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Study on Effect of Plastic Waste on Softer Grade (Vg-10) Bitumen

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ABSTRACT- Plastics are useful product but their disposal as a waste had become a serious problem, especially in India. Recycling of plastic waste into useful products is one of the solution for its disposal. Plastic can be used in the bituminous (asphaltic) pavement construction which may help in reducing the permanent deformation in the form of rutting the Pavement surface and also, its use in bituminous binders helps in the protection of our environment. PET (Polyethylene Terephthalate) is a form of plastic waste which is now being used as packaging material for a wide range of products and also in the packing of carbonated beverages. In this study, the effects of PET on various properties of the bitumen are discussed in details. PET was added @ 2.5% increment to the bitumen from 0% to 15% and various tests such as ductility test, penetration test, specific gravity test, softening point, flash and fire point and thin film oven test (TFOT) were performed. From the results of our study, it was inferred that the modified bitumen inherits better performance when compared to the virgin bitumen. The most effective percentage of Polyethylene Terephthalate (PET) waste in our study was seen between 10 to 12.5% by weight of the bitumen, beyond 12.5%properties like ductility of bitumen gets reduced. Hence, PET could be used more effectively up to the percentage of 12.5%.

KEYWORDS- Plastic waste (PET), Penetration, Ductility, Viscosity, Bitumen, TFOT

I. INTRODUCTION

Most of the highways in India are bituminous pavement, called flexible pavements, having less initial cost and maintenance cost. Thus, there may be scarcity of bitumen. On the other side, use of plastic has become common in today's lifestyle. If not recycled, they might impose serious threat to both aquatic as well as to the terrestrial living being [1]. Industrial plastic waste is mainly the source of primary waste plastic. Secondary waste plastic recycling involves the reclaim portion of the consumer material. The source of secondary waste is not unknown because it contains different types of plastics. Also, hazardous effect of the waste is also causing threat to the population of water animals and birds [12]. Tyre waste is the other main part of the polymer and is required to be disposed. If disposed by incineration and land filling, it creates environmental and health problems. Thus, the disposal of tyre waste is done by utilizing it in bituminous road construction. Proper utilization of such waste in bituminous road construction minimizes the cost of construction of road, improves the quality and life. [2]The highways which are important in India are built by bituminous concrete (BC) or by dense bituminous macadam (DBM). The recycled plastics such as; polyethylene can successfully be used in the formation of polymer modified asphalt bitumen or cement. Recycled polyethylene from the grocery bags when used in bitumen pavements results in the reduced rutting and low temperature cracking of the surfaces of the pavement [5]. The dense bituminous macadam (DBM) is the layer of base course of the flexible pavements which is used in the construction of roads under heavy conditions of traffic load. In the present time, DBM is recommended for the use as the binder course and base course for roads under heavy traffic loads. The performance of the bitumen pavement depends mainly up on the pavement design factors and the other prevailing factors like drainage, climatic and traffic load factors, etc. The life of the pavement and its performance depends on the sufficient sub-grade supporting properties of the material used and on the thickness of different pavement layers, considering the climatic and traffic factors. The Increased traffic volumes, vehicular loads and the tire pressures are being increasingly causing the abrasion of the pavement at the accelerated rate [1]. It has been seen that the plastic being the non-bio-degradable material can remain for about 4500 years on the earth without getting decomposed. This may cause health problems such as reproduction related problems in the human and animals like abnormalities of genitals etc. The results of various studies on the performance of the pavements indicates that the useful life of the bitumen pavements, made of traditional un-modified binders, has decreased from the average value of the 6-7 years in the past to about 3-4 years recently. It is well known that the durability requirements of the traditional bituminous binder overlays are not meet, in general, under the prevailing climatic conditions and heavy traffic conditions while as the polymer modified bitumen (PMB), known as higher performance binder, allows the highway engineer to build and design the durable bituminous surface. It has been proven all over the world that these binders are economical and have better field performance when the cost of life cycle is taken into account. [4] The performance of the bituminous mixtures which are used for surfacing the flexible pavements can be exceptionally improved by the introduction of certain suitable additives

to the bitumen and these additives may be by-products, commercial materials or even the processed waste materials. The recycled plastics such as; polyethylene can successfully be used in the formation of polymer modified asphalt bitumen or cement. Recycled polyethylene from the grocery bags when used in bitumen pavements results in the reduced rutting and low temperature cracking of the surfaces of the pavement.

Present disposal of plastic waste is either by land filling or by incineration but both these processes have negative effect on the environment and hence, an alternate use for plastic waste is needed In India, the concept of waste plastic utilization in the flexible pavement construction has been developed since 2000. In the flexible pavement construction, the binding of the aggregates together is done by the bitumen, by coating over the surfaces of the aggregate particles. It also results in the improved strength and the life of road pavement but its resistance to the water is poor. The use of waste plastic in the bitumen is carried out in the similar way as in the polymer modified bitumen. Thus, modified bitumen is one of the important material of construction for the flexible road pavements[11]. It has been seen that consumptive processes as well as the technological processes results in the formation of solid waste. In the beginning of the process, solid waste is generated with the recovery of raw materials and then in the technological process at every step of conversion of raw material into the product of consumption. In urban areas, the process of utilization of certain products results in the formation of the solid waste. Moreover, other processes such as park cleaning, street cleaning, and air pollution control measures, waste-water treatment etc. also results in the production of solid waste in the urban areas.

II. LITERATURE REVIEW

Dhumdalwar et al [3] carried out study on comparison of properties of plastic modified bitumen with the normal bitumen. In this study, it was noticed that ductility and penetration values of the modified bitumen decreases with the increase in percentage of the polypropylene plastic additive up to 12%.

Rzazei et al [5] Study the "effect of styrene butadiene polymer and nano-sio2 on the high temperature performance of hot-mix asphalt" in the Civil Engineering Department, at Tehran, Iran,. In this study, Marshall stability test for the flow value was conducted and the interaction of Nano-sio2 with the surface of the aggregate was checked to increase the resistance of bitumen against stress.

Lu et al [6] In this paper, "Long time durability of the PMB on the bridge deck pavements". RTFO test was conducted on the bitumen along with the conventional tests using SBS polymer modified bitumen for tough environmental conditions. It was found that modified bitumen offers better results than normal bitumen.

Ramdave and Patekar [7] aims to address on "Quality control and assurance of bitumen viscosity graded approach". Tests like kinematic viscosity, viscosity at 60 0C, solubility in trichloroethylene were conducted on the PET modified bitumen and it was seen that viscosity gets modified and solubility also improves.

Wahab and Rehman [8] used PET as the partial replacement of the fine aggregates in the modified asphalt in their study. From the economy point of view they suggested that the recycled PET may help in reducing the cost of the road construction because PET being cheaper and easily available than the bitumen and also enhances the service life and performance of the road. They concluded that the PET modified bitumen gives more advantages when compared to the normal bitumen mixture, considering the permanent deformation.

Ahmadinia et al [9] investigated the application of the plastic waste bottles (PET) in the SMA. The bitumen used was VG-30 grade and PET was added as 0%, 2%, 4%, 6%, 8%, and 10% by weight of the bitumen. Various tests such as moisture susceptibility, wheel tracking, resilient modulus and the drain down tests were performed on the modified bitumen. The results of his study showed that the introduction of PET into SMA improves its resistance against the deformation such as rutting, increases stiffness of the mix, gives lesser binder drain down and also provides recycling and reuse of waste in more eco-friendly and economical way.

Prusty et al [10] carried out study on the modification of the B.C mixes with the polythene waste. The various percentages of the waste polyethene were used by him for the preparation of mixes with the different aggregate grading given in the IRC code. He used 80/100 grade of bitumen in his study and for determining its optimum polythene content, Marshall properties such as flow value, stability, air voids and unit weight were used. He concluded from his study that more durable and stable mix can be obtained for the pavements by polymer modification of the bitumen.

III. EXPERIMENTAL INVESTIGATION

A. Materials Used

In this study, the materials used are Polyethylene Teryphthalate (PET) and VG-10 grade bitumen. The properties of these materials are discussed below in detail:

- **PET Plastic Waste**

Now-a-days, plastic waste is available in enormous because it has become part and parcel of our lives. They either get mixed with Municipal Solid Waste and/or thrown over land area. The plastic waste can be easily blended with the bitumen because the process of bituminous road construction is carried out in the temperature range of 155-165^{0}C. In our study Polyethylene Teryphthalate (PET) is used as a plastic waste. PET is a form of plastic from the polyester family and is now popularly being used mainly as the packaging materials in the food industry for mineral water, oil, soft drinks, milk, bakery products, salad dressings, cosmetics, frozen foods, cleaner and many more products in the food industry. [4] PET is commonly being used in the manufacture of food and beverage containers. To overcome the global problem of plastic imparted pollution, the government as well as the industrial estates are in search of more eco-friendly options for the disposal of plastic wastes. The traffic volumes are increasing day by day and existing roads are getting deterioration at the increased rate and hence, need to be

re-layed. Also, with the increase in demand, the new highway projects are being constructed to meet the pace of traffic demands. Therefore, the asphalt industry tries to incorporate the PET plastic waste into the asphalt pavement so as to have judicious utilization of PET and to minimize the growing bitumen demand. PET plastic can also be incorporated in the asphalt mixture as the aggregate replacement. In the process of aggregate replacement the portion of the fine aggregate or coarse aggregate is made to replace with the similar size PET particles to form the plastic-asphalt mixture.

- **VG-10 Grade Bitumen**

It is also called 80/100 grade bitumen. It is the thinner material which is having lower softening point. The VG-10 bitumen is widely used for construction and surfacing of the roads in the colder temperature region. The mild thickness grade of bitumen VG-10 are recommended for the zones with the average mean temperature of about 30 ^{0}c or lower. Thus, it is mostly used in the cool climatic high saturated zones of the Northern India. In India the smallest mean temperature, which is likely near bitumen temperature, happens in the month of January in India and ranges from -2^{0}c to 21 ^{0}c. Bitumen is a viscous liquid, or a solid, which is soluble in trichloroethylene and is substantially non-volatile and softens gradually when heated. It is black or brown in colour & possesses waterproofing properties. It is obtained by refinery processes from petroleum. This is the softest of all grades available in India. This is suitable for low volume roads and is still widely used in the country.

B. Various Tests Performed

- Ductility Test
- Penetration Test
- Softening Point Test
- Viscosity Test
- Flash Point Test and Fire Point Test
- Specific Gravity Test
- TFOT Test

C. Sample Preparation

Firstly VG 10 grade bitumen is heated and the heating is continued until it becomes liquid. The polyethylene Terephthalate (PET) waste is added in percentage of 2.5% (by weight) to the 800 g of VG-10 grade bitumen. Then PET is added in increments of about 2.5% up to 15% by weight of bitumen (5.0%, 7.5%, 10%, 12.5% & 15%) to the softer grade (VG-10) bitumen and the mixture is heated up to 160 ^{0}C. The bitumen and PET waste is mixed thoroughly by using stirrer till the mixture attains homogeneity. After mixing, various physical properties such as ductility, softening point, penetration value, flash and fire point tests are conducted as per the test specifications.

Figure 1: Bitumen Mixed Sample

Figure 2: PET Plastic Particles

Table 1: Observed Properties of the Normal VG-10 Grade Bitumen

S. No.	Characteristics	Unit	VG-10
1.	Ductility	cm	78
2.	Penetration	mm	84
3.	Softening Point	c^o	47
4.	Viscosity	Sec.	5.5
5.	Flash Point	c^o	280
6.	Fire Point	c^o	320
7.	Specific Gravity	-	1.010

IV. RESULT AND DISCUSSION

The result and discussion of PET effect on various properties of the plain bitumen, after conducting various tests, are discussed in this section.

A. Effect of PET on Ductility of Bitumen

From the experimental work, the result of PET on various properties of the bitumen is mentioned in Table 2 and the variation of ductility is illustrated in graph 1 below;

Table 2: Effect of PET on Ductility

PET %	Initial Reading (cm).(a)	Final Reading (cm). (b)			Ductibilty(a-b)			Mean Ductility (cm)
0%	0	78	77.6	78.4	78	77.6	78.4	78
2.5%	0	83.4	82.6	83	83.4	82.6	83	83
5%	0	87.8	86.4	86.8	87.8	86.4	86.8	87
7.5%	0	89.6	88.2	89.2	89.6	88.2	89.2	89
10%	0	91.4	92.2	92.4	91.4	92.2	92.4	92
12.5%	0	92.4	93.2	93.4	92.4	93.2	93.4	93
15%	0	90.2	89.8	90	90.2	89.8	90	90

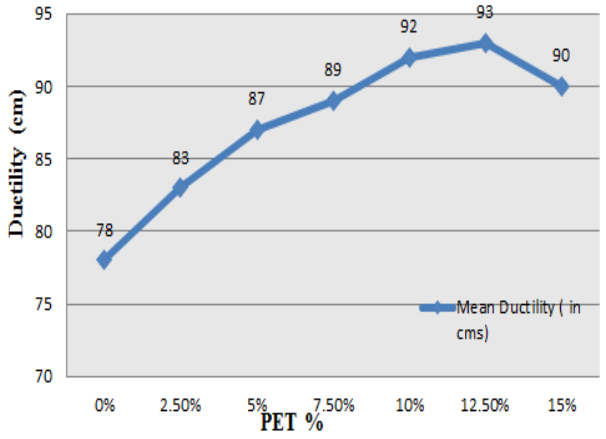

Figure 3: Variation of ductility of bitumen with PET

The ductility of the material is measured by distance (in cm) up to which it elongates before breaking, when a standard specimen is pulled apart at a specific temperature and speed. The distance at which the bitumen thread breaks was taken as the ductility in thus test. From Table 2 and Figure. 3, the observed values shows that the ductility of the virgin bitumen increases on the addition of PET. The increase was observed as 6.4%, 11.5%, 14.1%, 17.9% and 19.2% on adding PET from 2.5% to 12.5% respectively`, when compared to the virgin bitumen but the ductility value decreases by 15.4% on addition of 15% PET. The increase in the value of ductility can be because of the interlocking of molecules of the polymer with the bitumen and decline after 12.5% may be because of the excess plastic waste which might make the bitumen stiffen. The increase in the value of the ductility helps to improve the workability of the bitumen concrete and also does uniform coating of the aggregate.

B. Effect of PET on Penetration Value of Bitumen

Table 3: Effect of PET on Penetration of Bitumen

PET %	Initial Penetration (mm)	Final Penetration (mm)			Mean penetration(in mm)
0	0	81	84	83	82.67
2.5	0	82	81	83	82
5	0	80	81	82	81
7.5	0	79	78	77	78
10	0	74	75	73	74
12.5	0	72	71	70	71
15	0	66	68	67	67

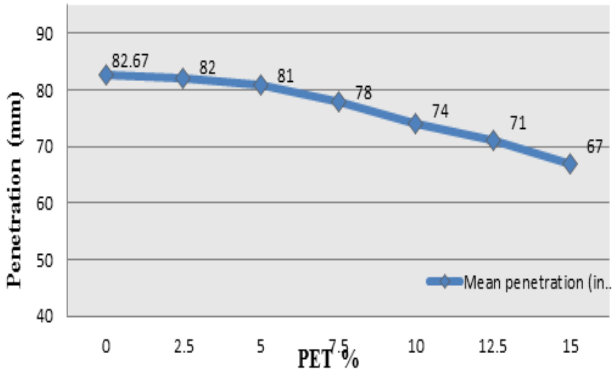

Figure 4: Variation of Penetration with PET

Table 3 and Figure 4 shows the variation of the penetration value, as observed in the laboratory, of the bitumen modified with PET. Thus, the penetration value of the bitumen and its consistency decreases on increasing the PET content and the decrease is found to be about 2.38%, 3.57%, 7.14%, 15.47% and 20.24% with the 2.5%, 5%, 7.5%, 10%, 12.5% and 15% addition of PET respectively, as compared to the plain bitumen. Thus, from the results of our study it was inferred that the introduction of PET makes the bitumen more consistent and harder than the plain bitumen and hence, improves its rutting resistance. Therefore, PET modified bitumen can be used in relatively hotter regions and it can perform comparatively better under the heavy traffic conditions.

C. Effect of PET on Viscosity of Bitumen

Table 4: Effect of PET on Viscosity of the Bitumen

PET %	VISCOSITY (Sec.)		MEAN VICOSITTY (Sec.)
0	4	6	5.0
2.5	6	6.8	6.4
5	6.8	7.4	7.1
7.5	7.2	7.9	7.55
10	7.6	8.0	7.8
12.5	7.8	8	7.9
15	8	8.2	8.1

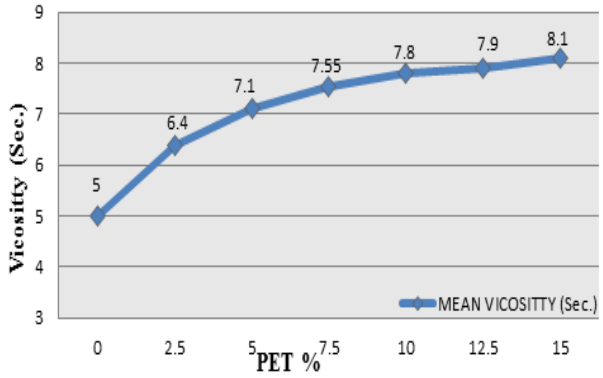

Figure 5: Variation of Viscosity with PET%

Figure 5 shows the variation of the viscosity of the bitumen with the PET plastic waste as observed in the laboratory and Table 4 shows the effect of PET on the viscosity of the plain bitumen. It is reflecting by the results of our study that the viscosity of the plain bitumen gets increased on the addition of PET and the increase is found to be significant up to 12.5% PET addition. The increase in the viscosity of the plain bitumen is found to be 14.5% to 48% on the addition of PET from 2.5% to 15%. Thus, form our study it was concluded that the PET modified bitumen have enhanced workability when compared to the plain bitumen.

D. Effect of PET on Softening Point of Bitumen

Table 5: Effect of PET on Softening Point of Bitumen

PET %	Temp. when ball touches bottom (in ^{0}C)		Mean Softening point(in ^{0}C)
0	44.5	45.5	45
2.5	46.5	48.5	47.5
5	48	49	48.5
7.5	49.5	50.5	50
10	50.5	52	51.25
12.5	52.5	53.5	53
15	54	56	55

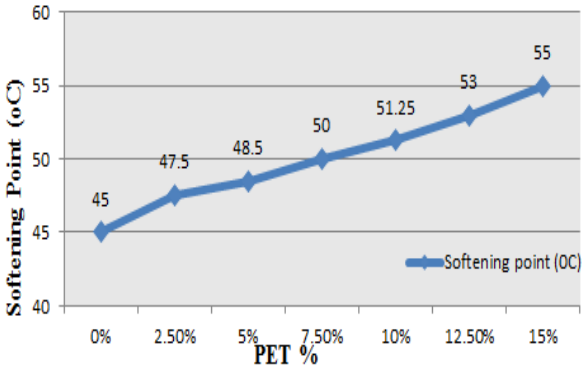

Figure 6: Variation of Softening Point with PET %

Table 5 and Figure 6 reflects that the softening point of the bitumen increases with the increase in the PET content. The increase was found to be 47 ^{0}C and 55.5 ^{0}C for the plain bitumen and PET modified bitumen respectively. This means that the resistance of the bitumen to the heat is increased and its tendency to soften in hot weather is reduced and hence, the PET modified bitumen becomes lesser susceptible to the temperature variations.

E. Effect of PET on Viscosity of Bitumen

Table 6: Effect of PET on Viscosity of the Bitumen

PET %	VISCOSITY (Sec.)		MEAN VICOSITTY (Sec.)
0	4	6	5.0
2.5	6	6.8	6.4
5	6.8	7.4	7.1
7.5	7.2	7.9	7.55
10	7.6	8.0	7.8
12.5	7.8	8	7.9
15	8	8.2	8.1

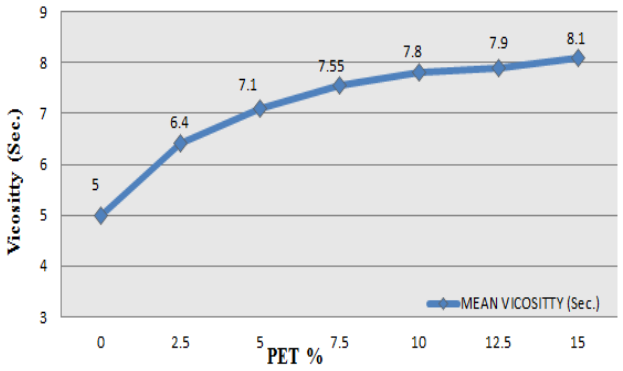

Figure 7: Variation of viscosity with PET%

Figure 7 shows the variation of the viscosity of the bitumen with the PET plastic waste as observed in the laboratory and Table 6 shows the effect of PET on the viscosity of the plain bitumen. It is reflecting by the results of our study that the viscosity of the plain bitumen gets increased on the addition of PET and the increase is found to be significant up to 12.5% PET addition. The increase in the viscosity of the plain bitumen is found to be 14.5% to 48% on the addition of PET from 2.5% to 15%. Thus, form our study it was concluded that the PET modified bitumen have enhanced workability when compared to the plain bitumen.

F. Effect on Flash Point of the Bitumen

Table 7: Effect of PET on Flash Point of the Bitumen

PET %	Flash Point (^{0}C)
0	280
2.5	284
5	286
7.5	290
10	295
12.5	300
15	303

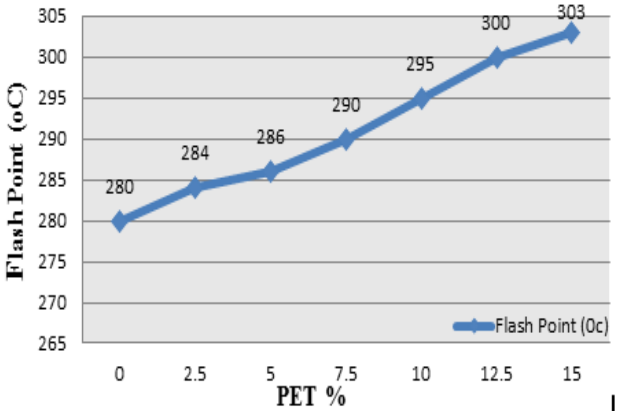

Figure 8: Variation of Flash Point of Bitumen with the Variation PET %

From Table 7 and Figure 8, it was observed that the flash point of the bitumen gets increased on the addition of PET. The flash point was observed between 280^0c and 303^0c. Thus, the trend infers that the resistance of the bitumen to the burning hazards gets efficiently improved on theaddition of PET from 2.5% to 15%.

Table 8: Effect of PET on Fire Point of Bitumen

PET %	Fire Point (^{0}c)
0	320
2.5	325
5	328
7.5	331
10	333
12.5	340
15	337

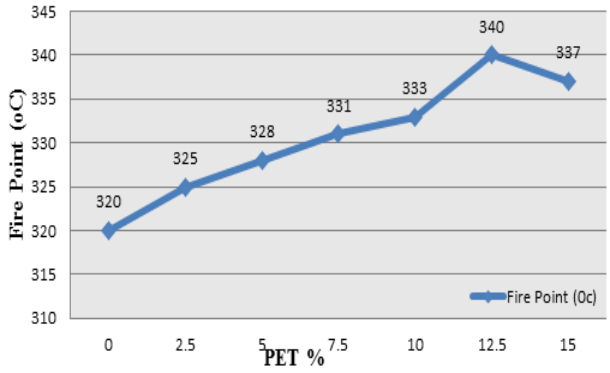

Figure 9: Variation of Fire Point of Bitumen with Variation of PET %

From Table 8 and Figure 9, it was observed that the fire point of the bitumen gets increased on the addition of PET. The fire point was observed between 320 ^{0}c and 337 ^{0}c. Thus, the trend infers that the resistance of the bitumen to the burning hazards gets efficiently improved on theaddition of PET from 2.5% to 15%.

G. Effect on Specific Gravity of Normal Bitumen

Table 9: Effect of PET on Specific Gravity of Bitumen

PET%	Weight (in grams)				S.G = (c-a) / [(b-a)-(d-c)]
0	42.303	74.898	65.201	74.320	1.010
2.5	43.212	76.120	68.300	77.220	1.016
5	42.802	75.210	68.420	68.421	1.020
7.5	42.920	74.098	66.320	66.326	1.023
10	43.103	76.210	68.421	68.422	1.029
12.5	42.780	75.198	68.328	68.317	1.030
15	43.080	76.023	67.922	67.928	1.030

Specific gravity test is the ratio of the mass/density of a material to the mass/density of a reference material for the given volume. The specific gravity of pure bitumen ranges from 0.97 to 1.02 but it will be higher, if the bitumen carries the mineral impurities. Specific gravity of the bitumen is finally calculated by the following formula;

Specific Gravity = (c – a) / [(b-a)-(d-c)].

Where,
a = Weight of specific gravity bottle in grams.
b = Weight of specific gravity bottle filled with distilled water in grams.
c = Weight of specific gravity bottle half filled with bitumen, in grams.
d = Weight of specific gravity bottle about half filled with distilled water and the rest filled with the bitumen material, in grams.

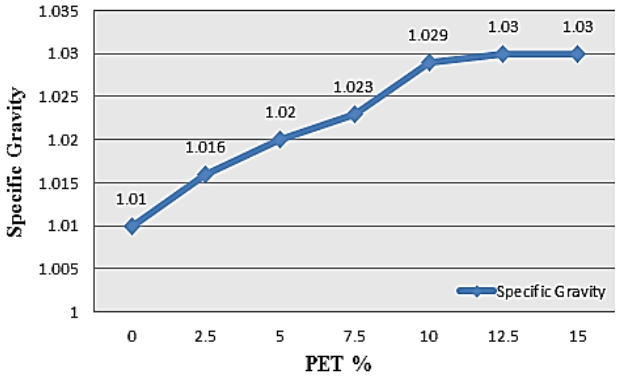

Figure 10: Variation of Specific Gravity with PET %

It is clear from the Table 9 and Figure 10 that the specific gravity of the bitumen increases from 1.01 to 1.03. The increase in specific gravity of the bitumen means the density of the material has increased and since density is mass per unit volume, there are different ways this is possible- either the mass increases or the volume decreases or both, which can be cleared by studying its micro structure.

Table 10: Loss in Weight of the Residue After TFOT

PET %	% Loss of weight afterTFOT	Permissible limit as per IRC: SP: 53-2002
0	0.12	1.0% max.
2.5	0.10	1.0% max.
5	0.08	1.0% max.
7.5	0.07	1.0% max.
10	0.065	1.0% max.
12.5	0.065	1.0% max
15	0.05	1.0% max.

From Table 10, results after short term aging and the initial stage results indicated that properties of the PET modified bitumen get improved. Also, the percentage loss of weight is reducing and is within the specified limit of code (1% max.).

V. CONCLUSION

- In this study, utilization of plastic waste is eco-friendly that has been completely utilized without any negative impact on environment.
- The results of our study indicates that the PET modified bituminous binder have better results in comparison to the ordinary bitumen mixture due to increase in the physical properties of the virgin bitumen.
- With the addition of PET, the ductility of normal bitumen is observed to be increases significantly up to 12.5% addition of PET, whereas, the ductility decreases at and beyond 15% PET addition.
- On increasing the PET content it has been observed that the penetration property of normal bitumen decreases. Also, modified bitumen becomes harder and much consistent than the normal bitumen, resulting in improvement of the rutting resistance.
- The viscosity and softening point of the bitumen is also found to be increased on addition of PET, as bitumen becomes more resistant to heat and thus, reduces its propensity to soften in hot weather.
- It was observed that the flash point of the bitumen increases as the PET percentage increases. Also, fire point of the bitumen increases significantly up to 12.5%, whereas the value slight declines at the 15% PET.
- Results after short term aging and the initial stage results indicated that properties of the PET modified bitumen get improved. Also, the percentage loss of weight is reducing and is within the specified limit of code (1% max.).
- From the economy point of view, the recycled PET may be helpful in reducing the cost of the road construction, due to cheaper price of PET and easily available than the bitumen. Hence, enhances the service life and performance of the road.

Hence, in this study it is concluded that use of Polyethylene plastic waste (PET), inthe form of plastic bottles, in the bitumen results in improved engineering properties of bituminous binder up to the percentage of 12.5%. Therefore, PET would be used more effectively up to 12.5% by weight of bitumen. Thus, this investigation utilizes most beneficially the non-degradable plastics and results in better wear resistant, flexible and durable roads thereby lower the maintenance cost of roads.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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