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Improvement of Asphaltic Concrete by Using Waste Polyethylen Terephthalate (PET)

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ABSTRACT: This study examines properties of waste plastic water bottles, polyethylene terephthalate (PET). The waste polymer was added to the normal bitumen penetration grade (80/100) prepared Marshall Samples using ACW-14 to investigate Marshall Parameters of polymer modified bitumen and compare with conventional bitumen. Thermal analysis of PET waste polymer was carried out using TGA and DSC to study decomposition and melting temperature of the waste polymer and also select suitable type of polymer because compatibility of the material is an essential. Basic penetration, softening point, ductility test was performed and study finding shows that penetration and ductility decrease while softening point increase by addition of polymers. Marshall analysis of the study found that by addition of 9% polymers to the bitumen by weight of 5.5% at optimum level increase Marshall properties and give all positive response for polymers PET such as stability increase up to 60-70%, stiffness, flow, density and voids of the polymer modified bitumen found positively improving and enhancement was observed compared to conventional, which is the key objective of this study. In conclusion the polymers modified bitumen improves stability, workability and reduce deformation in road pavement.

KEYWORDS: Waste Polymers, Polyethylene terephthalate (PET), Bitumen, Wet process, Marshall Stability

I. INTRODUCTION

Facts of the matter, plastics made products are on our fingertips every day in the form of toothpaste, water bottle, disposable plastic cups, spoon, computer and vehicle steering etc. plastic is flexible, cheap and convenient therefore extensively use for packing purposes. Fifty percent plastic made products such as plastic bags, beverage bottles etc use one time only [1]. Nearly one billion people across the globe have no access to clean and safe water and mostly buy water available in plastic bottles [2]. The beverage selling has increased by 500% and bottled water was found the best-selling product on earth [3]. Polyethylene terephthalate (PET) produce from the polymers are the core source for water bottles. An enormous benefits of plastic polymers products such as Polyethylene terephthalate (PET) extensively use for beverage carrying container, Polypropylene (PP) use for disposable cups, spoons and plates, Polyethylene (PE) use in plastic bags and other materials. Despite huge advantages of polymers made materials but these are real threats for environment as well as human health [4]. In other words, huge contribution of waste polymers are the threat to environment and human health related issues due to long decomposable nature of the polymers. The study revealed that worldwide, 50 billion of waste water bottle generate every year and expected to increase [5]. This is the major issue in many developing and under developing countries to recycle and reuse waste polymers but inefficient and high cost consuming projects avoids the process of recycle and reusing so lastly goes to landfills.

Since the situation of waste polymers found worse on earth for last two decades, several research studies have been conducted to reuse various types of waste polymers in road construction replace aggregates or added to the bitumen to enhance properties of bitumen mixture. According to [4, 6-10] polymers improve the properties of bitumen and increase Marshall Stability of asphaltic concrete. In this research paper 80/100 bitumen has been modified by addition of waste plastic bottles (polyethylene terephthalate).

The objectives of the study are to study thermal properties of waste polyethylene terephthalate (PET) and to examine properties of PET modified bitumen and Marshall Mixture with comparison of traditional bitumen.

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II. RELATED WORK

Bitumen is the core binding ingredient of asphaltic concrete [11.Molten bitumen is coated over hot stone aggregate where bitumen acts as binder material. Potholes, crocodile, pavement distress and rutting are the failures occur due to the maximum voids present in the asphaltic concrete and failures counted due to improper selection of bitumen [12]. Previously to reduce pavement distress against rutting and other failure various types of additives use in binding material and these material increase cost of the road pavement [10, 11, and 12]. Laterally, polymer waste management is one of the alarming issues all over the world. Mainly, reuse, recycle and land falls dumping techniques use to manage waste polymers [14]. Malaysia produce 19,000 ton/day of waste across the country and 3-5% recycle and majorities end on landfalls [14, 15 and 16]. The utilization of waste polymers in the modification of road pavement surface found an economical, efficient and reliable technique of waste polymers treatment [4, 6 7, 8, 9, 10, 12 and 13]. Asphalt modification over waste polymers has a long history [6]. The first polymers using modified project were done in the Europe and North America by using waste latex rubber tires to achieve durable asphalt pavement in the 1950s, satisfactory results were obtained.

In 1970's asphalt modification over waste rubber latex tire was discontinue due to higher cost, bleeding in hot weather due to segregation of course aggregate [6, 17 and 18]. In the result, engineers and scientist were looking forward to find alternative which is more economical and efficient. Several attempts have been made to improve properties of bitumen and Marshall by substitution some portion of the asphaltic concrete ingredients over waste polymers. Early 1994, bitumen was modified by adding plastomers (high density and low density polyethylene) in New York [6]. The findings of the modified asphalt substituted by 30% waste plastic polyethylene (PE) enhanced properties of asphalt such as durability, fatigue minimizes the mix density by 16% and increase 250% Marshall stability [6, 19]. The remarkable improvement in Marshall Stability, rutting and water resistance have seen by 15% replacement of course aggregate with low density polyethylene [20]. Study revealed that addition of waste polyethylene by weight of base bitumen 1-3 % increases the properties of Marshall Stability [7]. Polypropylene has good resistance to chemical, fatigue, creep and wear, low water absorption, cheap in cost and good thermal expansion. In addition, by addition of polypropylene significantly improvement has be noted in bitumen properties [22].

An appropriate mixing of waste polyethylene terephthalate (PET) with bitumen on specified environment, remarkable improvement has been seen in the properties of bitumen and Marshall Mix. Furthermore, waste polymers addition to the road pavement decrease the cost and also reduce pressure on landfills as well increase rate of waste reusing for strengthen road pavement [4, 22, and 23]. According to [4, 6, 17, 18, 19, 20, 22, 23, 24, 25 and 26] bitumen modification has found resistive against permanent deformation, enhance the service life of the road pavement, reduce viscosity, improve stability and stiffness, crack, fatigue, abrasion improved and reduce the thickness of the road pavement.

SELECTION OF WASTE POLYMER

Several past studies proposed selection of polymer modifiers are based on transition temperature, mechanical properties and modifiers compatibilities [17, 26, 27 and 28]. It is an essential appropriate polymer material has been selected to enhance the properties of asphalt rather than to lose weight/ getting a lock acquired properties. An Appropriate polymer used to modify bitumen in the result improved aging effect, rutting, fatigue, Marshall Stability and prolong lifetime of the pavement [31].

Transition Temperature: This is an important in the process of polymer selection to know the transition temperature of the polymer [28]. Transition temperature is one of the important properties of polymer and directly link with mechanical properties of the same polymers like (hardness, elongation, brittleness and strength). Indifferent chemical composition of polymers has a different value of glass transition temperature glass transition temperature of polyethylene (PE) is -125 while PET polyethylene terephthalatehas 69. Most commonly techniques used to determine the transition temperature is Differential Scanning Calorimetry [29].

Compatibility: Compatibility of polymer plays an important role and it believes that the functionality of blends depends on compatibility. In addition to, compatibility depends on chemical composition of asphalt base, type of polymer and process of mixing. Blend will be considered compatible if the polymer is completely soluble in bitumen [31].Unification during storage period of blend is compatibility of mix [32]. Study found that compatibility of polymer modified bitumen is influenced by temperature and thermal properties of blend [33].A large number of polymers are not soluble in bitumen at some extent, separation occurs due to lose bonding between them [31]. To reduce the risk of separation among the mixture (blends) appropriate selection of either bitumen or polymer is important [32 and 33]. In the result of bad compatibility between polymer and bitumen poor storage stability of polymer modified bitumen occurred, because of unmatchable properties of polymers and bitumen such as density, solubility and thermal properties [34].

Mechanical Property of Polymers: Commonly, polymers refers to viscoelastic and transitional existence occurs between liquid and elastic solid, moreover polymers obey ideal liner elastic solid Hooke‘s law (stress is proportion to strain) also ideal liner viscous liquid Newton‘s law (stress is proportion to the rate of change of strain). Polymer behavior indicates that at low temperature behave like glass and on high temperature shows viscous properties. The proposed mechanical properties polymer must exist during mixing with bitumen are low transition temperature, high melting point and high cohesion. Moreover, chemical structure of polymer like amorphous and crystalline structure may affect the process of modification of asphalt [27, 28 and 29].

III. METHODOLOGY

Penetration grade 80/100 bitumen is selected as a binder. ACW-14 aggregate was used in this study. Raw waste polyethylene terephthalate (PET) was collected from the cafeteria of Infrastructure University of Kuala Lumpur (IUKL because huge plastic bottle made of polyethylene terephthalate (PET) generated every day. Thermal analysis study of polyethylene terephthalate (PET) was conducted using thermogravimetric analysis (TGA) and differential scanning calorimeter (DSC). Both polymers material was further processed for crushing to the nearest plastic industry after ensure materials are properly clean and washed. Waste plastic material was fine grained crushed in to the maximum size of 2mm.

IV. EXPERIMENTAL RESULTS

THERMAL ANALYSIS OF POLYETHYLENE TEREPHTHALATE (PET)

Thermal Decomposition Temperature: TGA

The polyethylene terephthalate (PET) samples were heated on various temperatures to monitor weight loss on different interval of times to determine decomposition temperature and thermal stability of the polymer sample. The obtained results is shown in Table 1 and Figure 1 indicated decomposition temperature range (280-360 ^{o}C) while end temperature was noted in the range of (487-584 ^{o}C). Study result shows that all samples of PET polymers were undergone 100% loss of weight during thermal temperature increasing process. This shows that polymers loss weight by increasing temperature and also loss their physical and chemical properties. Polymers has low decomposition temperate are more compatible compared to has higher decomposition temperature during mixing with bitumen [12].

Table 1: Decomposition temperature

Polymer	Samples	Total Weight Loss (%)	Start Temp (^{o}C)	End Temp (^{o}C)
PET	1	-13.638	280.63	488.44
	2	-19.42	360.53	487.16
	3	-14.25	282.34	584.71

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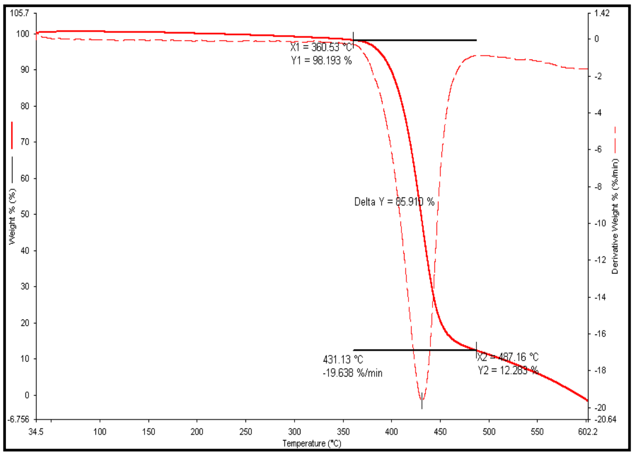

Figure 1: Decomposition temperature of PET

Differential scanning calorimeter (DSC)

A sample known mass is heated or cooled and change in heat capacity is tracked as change in heat flow. As thermal energy is supplied to the sample its enthalpy increases and its temperature rises by an amount determined, for a given energy input, by the specific heat of the sample. In order to determine melting point of the waste polymer samples, DSC test was carried out. The obtained result is shown in Table 2 and Figure 2 indicates that PET samples abruptly lost weight and shows melting point temperature range 74-107 **(**^{o}C**).**

Table2: Melting Point of waste polymers

Polymer	**Samples**	**Initial Heat flow and Weight Loss (%)**	**Melting Point (°C)**
PET	1 2 3	8.99 14.74 10.56	74.56 75.14 106.94

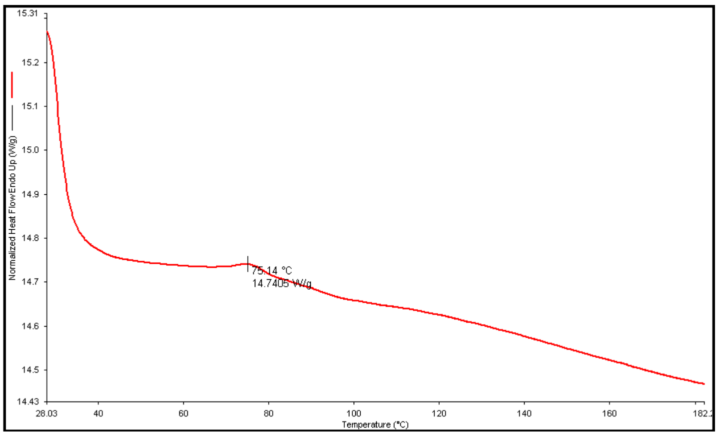

Figure2: Melting point of PET

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EXPERIMENTS AND SAMPLE PREPARATION

Unmodified and PET modified bitumen 80/100 was tested for following properties and obtained result is shown in table 3. Wet process of mixing procedure was adopted and crushed waste PET 3.0%, 6.0%, 9.0% and 12 % by weight of unmodified bitumen were mixed and mixture was blended for an hour to produce homogenous mixture, mixing speed was maintained 1500-3000RPM and the temperature was maintained 160-190C0, empirical test like penetration, softening, ductility were performed for modified bitumen and the process was repeated for all various percentage of quantities.

Table 3: Unmodified bitumen verse PET Modified

	Penetration value	Softening point value	Ductility
Unmodified bitumen	85.9	48.0	>100
3.0 % PET	81.1	54.1	83.0
6.0 % PET	74.5	58.1	69.7
9.0 % PET	66.7	59.7	42.9
12 % PET	57.3	63.2	24.2

By addition of PET in bitumen grade 80/100 shows penetration value decrease by increasing polymers contents in the bitumen and high penetration value reduce rutting effect in road pavement. Past studies [4, 9, 12, 22 and 31] justified the similar findings shows polymer addition in the bitumen reduce penetration value Less the penetration value of modified bitumen resulted harder and consistent bitumen, which enhance rutting properties of the mix, but it affect the flexibility of the bitumen. Softening point of bitumen increase by increase PET contents in the bitumen as shown in the table and indicate that higher softening point of bitumen resist against temperature and bitumen temperature susceptibility increase by addition of PET waste. Study revealed that by increasing polymers contents in the traditional bitumen softening point also increase [35 and 36]. Ductility of the PET modified bitumen with various concentration shows lower value compare to conventional.

In other words, polymer modified bitumen reduce ductility of the bitumen and higher concentrations has lower ductility. A study finding is justified with past studies of [37 and 38] stated that by increasing polymers contents in the bitumen ductility of the modified bitumen rapidly decrease.

MARSHALL PROPERTIES FOR POLYETHYLENE TEREPHTHALATE (PET)

Optimum bitumen content (OBM) of conventional bitumen was found by addition of 5.5% to the Marshall sample and further waste polymers PET plastic bottle content used ACW-14 was added as 3.0%, 6.0%, 9.0% and 12 % by the weight of OBC. Following Marshall Parameter is determined;

Density (Kg/cm3): Modified bitumen density found lower than the conventional bitumen. Maximum density was achieved by addition of 9.0% PET modified bitumen. Study shows that increasing waste polymers contents in the bitumen increase the density until certain level and then decrease. Figure 3 shows the obtained result density of polymer modified bitumen.

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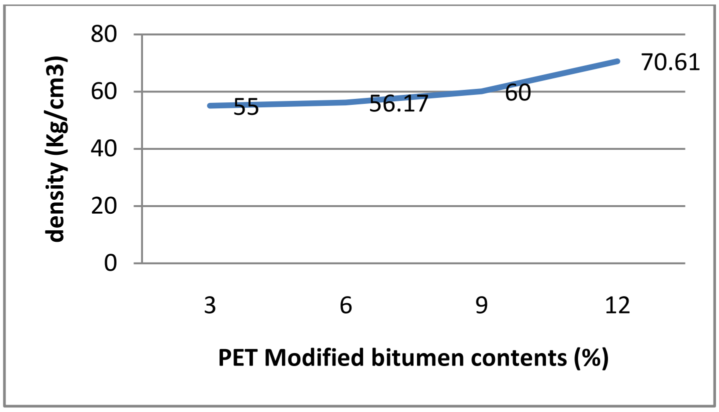

Figure 3: PET modified bitumen density

Marshall Stability (N): Study findings indicated that higher Marshall Stability is achieved by addition of PET waste polymers contents to the conventional bitumen. A figure 4 show the Marshall Stability of PET modified bitumen which shows that maximum Marshall stability was found by addition of 9.0% modified bitumen and further shows Marshall Stability decrease. In all conditions, addition of PET modified bitumen shows higher Marshal Stability compare to conventional bitumen and these finding shows that waste PET modified bitumen remarkably increase strength of the road pavement. Waste polymers are hydrocarbon with long chain and same as bitumen is also complex mixture of various chemicals and has long chain hydrocarbon when these two hydrocarbon mixed together some portion of the bitumen make a strong bonding with polymer hydrocarbon and in the result intermolecular bonding increase which may assist modified bitumen to increae stability and durability of the Marshall asphalt.

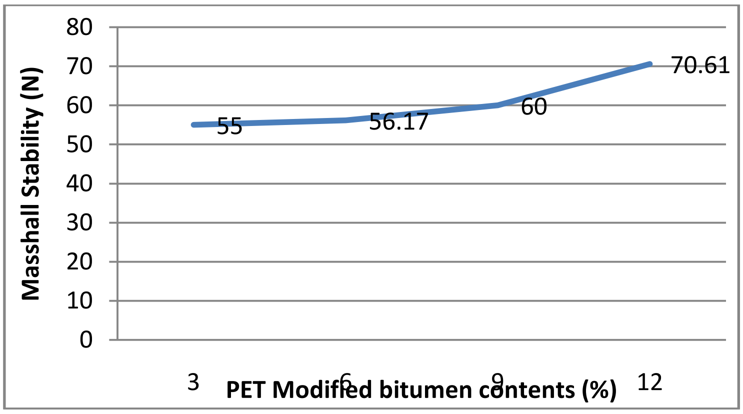

Figure 4: PET modified bitumen Marshall Stability

Flow (mm): Flow value of the Marshall sample shows the flexibility of the mix and greater flow indicates more flexible Marshall Sample. According to Malaysian public work department, 2008 allowable flow value is 2-4mm but BS, IS, ASTM recommended flow value is 2-5mm. PET modified Marshall Sample shows flow value gradually increase with increasing bitumen contents in the mix. In all conditions of mixing contents ratio shows 9.0% addition of waste polymers of PET sustain flow value of the Marshall mix and reduce deformation of the pavement surface. Figure 5 shows PET modified Marshall Flow values result.

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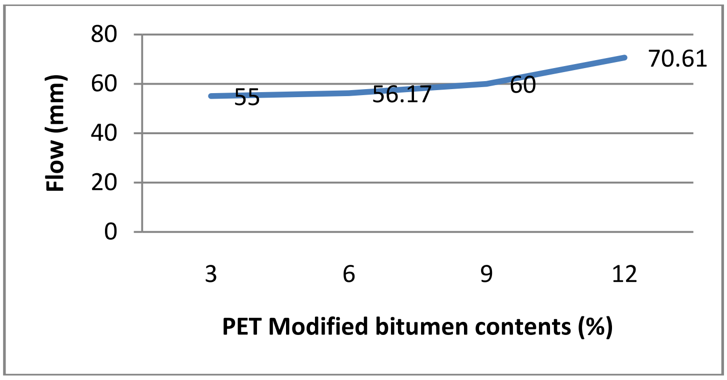

Figure 5: PET modified bitumen Flow (mm)

Stiffness (N/mm): Mixture stiffness is significant because higher stiffness resists against rutting and can show that mixture can stand on heavier load without any deformation. The findings of PET modified bitumen show higher stiffness compare to conventional bitumen and the highest stiffness result is obtained by addition of 9.0% of PET polymer contents to bitumen. A higher value of stiffness by addition of polymers were found in the past studies indicates stiffer mixture and enhance resistance against deformation is documented. Figure 6 show the stiffness of the PET modified bitumen Marshall Samples.

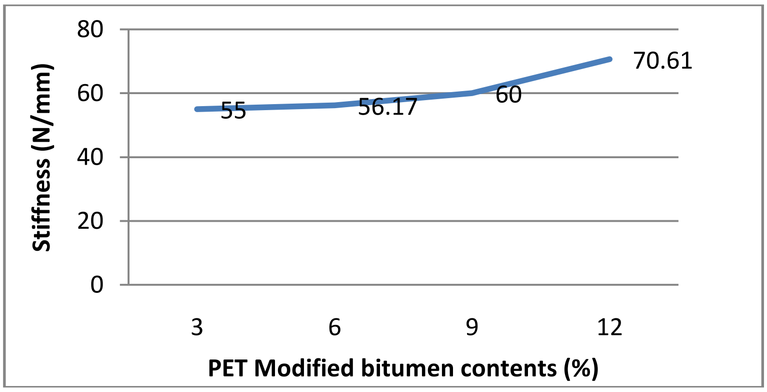

Figure 6: PET modified bitumen Stiffness

Voids Filled with Bitumen (VFB %): Past track shows that voids filled with bitumen increase by increasing polymer contents. Moreover, voids filled contents has strong relation with voids total mix and density, range voids contents was determined in at polymer addition of 9.0% by weight of optimum bitumen contents (OBC) which was 5.5 %. Study results shows that PET modified bitumen has strong bonding with asphaltic material and PET modified bitumen shows satisfactory result of VFB by 9.0% of polymer contents in the bitumen.

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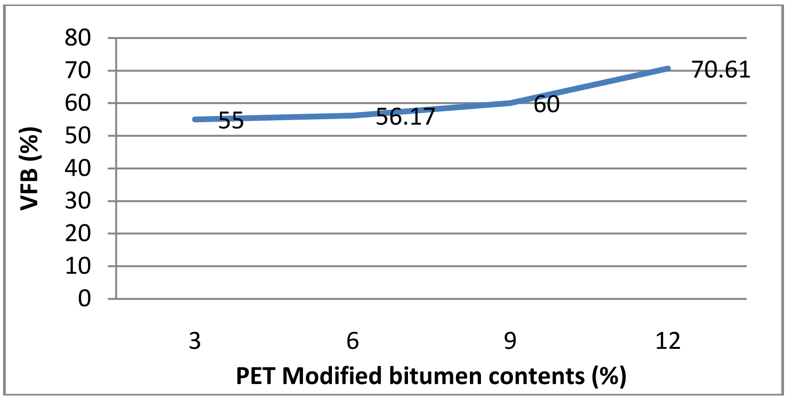

DISCUSSION

Polymer has similar characteristic likewise asphalt both are hydrocarbon material and has strong bonding quality. Thermal analysis of the PET polymer shows that waste PET made has high matching with bitumen material and creates strong bonding in between the polymer and bitumen molecules in the result enhancement of bitumen is occurs. In addition, PET modified bitumen improved various properties and characteristic of the unmodified bitumen such as penetration, softening point, ductility and Marshall Stability and stiffness. Penetration value of the conventional bitumen and polymers modified bitumen was compared in this study, polyethylene terephthalate modified bitumen has lower penetration compare to conventional. Study pointed that lower penetration value of the bitumen enhance properties of the pavement materials. Softening point result indicate that PET modified bitumen has higher value of softening point which shows less temperature susceptible and improve properties of the bitumen material. PET polymer tough nature reduces the ductility of the bitumen and this will reduce creep and fatigue in bitumen material. Generally, the addition of polymers to the bitumen density decrease while addition of polymers shows density increase with increasing polymer contents in the bitumen blend and highest density was achieved on 9.0%.

Study justified with the past Marshall Stability of the bitumen increase 50-60% by addition of waste polymer, study findings shows that by addition of 9.0% highest Marshall Stability in mix was achieved and likewise stiffness, flow and voids filled with bitumen properties of the Marshall Mix was improved Percentage of the void total mix found to decrease while increasing modified bitumen contents in the Marshall Mix. In flexible material higher flexibility is the result of the higher flow value, polymer modified bitumen shows higher flow value due to higher concentration of polymer in bitumen blend.

V. CONCLUSION

Thermal analysis of waste Polyethylene terephthalate (PET) using Thermogravimetric analysis (TGA) and differential scanning calorimeter (DSC) was carried out in the result study concluded that PET has high compatibility with bitumen grade 80/100 and completely soluble in bitumen at temperature range of 160-190 ^{o}C. Moreover, improving properties of bitumen material is witness evidence of the PET strong bonding with bitumen material. By addition of waste Polyethylene terephthalate (PET) 9.0% to the weight of conventional bitumen grade 80/100 shows lower penetration and ductility value while softening point value increase. Modified bitumen mix has a tendency of separation from the bottom to the top of the mix; it might be in the result of the insufficient mixing, imbalance temperature of heating during the mixing process. Marshall Stability analysis was deeply studied and concluded that polymer modified bitumen has higher stability compared to normal bitumen up to certain limit as by the addition of 9.0% polymer contents increased 50-70% stability value of the Marshall mix. Study revealed that stiffness of the modified bitumen is significantly improved which shows highly resistance against rutting and permanent deformation. In short, study concludes that by using waste Polyethylene terephthalate (PET) significantly enhanced properties of 80/100 bitumen in the result Marshall Stability and stiffness of the pavement remarkably increased.

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Bitumen Contents (%)	**Density (Kg/cm^3)**	**Stability (N)**	**VTM (%)**	**VFB (%)**	**Flow (mm)**	**Stiffness (N/mm)**
4.5	2.24	7227.6	9.39	51.24	2.540	2845.51
5.0	2.35	9554.0	5.24	66.73	2.89	3306.61
5.5	2.39	15530.0	3.51	76.18	3.56	4362.35
6.0	2.37	12491.5	2.76	82.62	4.07	3069.16

Analysis parameter and JKR standard for optimum bitumen content (OBM)

Marshal Properties	**JKR/SPJ/2008-S4**	**Results (ACW-14)**	**Status**
Stability	>8000 N	15530 N	OK
Flow	2-4mm	3.56mm	OK
Stiffness	> 2000 N/mm	4362.35N	OK
VFB (Voids filled bitumen)	70-80 %	76.18 %	OK
VTM (Voids in total Mix)	3% -5 %	3.51 %	OK

Polyethylene Terephthalate (PET) Modified Bitumen

PET Contents	**Density (Kg/cm^3)**	**Stability (N)**	**VTM (%)**	**VFB (%)**	**Flow (mm)**	**Stiffness (N/mm)**
3.0%	2.19	15137.1	5.60	55.00	3.67	4124.55
6.0%	2.21	16599.7	3.49	56.17	3.82	4345.24
9.0%	2.24	22516.4	3.12	60.00	4.29	5248.50
12%	2.17	19889.4	2.53	70.61	5.02	3907.54