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Experimental Investigation of Geopolymer Flexible Pavement with Waste Plastics Aggregates

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ABSTRACT

The world is facing a greater issue in the disposal of waste plastics and there is an intense need for research on alternate and sustainable solutions for environmental issues. Waste plastic can be used as aggregates or as a protective layer over aggregates to increase their strength. The aggregate used in flexible pavements was investigated in this study, as well as the use of Geo-Polymer to improve the pavement's strength and durability. The design of the pavement is done according to the Indian standard codes IRC. Dense bituminous macadam and base courses are taken into account as per the design criteria. The geo-polymer flexible pavement was tested for properties such as the wearing test. Other fundamental tests for aggregate and bitumen used in pavements include specific gravity, flash point, fire point, ductility, softening point, penetration test, water absorption test, bonding strength, durability, and temperature resistance. When geo-polymer plastic bitumen is heated and put as a coating over the base course, it allows the user the air gaps with additional plastic and binds over the aggregate, resulting in increased road stability, smoothness, and vehicle braking effects. It is concluded that with 5% addition of the geo-polymer with bitumen has performed well in all aspects of the bitumen characteristics.

INTRODUCTION

In India, a growing concern in the usage of plastic waste is the major issue, and the trend of increased use is expected to continue. Chocolate wrappers, beverages bottles, and other different forms of plastics are the reasons for several important environmental problems. Plastic consumes enormous embodied energy and depletes our environment in various ways drastically. Plastics are used widely in the construction industry due to their easy handling and packaging features, as well as their lightweight, cost, and strength. Plastics are made of highly pestilent materials that are resistant to biodegradation, meaning they will have a significant environmental impact after use. The waste plastics used in this context are polypropylene (PP), polyethylene (PE), and polystyrene (PS). The softening point of the polymers is between 120-160°C and these plastics do not release any harmful gases when heated to these temperatures. These plastics can produce a coating or lamination on the aggregate's surface. Plastics are sprayed over the aggregate at a temperature of 160°C.

For many years, plastic has been used in pavement, particularly flexible or bitumen pavements, to improve the pavement's stability, strength, and durability while lowering the overall cost of construction by gradually replacing bitumen with waste plastic to a certain percentage. Waste plastics are poured and heated with the bitumen for about 40 seconds to properly mix it so that no extra equipment or machinery is required to be attached to the current plant; the waste plastic melts and combines with the bitumen with its own heat, so no additional fuel is required. Extensive research is continuously being carried out to determine the best value for plastic in flexible pavement construction.

Justo & Veeraragavan (2002) concluded that a significant amount of plastic in the range of 8% will reduce bitumen usage by 0.4%. Rajasekaran et al. (2013) the qualities of bitumen were improved when waste plastic was included in the bitumen, which also raised the product's binding property. It is also observed that the durability is enhanced when the penetration value is reduced and the temperature of softening point is increased and this also results in improving the property of the bitumen. Xu & Van (2000) prepared a mixture of alkaline solution and alumino-silicate in the proportion of 1:0.33 as a mass ratio in which the geo-polymeric reaction is stimulated. This process continues with the mixing of alumino-silicate powder into the mass to form a thick gel of geo-polymer. After curing at 35°C with stilbite source material for 72 h, it was observed that the compressive strength of the sample would reach around 20 MPa. According to Van et al. (2002), the compressive strength of the product reached around 80 MPa when the basic materials for the pavement combination were demolition debris and fly ash. A ratio of 0.4 is maintained between the solution and the powder mass and the content of the alkaline liquids is sodium silicate (3.5%), water (20%), and sodium or potassium hydroxide (4%). Davidovits (1989) prepared geo-polymer paste with different ratios of molar oxides and different compositions of mixtures such as a ratio of Na_2O & SiO_2 of 0.2 to 0.48; a ratio of SiO_2 & Al_2O_3 of 3.3 to 4, 5; and a ratio of H_2O and Na_2O of 10 to 25. Compressive strength was relatively low in mixtures with a lot of water. Mixtures having high water content produced very low compressive strength. It was perceived that the optimal proportion of mix is achieved when the ratio of Na_2O and SiO_2 was 0.25, the ratio of H_2O and Na_2O was 9.9, and the ratio of SiO_2 and Al_2O_3 was 3.2. Liu et al. (2014) discussed that the density of the geopolymer foamed from oil palm shell is around 1400 $kg.m^{-3}$. The mix was prepared using discarded cementitious materials like fly ash (FA) and ash from palm oil fuel and shells of oil palm was used as lightweight coarse aggregate (LWA). It was also observed that there was a 48% reduction in thermal conductivity for brick and 22% in the block than the conventional materials. It was found that the thermal conductivity of oil palm shell foamed geopolymer is around 0.5 $W.mK^{-1}$. Rangan (2009) had stated that fly ash added to geopolymer concrete provides high resistance to acid and sulfate assaults. The behavior and short-term features of compression and tension were investigated, and relative conclusions were reached. Alanazi et al. (2016) observed through experimental investigation that the curing time influences the bond strength considerably. When the geopolymer is compared to traditional cement mortar, several characteristics are investigated, as well as the influence of various acids on the cement mortar and in turn, the bond strength of the geopolymer. Also, metakaolin geopolymer is added as repair material to the pavement in addition to the base materials. It was also discovered that when Metakaolin geopolymer was added, 80% of the characteristic strength was reached within 3 days of curing. The thermally insulating properties of geopolymer composites made with a lightweight material such as waste expanded polystyrene were investigated. The manufacturing of this sustainable material is also indicated in this research. This study shows that the properties have been upgraded than the Portland cement-based materials like having improved strength and lower thermal conductivity (Colangelo et al. 2018, Hoy et al. 2017). Saravanan et al. (2010) studied the geopolymer concrete and concluded that the CO_2 emission could be efficiently reduced in active and passive ways by reducing the cement production, thus supporting nature. Sreevidya et al. (2010) investigated the effects of cement on climate change and concluded that no-cement concrete, such as fly-ash-based geopolymer concrete, should be examined at various stages.

There is only scarce literature for geopolymer-based flexible pavement developed with waste plastics and plastic coated aggregates. In this context, the optimum percentage of plastic coating and optimum percentage of polymer to modify the bitumen and develop the geopolymer-based flexible pavement have been studied.

OBJECTIVES OF THE STUDY

The core objective of the context is the effective usage of waste plastic which does not affect society and the environment. The breakdowns of the objectives are as follows

- To arrive at the efficient percentage of waste plastic to be added with the bitumen that exhibits the same or improved strength.
- To obtain the optimum percentage of plastics that has to be coated over the aggregates will give superior performance.
- To investigate the geopolymer mixed with bitumen which increases the Wearing property of the modified bitumen road.

MATERIALS AND METHODS

The materials tested in the asphalt pavement system are aggregate, bitumen, and modified bitumen. Experiments such as specific gravity test, viscosity test, ductility test, flash point test, softening point test, and thermal study, were done for bitumen. Also, tests like the specific gravity test, aggregate impact value test, and water absorption test were performed for the aggregates of all sizes (6mm, 10mm, and 20 mm). Further tests were done on the road in the field such as wearing test and core cutting test.

Bitumen

Table 1 shows the physical properties of bitumen used in the study. The tests on the materials are done based on the suitable Indian Standard codes. The specific gravity of bitumen is done as per the standard procedures of IS 1202-1978. The flashpoint and fire point of the bitumen are found based on the procedure of IS1209-1978. Ductility test of the bitumen is arrived as per the IS1208-1978. The Softening point temperature and the penetration test value of bitumen are calculated based on the standard procedure of IS1205-1978 and 1203-1978 respectively.

Table 1: Physical properties of bitumen.

Particulars	Values from Results	Values Limited
Specific gravity of bitumen	1.032	0.99
Flash point of bitumen	290°C	220°C
Fire point of bitumen	325°C	270°C
Ductility test of bitumen	40 cm	50
Softening point of bitumen	52.19°C	47°C
Penetration test of bitumen	60 mm	45 mm

Specific gravity is defined as the ratio of the mass of the specific volume of bitumen to the mass of the volume of water equal to the bitumen, assuming that both the bitumen and the water are kept at 27°C. The elongation of the bitumen in centimeters before it breaks when the briquette specimen is pulled at a set speed and temperature is known as the ductility of the bitumen. The bituminous substance leaches off a volatile liquid at higher temperatures, which might catch fire and look like a flash depending on the grade. When bitumen is modified, this is a vital point to investigate to determine when the resulting product reaches the flash point. The main difference between the flashpoint and the fire point is that the flashpoint is the lowest temperature at which the material, the vapor, fires, and flashes temporarily, whereas the Fire Point is the temperature at which the material fires and burns slightly higher than the Flashpoint temperature.

The resistance of the bitumen at the molten state to the flow is called Viscosity, and thus it can be termed as the inverse of fluidity. This property justifies the fluid property of bitumen that also determines the workability of the bitumen. The level of spreading of the bitumen and penetration of the same through the aggregates are justified by the degree of viscosity and which is directly proportional to the temperature. The degree of viscosity that is obtained to satisfy the best usage of the bitumen is measured by the softening point, which is the measured temperature to reach the specific viscosity.

The penetration value of the bitumen is measured with standard needle arrangement, with a standard temperature of bitumen and applied load, and rate of loading. At the said standard condition, the penetration is measured in a tenth of a millimeter.

Aggregate

The physical properties of the aggregates are tested before the fabrication of the system. The sizes of aggregates used are 6 mm, 10 mm, and 20 mm. Also, the dust form of aggregates is used for better packing of the aggregates and optimizing the usage of bitumen. The specific gravity of all sizes of aggregates is arrived as per IS2386 (Part III). The aggregate impact value test is done based on the procedure prescribed in the IS2386 (Part IV). The physical appearance of the aggregate is observed and justified to get the stripping value of the aggregate. The water absorption test is arrived as per IS2386 (Part III). The physical properties of aggregate used for specimens are listed in Table 2 with its corresponding test values and permissible limits.

Plastic Coated Aggregate

The problem of waste plastics and their disposal is a global issue. It is critical to find a wise idea for using waste plastics in a sustainable manner. The aggregates are covered with waste plastics to improve their strength and in turn the subgrade. The plastics are added in terms of weight percentage and the performance of the aggregates is studied with different percentages of plastic coatings to arrive at the optimum percentage. The plastic coatings vary from 10% to 40%, at every 10% interval. Its crushing strength and the bending strength are calculated with the cube test and prism test respectively. Table 3 shows the compressive strength and flexure strength of the waste plastic wastes.

Table 2: Physical properties of aggregate.

Particulars	Values from Results	Values Limited
Aggregate impact value test	21.19	Max30 %
Specific gravity of aggregate [20 mm]	2.43	-
Specific gravity of aggregate [10 mm]	2.57	-
Specific gravity of aggregate [6 mm]	2.47	-
Specific gravity of aggregate [dust]	2.62	-
Stripping value of aggregate	43%	5%
Water absorption	0.38	Max 2 %

Table 3: Characterization of waste plastic.

Percentage of plastic-coated on the aggregate surface	Crushing load value [MPa]	Bending load value [MPa]
10 %	240	315
20%	260	325
30%	280	340
40%	310	380

When the aggregates are tested for impact resistance, the strength is found to be reduced slightly. Table 4 shows the aggregate impact value of the samples taken and added with different percentages of plastics. This decrease in strength can be compensated when used with polymer-modified bitumen.

Polymer

The objective of using the polymer in the bitumen is to modify the bitumen characteristic to suit the other modified (plastic and plastic coated) aggregates used in the pavement. The polymers initially chosen for the study are Polyethylene (PE), Polypropylene (PP), and Polystyrene (PS). The thermal study is done over these polymers and the suitable polymer is chosen. Table 5. shows the thermal properties and characteristics of different polymers.

Polymer Modified Bitumen

Bonding and monolithic difficulties are encountered while working with plastic plastic-coated aggregates and other modified raw materials in pavement fabrication. All these problems will be eliminated by using polymer-modified bitumen in combination with plastic-coated aggregate. Different percentages of geo-polymer were added with the bitumen and studied to obtain the optimum value of the bitumen characteristics. Table 6. shows the comparison of the bitumen characteristics such as ductility, penetration value and softening point.

Road

Apart from the tests conducted for the materials, tests are conducted for the road sample fabricated with the said bitumen and aggregates. A wearing test is done for the road sample. Wearing test is conducted on base course layer filled with polyethylene, polystyrene, and polypropylene and by adding geopolymer chemicals in the texture of base course layer which determines the temperature and friction effect of the vehicle.

A thermometer is fixed in the layer of the base course which shows the definite temperature of the pavement. The vehicle is fixed at that spot, and friction between the tire and the pavement causes the tire to wear in the flexible pavement, causing the temperature to rise. The base course contains geopolymer chemically enhanced with bitumen, which improves the layer's bonding strength and the pavement's temperature resistance. Table 7 shows the results of wearing temperature before and after the test is performed on the geopolymer flexible pavement.

RESULTS AND DISCUSSION

Strength Performance of Waste Plastics

According to the results of standardized testing, the crushing strength increased by 20% when the coating was increased from 10% to 40%. Furthermore, increasing the plastic coating content from 10% to 40% improves flexural strength by up to 20%. Fig. 1 depicts the relative performance of varying percentages of waste plastics.

Aggregate Impact Value

The increase in the plastic percentage by 2% made the aggregate impact strength fall by 25%. To consider this negative performance, the addition of the geopolymer to the bitumen

Table 4: Characteristics of aggregate coated with plastic.

Percentage of plastic	Aggregate impact value [kN]
0 %	25.00
1 %	20.03
2 %	18.09

Table 5: Thermal study on polymers.

Polymer	Softening Temperature [°C]	Decomposition Temperature [°C]	Products reported
PE	100-120	270-350	CH4,C2H6
PP	140-160	270-300	C_2H_6
PS	110-140	300-350	C_6H_6

Table 6: Characterization of polymer modified bitumen.

Percentage of plastic added	Bitumen Ductility [cm]	Penetration Value [mm]	Softening Point [°C]
1%	65	96	55
2%	54	89	49
3%	19	78	48
5%	12	56	73
10%	8	0	76

Table 7: Wearing test on the road.

Time (sec)	Geo-polymer flexible pavement (before) [°C]	Geo-polymer flexible pavement (after) [°C]
10	37	48
20	40	60
30	41	75

is done. The polymer binding will overcome this reduction of aggregate impact strength. Fig. 2 shows the comparison of aggregate impact values of different percentages of plastic coating.

Thermal Study on Polymers

Suitable polymer selection is done based on the softening and decomposition temperature. The polymer must consist of a lower softening temperature and higher deposition temperature. The polystyrene polymer has optimum performance when compared with the other two polymers namely polyethylene and polypropylene. The softening point temperature of the PS is about 12% higher than the PE and PP polymers and the decomposition temperature of the PS is 18% higher than the average of PE and PP polymers.

Because of its better softening and decomposition temperature characteristics, the polystyrene polymer was chosen for the formation of modified geopolymer bitumen. The variance in softening point temperature and breakdown temperature for different types of polymers is shown in Fig. 3.

Ductility, Penetration, and Softening Performance

From the comparison, it was found that adding 5% plastic to the bitumen improves the optimum performance. This proportion is the only way to get the best ductility and penetration. Furthermore, the variance in softening point is just 10%, which will not be a major hurdle in determining the proportion of geopolymer in the modified bitumen.

Fig. 4 represents the variation of ductility and penetration value for different percentages of plastics. Also, Fig. 5 shows the variation of softening points for various plastic percentages in bitumen.

Wearing Temperature of Geopolymer Flexible Pavement

The difference in wearing temperature before and after the vehicle tire friction test is shown in Fig. 6. The friction test is carried out for various lengths of time, with the temperature of the geopolymer flexible pavement reaching just 70°C after 30 s of friction.

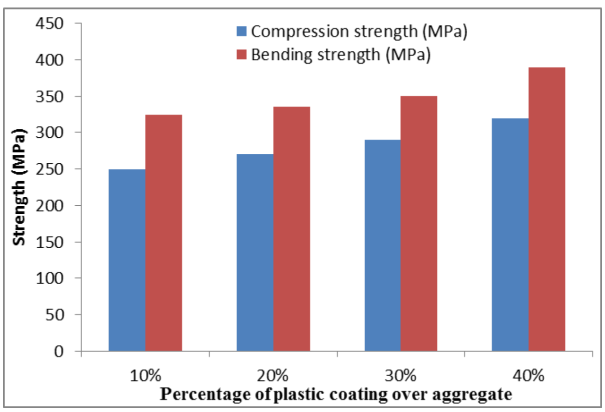

Fig. 1: Strength performance of waste plastics.

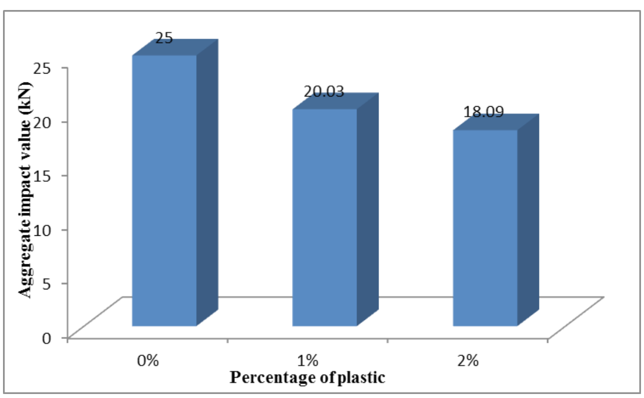

Fig. 2: Aggregate Impact Value of plastic-coated aggregate.

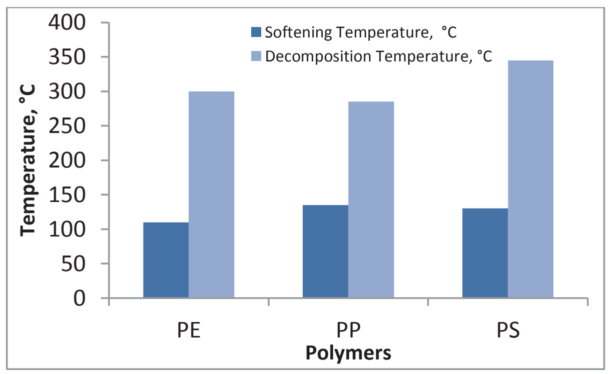

Fig. 3: Softening and decomposition temperature of different polymers.

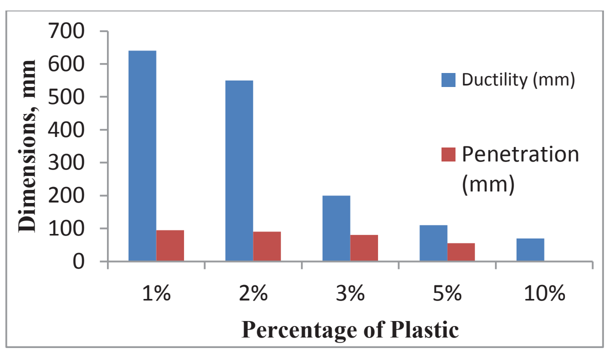

Fig. 4: Ductility and penetration performance of modified bitumen.

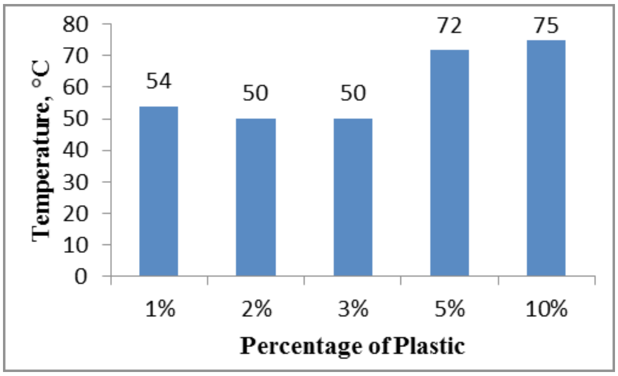

Fig. 5: Softeing point of modified bitumen.

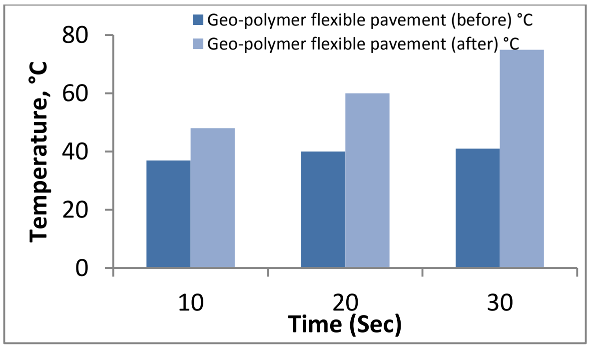

Fig. 6: Wearing temperature of geopolymer flexible pavement.

CONCLUSION

An extensive study on the geopolymer modified concrete is done with plastic waste coated aggregate and polymer modified bitumen. Various tests for the aggregates, bitumen, polymer, modified bitumen and polymer-modified flexible pavement are conducted in the study, and the following conclusions are arrived.

1. The plastic coating done for 40% of weight to the natural aggregate has performed well in all the characteristic tests of aggregate like crushing test and impact strength.
2. The softening and decomposition temperatures of polypropylene polymer were optimal, and it was excellent for mixing with bitumen.
3. Modified polymer bitumen containing 5% polypropylene polymer performs better in ductility and penetration tests, making it appropriate for the preparation of geopolymer modified flexible pavement.
4. The geopolymer modified performed well in the mandatory criteria of wearing temperature test which makes the pavement suitable for traffic utilization.

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