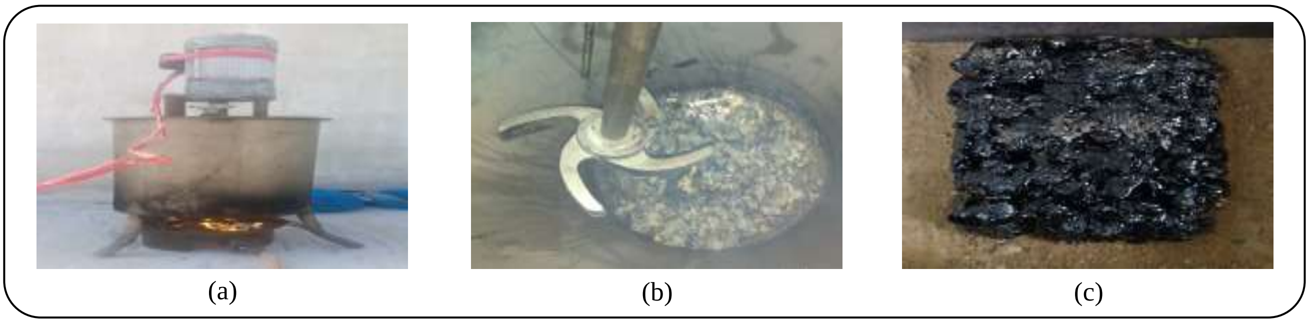


Fig. 3. (a) Reactor for PCA production (b) Agitator inside reactor vessel (c) Sample of PCA with bitumen.

EXPERIMENTAL SECTION

PCA is prepared in a pre-designed reactor to achieve the required temperature and agitating conditions. After preparing samples, they are tested to evaluate their performance.

Pre-designed equipment

This study worked on pre-designed equipment to get samples of polymer-coated aggregate. A reactor that has a cylindrical vessel which is made up of stainless steel, this reactor can do simultaneous heating and mixing. The vessel is the main component of the reactor, in which heating and mixing take place simultaneously of the aggregates and plastics. Continuous mixing was required to uniformly coat the molten polymer over the aggregate and uniform heat distribution. A high-power motor was supplied with the reactor for agitation. The motor's power was high because the raw materials were solid, and they needed continuous mixing. The shaft of the agitator was joined mechanically with the base of the motor. A temperature gauge was present on the lid of the vessel to measure the temperature of the mixture. In the equipment, the source of heating was a burner. The fuel for the burner was LPG, and it was located at the base of the vessel. The flame was controlled manually to control the temperature of PCA. The vessel was covered with a lid with a motor mounted on it. The minimum temperature required of the mixture is T = 100°C (the desired temperature is between 100 °C – 200 °C), the diameter D ≈ 0.45m, height H ≈ 0.75m, and the impeller is a curved blade impeller as shown in Fig. 3 (a, b).

Procedure

Firstly the aggregates of the required size are heated at around 180 to 200 ºC (plastic becomes soft and doesn't release toxic gases at this temperature. The shredded waste plastic is laid out over the hot aggregate in the reactor, and continuous agitation is done to achieve a uniform coating on aggregate, as shown in Fig. 3 (b). Temperature and heating must be controlled during the mixing. The plastic melts and gets coated completely over the hot aggregate within a few minutes, and PCA is obtained in the reactor. Then molten bitumen is added over it, bitumen-PCA mixture is obtained. Then pour the mixture into a mold that contains sand on its surface so that it does not stick, and mold it to achieve a brick-like shape, as shown in Fig. 3 (c). The process is repeated to create multiple samples. The process flow diagram for PCA production for road material is shown in Fig. 4 (a). PID of equipment used for PCA production is shown in Fig. 4 (b). The aggregate composition was kept fixed while the plastic composition was varied (between 5-15 %), as shown in Table 1. Consequently, the composition of bitumen also changed. The total weight of each sample is 890g, and the aggregate percentage in each sample is 75%.

Testing work

To find out the best proportion of plastic and to predict the viability of the material Polymer-Coated Aggregate (PCA) for road construction, seven tests were performed as mentioned in Table 2.

Marshall stability test

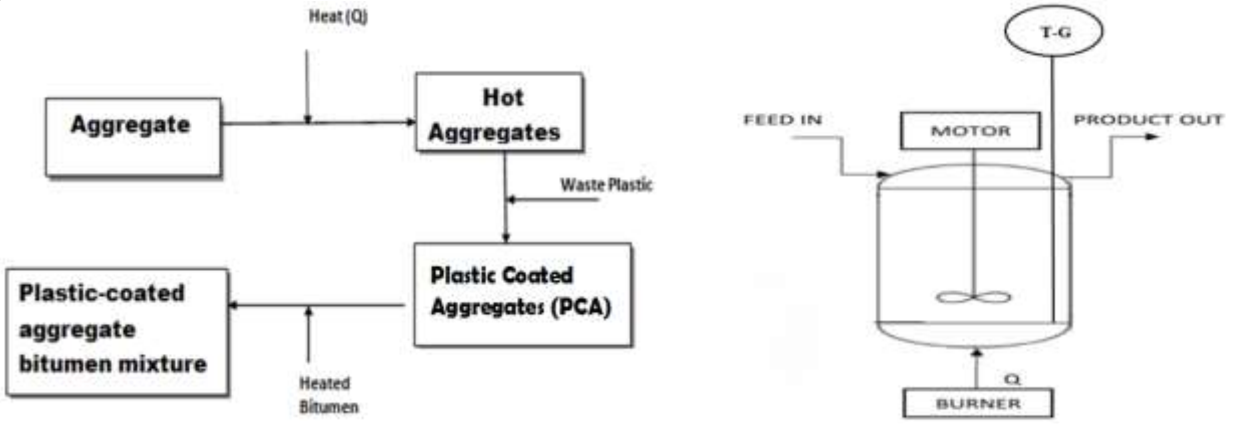
Marshall Stability test is performed to find out the plastic deformation of the road paving material. It helps to find the maximum load of the road material specimen can bear. Void analysis can also be done to predict the compactness or binding between aggregates and bitumen**.** The standard values for the parameter found in this test are given in Table 2—standard code of the test ASTM D1559-89 and AASHTO T245-82. The standard testing conditions are that the specimen should have a diameter

Table 1: Temperature and plastic percentage of each sample.

Sample	Plastic %	Temperature (°C)	Sample	Plastic %	Temperature (°C)
1	5	145	7	11	142
2	6	140	8	12	140
3	7	143	9	13	142
4	8	138	10	14	150
5	9	142	11	15	148
6	10	144			

Table 2: Tests performed on a polymer-coated aggregate.

Sr. No.	Test Name	Property Measured	Standard Value
1	Marshall stability test	Marshall flow (*vertical deformation*)	8-18
		Marshall stability (kg) (m*aximum load)*	680 (min)
2	Crushing value test	Crushing strength	Maximum 45%
3	Specific gravity test	Bulk specific gravity	2.2 – 2.5
		Bulk SSD specific gravity	N/A
		Apparent specific gravity	2.4-2.7
4	Impact value test	Toughness	Maximum 30%
5	Los Angeles test	Hardness	Maximum 30%
6	Stripping test	Adhesion to bitumen	Maximum 5%
7	Moisture absorption test	Water retention in sample	0.1-2%



(a) (b)

Fig. 4: (a) Process flow of PCA production for road material (b) Process and instrumentation diagram of the reactor.

of 6 inches and a height of 2.5 inches. The weight of the sample is 1200 grams and the temperature 60°C at the time of flow and stability, and proper tampering must be assured during sampling. Mix with 4% (by weight of aggregate) bitumen Fig. 5 (a). It is to be noted that for the experiment, 12 samples of polymer-coated aggregates with the plastic composition varying from 0%, 5%, to 15 % were created.

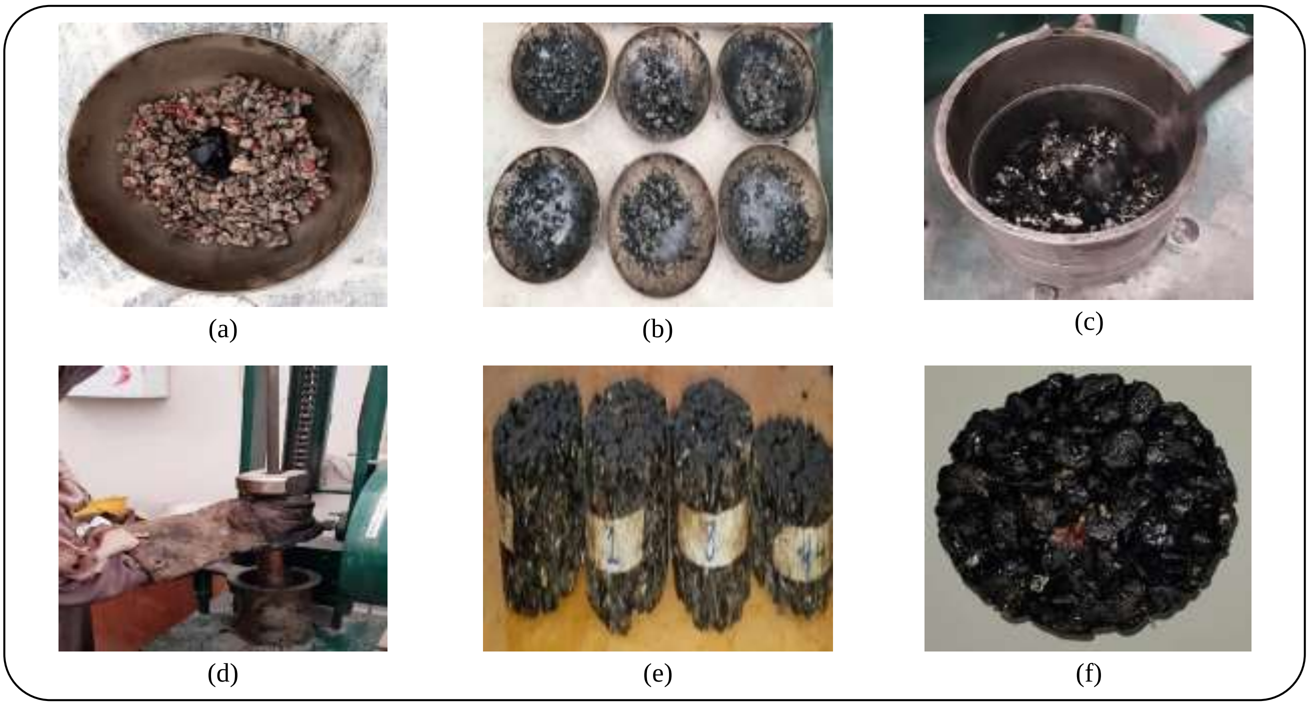


Fig. 5: (a) Sample before being mixed with bitumen (b) Heated samples from oven (c) Sample being added in Marshall Mold (d) Rammer being attached to the Compaction Pedestal (e) Molded samples (f) Top view of the sample

The materials are heated for about 2 hours, then taken out of the oven and cooled, as shown in Fig. 5 (b). The mixture is then placed in a heated Marshall mold with a collar and base. A filter paper is placed under the sample to avoid sticking the hot mixture on the base plate, as shown in Fig. 5 (c). The mold is then placed in the Marshall Compaction pedestal, and the rammer is placed carefully on the compaction pedestal, as shown in Fig. 5 (d). The material is compacted with 75 blows of the hammer. The sample is inverted and compacted in the other face with the same number of blows. After compaction, the sample is left for cooling. The sample is extracted by pushing it out of the extractor. The sample can stand for a few hours to cool shown in Fig. 5 (e). Fig. 5 (f) shows the top view of the sample. The mass of the sample in air and when submerged is used to measure the specimen's density to calculate the void properties.

Samples after preparation are placed in the water bath at 60°C for 30 - 40 minutes. 1. Samples are then removed from the water bath, dried, and placed in the lower segment of the breaking head, as shown in Fig. 6 (a). The upper segment of the breaking head is placed in position, and the complete assembly is placed on the testing machine. The flow meter is placed over the breaking head and is adjusted to read zero, as shown in Fig. 6 (b). Load is applied at a rate of 50 mm per minute until the maximum load reading is obtained. The maximum load reading in Newton is observed. Simultaneously, the flow as recorded on the flow meter in units of mm was also noted. After complete testing, the samples are discarded, as shown in Fig. 6 (c).

Crushing test

An aggregate crushing test is used to determine the relative measure of resistance to crushing under gradually increasing compressive load. Using this test, analyze the strength and toughness of our polymer-coated aggregates. Aggregates having lower crushing value would give a longer service life to the road and more economical performance. The maximum allowable aggregate crushing value ACV is suggested to be a maximum of 45%. Polymer-coated aggregate crushing value. Using this test evaluated the hardness of our polymer-coated aggregates samples. The sample with the lowest aggregate crushing value will be regarded as the best sample.

Specific gravity

Aggregates are the main component of road pavements. Its quality greatly affects the workability of the road, its strength, and its durability. One of the tests that help predict the strength of aggregates is the specific

(a) (b) (c)

Fig. 6: (a) Placing sample in breaking head (b) Flowmeter attached to breaking head (c) Deformed sample.

gravity test weaker-specific gravity indicates a high percentage of air void present in the aggregate. The specific gravity test measures the aggregate's weight under three different sample conditions: dried sample, Saturated Surface Dry (SSD, water fills the aggregate pores), and submerged in water (weight underwater). The three parameters, the sample's apparent specific gravity, bulk specific gravity, and bulk SSD specific gravity, can be evaluated using weight under different conditions. Generally, aggregate used in road construction will have a bulk specific gravity between 2.4 - 2.7 and specific gravity of less than 2.7.

Impact test

As the vehicles move on the ground, they produce a sudden impact, which causes deformation on the road unless the aggregates are strong enough to resist the sudden load shock. The resistance of sudden shock, load, or impact of aggregates can be evaluated through the impact value test. The maximum allowable aggregate impact value AIV is suggested to be a maximum of 30 %. The objective is to find the impact value of aggregates of different compositions of plastic. Select the best sample having the lowest AIV value.

Stripping test

This test aims to find out the de-adhered material from the polymer-coated aggregate. The idea is to predict the resistance of bitumen to detach from the rock sample coated with plastic. But usually, water on the road surface lessens bonding strength, and bitumen gets detached from the road surface. It is known as the stripping of bitumen. The stripping value is the ratio of the average uncovered or stripped area observed visually to the total area of aggregates. It is preferred to predict results based on visual inspection, but the striped material can also be filtered and weighed using an analytical balance.

Los Angeles abrasion test

The objective is to check the strength and hardness of the material. It helps to predict the extent to which the material can withstand abrasion offsets of traffic for a long time. Set the rpm or revolution of the machine to between 30-33 rpm. Use the steel spheres according to the weight of the sample, as shown in Table 3 the standard code of test ASTM C131-89, AASHTO T96-83. The apparatus is L.

Moisture absorption test

A moisture absorption test is performed to determine how much water content is retained in the given sample over some time. The difference in dry weight and weight after the test is evaluated in terms of percentage. More absorption will indicate more porosity in the aggregate, while a lesser absorption indicates good aggregate quality having fewer voids. This test will also help us to predict the performance of aggregates under humid conditions and different weather conditions like excessive rain, and freeze-thaw conditions. The standard code for this test is ASTM C 127-88 and AASHTO T85-81. There is no specific value for this test, but moisture absorption for aggregates should be less than 3%.

RESULTS AND DISCUSSION

Marshall stability test

Table 4 shows the reading of the specimen used in this test. In columns 3, 4, 5 different heights of the specimen are taken. It's done to find the average height of the specimen. Since the standard height of the specimen for testing is 63 mm, which was not obtained in some samples due to

Table 3: Grading table for samples.

Grading	Number of Spheres	Weight of Aggregate (kg)
A	12	5
B	11	4.58
C	8	3.33
D	6	2.5

Table 4: Marshall Stability test sample readings.

Sample	Plastic %	Height-1 (mm)	Height-2 (mm)	Height-3 (mm)	Average Height (mm)	Weight of Sample (g)	Correction Factor
1	0%	67.9	67.82	67.36	67.69333	1011.3	0.89
2	5%	67.9	67.91	67.84	67.833	1015.6	0.9
3	6%	63.12	63.2	64.11	63.476	856.1	1
4	7%	65.2	65.17	65.71	65.36	947.5	0.95
5	8%	46.91	48.32	45.74	46.99	719	1.81
6	9%	64.12	67.86	65.29	65.723	668.2	0.97
7	10%	71.39	72.28	72.6	72.09	868.1	0.81
8	11%	72.8	68.05	69.17	70.00	1019.7	0.83
9	12%	71.7	73.63	74.64	73.123	1080.2	0.81
10	13%	60.47	60.69	61.62	60.92	841.8	1.05
11	14%	80.61	79.01	80.72	80.03	1089	0.75
12	15%	80.78	76.3	78.9	78.66	1140.1	0.76

problems in compactness, a correction factor was applied to match the standard condition of weight and height for this test. Correction factor values are taken from the Marshall mix design parameter. Marshall Flow is vertical deformation in the sample. Marshall Stability is the maximum load the specimen can bear. It's measured in kilograms. Air void % analysis is done using the weight of the submerged specimen and dry specimen mentioned in the procedure above.

By performing this test, we obtain values of Marshall Stability, Marshall Flow, and Air void %. These parameters will compare and decide the best sample. Fig. 7 shows a Marshall Stability value versus plastic composition plotted. For this test, 12 samples, all the aggregates were coated with plastic except for one. Conventional aggregate (0% plastic) is a sample without plastic coating that was used to compare the enhancement properties of modified aggregates. From Fig. 7, we observe the Marshall Stability of conventional aggregate with 0% plastic is 1983 kg. For 5%, plastic stability increased to 2067 kgs. The sample with 6 % shows 1109 kg which is lower than the minimum value of stability which is 1500 kg. The trend of increment or decrement isn't linear or steady in this test as read the stability values for different samples. The highest value of Marshall Stability is attained by a sample with plastic composition 12%, and the lowest value is achieved by 9% plastic-coated aggregate [19, 20].

Comparing conventional aggregate's stability with a sample with 12% plastic composition, we see that capability of bearing maximum load is improved by 81%. The Maximum load value attained is 3607 kg. This sample with 12% coating is best based on stability. Out of 11 PCA samples, eight samples have shown better values than the conventional aggregate. Now let's discuss the air voids % in PCA samples. From Fig. 7, a gradual decrease in air voids% is observed till 8% coating, then an increase in air void % from 9% coated sample till 12% plastic

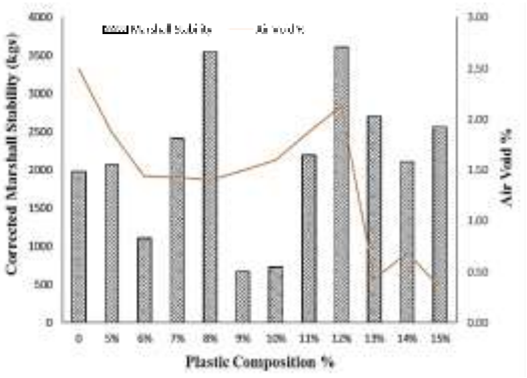


Fig. 7: Combined results of Marshall Stability and Air Voids.

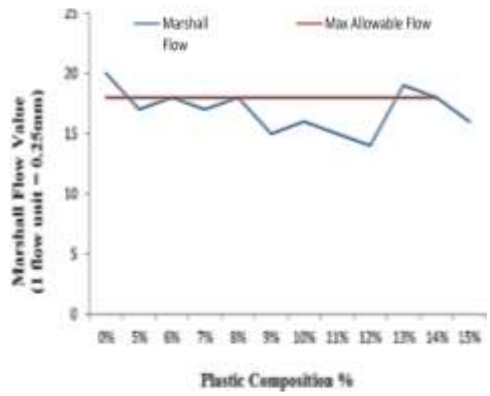


Fig. 8. Marshall Flow value results.

composition after that fluctuation in values is observed. The minimum value of air void % for road paving is between 2-3%. A value less than the minimum limit of air void % isn't recommended because air void % less than 2% will not allow expansion under traffic load during operation. It may result in road damage like cracking or rutting. So the decision for the best sample shall be made considering all these factors [8, 21].

With the incorporation of plastic, the value decreased from 0% to 8%, then an increase in air void in 9% to 12% of plastic samples. The lowest value of air void % is found in a sample coated with 15% plastic. The sample with conventional aggregates shows that air void % decreased from 2.49% to 0.34%. Now choose the sample that is having air voids % higher than 2%. From Fig. 7, see that only two samples have a value of air void% higher than 2%, that is, the sample with 0% plastic coating and the sample with 12% plastic coating. Hence these two samples are the best. But the final decision of a better sample will be based on air void % comparison with Marshall Flow value and Marshall Stability [21, 22]. The third parameter found is Marshall Flow which is the vertical deformation of the specimen. One unit of Marshall Flow Value is equivalent to 0.25mm deformation.

As shown in Fig. 8, the maximum allowable value is indicated by a red straight line. The maximum allowable value is 18 for Marshall Flow. Out of 12 samples, 10 samples have shown a value of Marshall Flow below the max allowable value and those are samples with 5%, 6%, 7%, 8%, 9%, 10%, 11%, 13%, 14%, and 15%. The sample with 12% plastic content is the best because it has the lowest flow value indicating the lowest vertical deformation. Conventional aggregates have vertical deformation more than allowable limits. A flow value of 20 indicates vertical deformation of 5 mm. Compared to the conventional aggregate, the sample with 12% plastic coating showed a flow value of 14, which is far better.

Now, after the individual parameter's result discussion, make a crucial decision of selecting the best sample for this test. As for all parameters, the best values are shown by samples of different plastic compositions; now we have to choose the optimum value sample by referring to the selection criteria of the best paving material. From Table 5, it is clear that a comparison of Marshall Flow and Marshall Stability with air void% to find samples with optimum values.

Fig. 7 shows a combined graph of air void% and Marshall Stability. As previously discussed, the max value of Marshall Stability is given by sample with 12% plastic coating, and for air voids %, 12% and 0% plastic-coated samples give the best value. A compromise has to be made to choose one sample with a max stability value and air void % higher than 2% [22, 23]. It refers to the selection criteria in Table 5; the minimum required value of Marshall Stability should be 680 kg. Now see the value of stability of 0% coated aggregate is 1983 kg, and that of 12% is 3607 kgs. The value of stability is improved by 81.89% by incorporating 12% plastic. Since the sample of plastic conternt12% offers much higher stability, 81.89% better with slightly lower Air void% than 0% aggregate, conclude that the sample with 12% plastic content is the best sample among all. The difference between the air void percent of 0% coated sample and 12% coated sample is only 14.47%. The value of 12% plastic-coated sample

Table 5: Selection criteria for the best sample of Marshall Stability.

Parameter	Standard Values	Sample Preferred
Marshall Stability	680 kg *(minimum)*	Maximum value obtained with optimum air void%
Flow Value	Heavy traffic - 8-18	Least possible with the least voids
Air voids	Not more than 3%	Not less than 2%

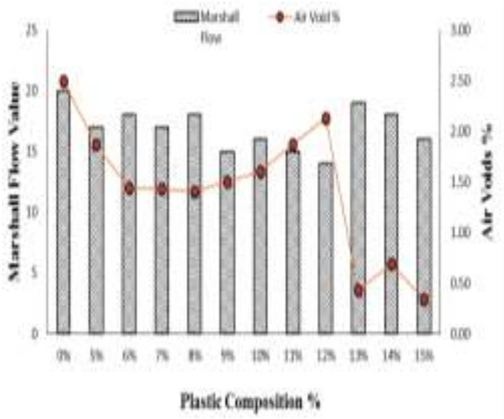


Fig. 9. Selection of optimum value of Marshall Flow.

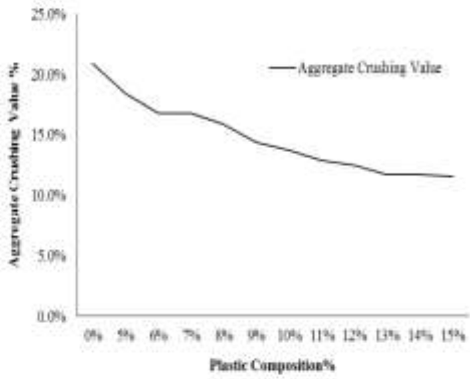


Fig. 10. Aggregate crushing value s.

air void % is 14.47% less than conventional aggregate, but it is still above the required limit.

Now a comparison is made between the Marshall Flow value and air void% to find the best sample. While choosing the best value of Marshall Flow, keep in mind that the sample should have less deformation and air void % not less than 2 %. Fig. 9 shows a sample with plastic content of 12%, which has the lowest value of Marshall flow, which indicates the least vertical deformation. Now from Fig. 9, see the red line, which is the air void %, that the highest percent of air void is present in samples with plastic content 0% and 12%. Although both the samples of plastic content 0% and 12% have shown air void % higher than 2%, the sample with 0% plastic content has Marshall Flow value higher than the allowable limit, due to which it cannot be suggested as a good sample. So a comparison of air void% and Marshall Flow value tells us that the sample with 12% coating is better. Thus, after performing the Marshall Stability test and carefully analyzing all the aspects, the sample with 12% plastic content is the best sample found from this test [4, 24].

Crushing test

The weight of the sieved sample is the weight removed from the sample after undergoing the test. The aggregate crushing value ACV is measured as (weight of sample passed through a sieve/initial weight of sample)*100. Sieving of the sample is done using a sieve of size 2.36 mm. The weight of the sieved sample is the weight of the sample that has passed through the sieve.

Fig. 10 shows the results of aggregate crushing value. The conventional aggregate that is the sample with 0% plastic has ACV 20.9%. ACV value is a % loss of aggregates from the sample in the shape of fine particles. For a sample with 5% plastic, the ACV value decreased to 18.4%; though it's not a significant change, it does indicate that with more content plastic, it may obtain a further decreasing trend. With Increased plastic %, we can see from Fig. 10 there's a trend moving downwards. The highest plastic % samples show the best possible ACV obtained. It means increasing the plastic content decreases the amount of mass loss when the sample undergoes crushing. Amongst all the samples, the lowest value of ACV is achieved by a sample with 15% plastic coating. All the other samples have values that lie under the limit. Hence plastic incorporation increases the crushing strength of aggregates when they undergo crushing [16, 25].

Specific gravity

In Table 6, value A is dry weight means the initial weight of the sample. B is the saturated surface dry weight

Table 6: Specific gravity sample readings.

Sample	Plastic Composition %	A Oven dry weight	B Saturated surface dry	C Weight in water	Bulk Specific Gravity	Bulk SSD Specific gravity	Apparent Specific Gravity
1	0	2000.1	2018	1165	2.34478	2.36576	2.395282
2	5	2000.3	2017.8	1189.4	2.41465	2.435779	2.466765
3	6	2000.2	2017.8	1190.4	2.41745	2.438723	2.469992
4	7	2000.3	2017.7	1199.5	2.44475	2.466022	2.497877
5	8	2000.1	2017.5	1201.36	2.4448	2.472002	2.504069
6	9	2000	2015	1202	2.44368	2.478474	2.506265
7	10	2000.4	2014	1223.39	2.4615	2.50178	2.574484
8	11	2000	2013.3	1230.4	2.4788	2.53378	2.598752
9	12	2000.7	2011	1233.73	2.48819	2.538	2.608576
10	13	2004.6	2017	1236.4	2.56802	2.58390	2.609476
11	14	2003.4	2010	1239	2.57889	2.607003	2.620879
12	15	2003.8	2004.2	1239.4	2.60178	2.620554	2.621402

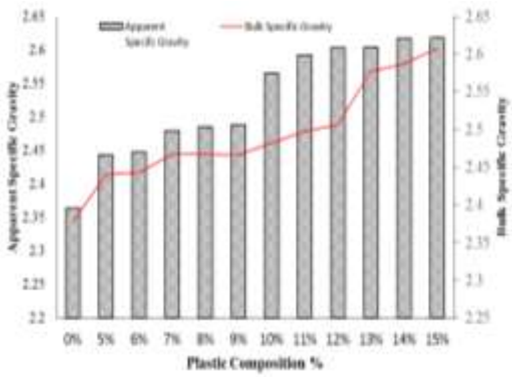


Fig. 11: Bulk specific gravity and apparent specific gravity comparison.

means weight after the sample was soaked for 24 h and dried. C is the submerged weight of water. Bulk SSD, apparent, and bulk specific gravity are measured using values A, B, and C.

Bulk SSD is the ratio of the weight in air of a unit volume of aggregate, including the weight of water within the voids filled by surging in water for 24 hours to the weight in air of an equal volume of gas-free distilled water at a stated temperature. Bulk-specific gravity is defined as the ratio of weight in air of a unit volume of aggregate, including permeable and impermeable voids in the particle to the weight in air of an equal volume of gas-free distilled water at a stated temperature. Specific gravity is the ratio of the weight of the impermeable portion of the aggregate to the weight in air of an equal volume of gas-free distilled water. Among all the three values, bulk specific gravity is the lowest of the three, Bulk SSD is intermediate, and apparent specific gravity is the highest. All values found are compared with plastic content [8, 26].

Fig. 11 shows the results of the specific gravity test; performed the test and weighted samples in three conditions to find three values which are bulk specific gravity, bulk SSD specific gravity, and apparent specific gravity. In Fig. 11, a specific gravity value has been shown versus plastic content. It's obvious from a clear observation that with an increase in plastic content, the specific gravity also increases. The conventional aggregate has a specific gravity of 2.39, which is also good. Still, from the results, coating aggregates with plastic enhances the specific gravity because aggregates with high specific gravity provide a longer life span to road life and durability [13, 16]. The highest specific gravity value is obtained in the sample with plastic content 14 % and 15 %, which is 2.62 for both. The standard value for specific gravity is between 2.4-2.7, so choose a value below this in Fig. 11. To decide the optimum value of apparent specific gravity, compare it with other values. The optimum values must be chosen keeping in mind the objectives of this test which is to find samples having a maximum allowable limit of apparent and bulk-specific gravity.

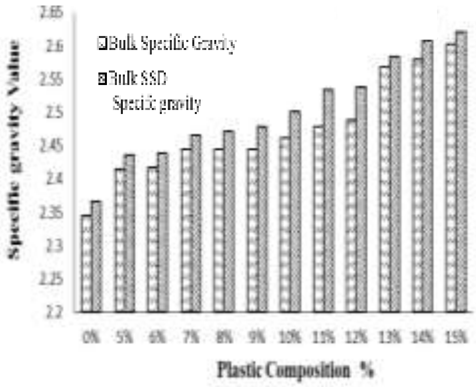


Fig. 12: Comparison of bulk SSD and bulk specific gravity.

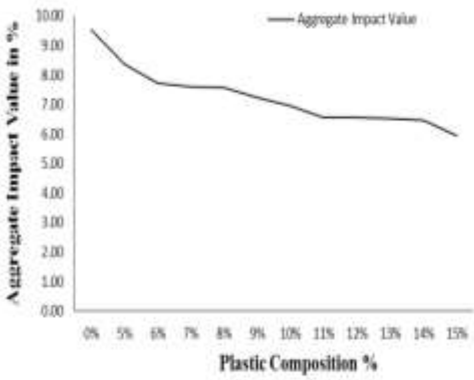


Fig. 13: Aggregate impact value.

From Fig. 12, it's clear that bulk-specific gravity and Bulk SSD-specific gravity both increase with the increase of plastic content. The optimum value for bulk-specific gravity is between 2.2 to 2.5. It is visible that some of the values for bulk specific gravity are exceeding the allowable limit; that is, the sample having plastic % greater than 12% is exceeding the maximum allowable for this parameter.

To select the optimum of apparent specific gravity and Bulk specific gravity, make a comparison between them. In Fig. 11, a graph for selecting the optimum value of apparent specific gravity is given. Observing the trend of bulk-specific gravity, see that from 0% to 15%, bulk-specific gravity's value continues to increase and exceed the allowable limit of 2.5. At 12% plastic content, see that bulk specific gravity has reached its maximum allowable value. The value of apparent specific gravity is 2.60, which is also the maximum allowable value. Since after 12% plastic composition, the bulk specific gravity of samples exceeds the maximum allowable limit, none can be selected as optimum. However, they have maximum allowable values for apparent specific gravity. PCA with 12% coating is declared the best sample with optimum values according to the analysis of this test [7, 13].

Impact test

Before the test, it was hypothesized that impact value would gradually decrease with an increase in % of plastic, and Fig. 13 supports our hypothesis. We can a decreasing trend for impact value with increased plastic content. The AIV value of conventional aggregate compared with polymer-coated aggregates is more than all PCA, which indicates that conventional aggregate has the least resistance toward impact. The maximum allowable value of the impact test is 30%, and in the samples, we achieved a maximum of 9.52% impact value, and the lowest is 5.94%. Although the conventional aggregate value also lies within the control range, the sample with 15% plastic coating has shown the best results [7, 9, 24].

Stripping test

From Fig. 14, it was noticed that the higher the percentage of plastic, the lower the % loss of bitumen from PCA. Higher plastic content has worked as a strong binder to decrease the de-adherence of bitumen from PCA samples [4, 6, 16, 19]. The sample with 15% has only 0.477% loss which is too low to be considered a loss, and it can say that loss for 15% plastic sample is nearly negligible. Hence conclude that the sample with 15% plastic has the lowest loss value of bitumen, so it is the best sample among all the coated samples.

LOS Angeles abrasion test

The low value of the Los Angeles abrasion test is better because it shows less detachment of material or deformation of the road material and indicates hardness. Fig. 15 shows the gradual decrease in Los Angeles' abrasion value. The conventional aggregate has the highest value of the Los Angeles abrasion test, indicating it is the weakest among the samples. The value of Los Angeles of the sample with plastic coating keeps on decreasing. The lowest value of LAA is obtained in the sample with 15% coating, which is only 6.6%. The maximum allowable value of Los Angele abrasion for roads with heavy traffic is set to be not more than 45%. Still, in aggregates samples, none of the values surpasses 45% abrasion value.

The coating of the polymer has significantly enhanced the hardness of aggregates. When selecting aggregate for road construction, one of the most required properties of aggregate is its hardness [3, 10, 19]. The better the hardness, the less it would need repair or maintenance, which can save cost.

Moisture absorption test

Fig. 16 shows that aggregate having 0% plastic has the highest moisture content, which is significantly decreased with the incorporation of plastic. The increased plastic composition lowers the voids in an aggregate. Now, comparing conventional aggregate and aggregate having the maximum plastic composition of 15%, the value of moisture content absorbed has improved by 91.85%. It means that permeable pores get filled, thereby reducing moisture content in the sample. Thus the result of the experiment shows that the incorporation of plastic in the aggregates has shown improvement up to 91.85%; the best sample is the sample with 15% plastic content [8, 18, 22].

CONCLUSIONS

This research explored the predictive relationship between plastic composition and enhancement of properties. Different tests were used as a methodology to investigate the performance of different samples with varying plastic compositions. For different tests, the best value is shown by different plastic % compositions. In the specific gravity test, samples with 14% plastic and 15% showed an equal value of specific gravity 2.62, but Bulk-specific gravity's value exceeds the maximum allowable range after 12%; thus, none of these two can be selected as the best samples. However, the sample with a 12% plastic composition has the best Bulk Specific gravity of 2.49, being under the allowable limit with a specific gravity value of 2.61, which is a good value to be selected as optimum. Hence based on Bulk Specific gravity value, select 12% plastic-coated as the optimum sample for this test. The Marshall Stability test sample with 9% has a good stability value, but it has an air void % of 1.5%, which is below the minimum required value, which is unacceptable. The next sample with 0% coating has a good void value but fails to deliver in the stability test; thus, rejected. Next is the sample with a 12% plastic composition, which has

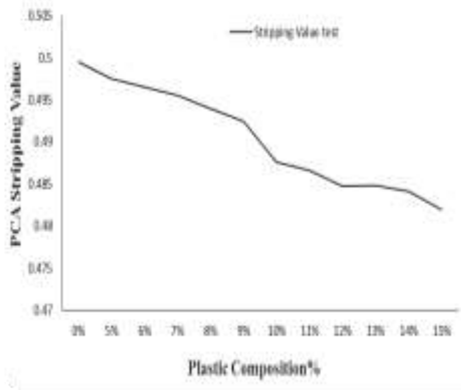


Fig. 14: Results of stripping test.

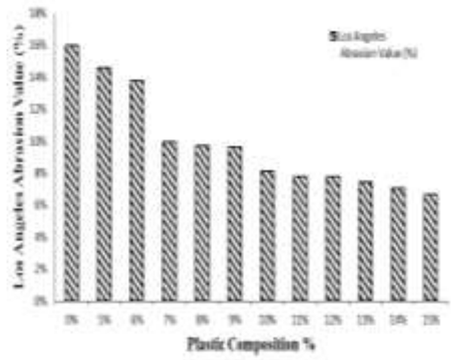


Fig. 15: LOS Angeles Abrasion test results.

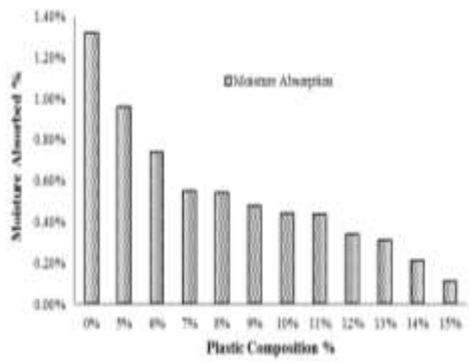


Fig. 16: Moisture absorption test results.

the stability of 3607 kgs. Its Marshall Flow value is 14, under the allowable limit, and air void % 2.13%.which is suitable for laboratory samples. Among all the points, 12% plastic composition is the best sample from the Marshall Stability test. For the Aggregate Impact Value (AIV) test, Aggregate Crushing Value (ACV) test, Los Angeles Abrasion (LAA) test, moisture absorption test, and stripping value test, although all the samples have achieved values under the allowable limit, the best value in all the tests is shown by a sample with a plastic coating 15%. But for the sample with 15% coating, stability, and air void % values aren't acceptable, which are the core parameters to select any sample. For stability and air void% best plastic composition is 12%. Thus based on these two parameters, select 12% plastic-coated sample as the "optimum sample" for the impact value test, crushing value test, Los Angeles Abrasion test, and stripping value test. Since all the test samples with 12% plastic composition hold optimum values, we conclude it to be the best sample suitable for road construction for commercial use. This research can be further implemented for different grades of bitumen. LDPE, HDPE, glass powder, and fibers waste materials can be taken as additives with bitumen.

Nomenclature

°C	Degree Celsius
PE	Polyethylene
PCA	Polymer coated aggregates
TG	Temperature gauge
LAA	Los Angeles abrasion
ACV	Aggregate crushing value
AIV	Aggregate impact value
ASTM	American society for testing material
ASHTOO	American association of state highway and transportation officials
SSD	Saturated surface dry

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