

Study on Use of Plastic Waste in Bituminous Mix for Flexible Pavements

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Abstract

The study investigates the use of waste plastic bottles (Polyethylene Terephthalate – PET) in bituminous mixes as a sustainable solution for road construction. Waste plastics, being non-biodegradable and environmentally hazardous, pose serious disposal challenges, but their incorporation in bituminous concrete and dense bituminous macadam can enhance strength and durability while reducing reliance on virgin materials. Experiments were conducted with varying PET content (0–14%) using the dry process, evaluating mechanical properties such as stability, flow, Marshall Quotient, retained stability, indirect tensile strength, and volumetric properties like air voids, VMA, and VFB. Results indicated that waste plastic can safely be used up to 14% of bitumen content, with 8–10% proving most efficient for achieving durable and economical flexible pavements, making this an environmentally viable disposal method with value addition.

Keywords: waste plastic, bituminous mix, flexible pavement, Polyethylene Terephthalate (PET), durability

Introduction

Economic competitiveness and productivity challenges for developed and developing countries are the major problems over last two decade. To achieve economic competitiveness, manufacturers have turned to making large vehicles to fulfil the delivery of goods (Ahmadinia et al. 2012). During early days, there was nominal traffic with lower axle loads on highways (Kumar and Goyal, 2011). Recently, Road Ministry of India has raised the legal axle load for various categories of commercial vehicle by about 25%. So, heavy vehicles are increasing in radical manner on roads. The expected life of pavement reduces due to these heavy vehicles. This problem can be solving, to some extent, by using high quality material or more effective construction techniques.

Production of various waste materials also increases with increase in population. Safe disposal of non-decaying waste materials with zero or negligible salvage value is an environmental hazard for developed and developing countries. Plastics, a commonly used material, which is friend to common man creates problem for environment after its use. Visibility of these wastes has been perceived as serious problem and targeted in solid waste management. Due to non-biodegradable properties plastics have long life. Uncontrolled burning of plastics leads to generation of many hazardous air pollutants which depends upon the type of plastic. End of plastic life in one application can be recycled in to a second life application through thermal treatment; each thermal treatment leads to certain degree of degradation in plastic quality. “Being a non-biodegradable material waste plastic does not decay with time and even if dumped in landfills, finds its way back in environment through air and water erosion, choke drains and drainage channels, eaten by unsuspecting grazing animals causing illness and death” (IRC SP, 2013).

Flexible pavements are the most common type of pavement, used worldwide with more than 95% of total road network. The huge consumption of raw material on daily basis for construction pavement all over the world leads to scarcity of natural resource after limited period. Properties and performance of bituminous mix largely depends upon the characteristics of raw material used and construction practices (Swami et al., 2004). A number of studies conclude that application of waste plastic in bituminous mixes improves their engineering properties. Waste plastic can be used in bituminous mixes by two methods i.e. wet method also known as polymer modified bitumen and dry method. In polymer modified bitumen method, waste plastic is mixed with bitumen; where as in dry method waste plastic coating is carried out over aggregates before using them in bituminous mixes (Sangita et al., 2011, Sabina et al., 2009).

Indian Road Congress (IRC: SP: 98-2013) “Guidelines for the use of waste plastic in hot bituminous mixes (dry process) in wearing courses” provide guidelines for utilization of plastic waste in flexible pavements highlighting following advantages and limitations:

Advantages

- Improvement in resistance to permanent deformation
- Improvement in resistance to water induced damage
- Improvement in durability

- Improvement in stability and strength
- Safe disposal of waste plastic
- Cost effectiveness

Limitations

- Recommended use of waste plastic made up of polyethylene terephthalate, low and high density polyethylene only
- Restriction on use of black coloured plastic waste
- Restriction on use of poly vinyl chloride - due to release of lethal levels of dioxins
- Wrong implementation of technology may produce harmful gases as waste plastic undergo thermal degradation at temperature beyond 180° C.

Importance of Research Topic

The topic “Experimental Investigation on Bituminous Mixes using Plastic Waste” has been selected for the research to determine suitability of waste plastic in road construction. This will help to increase the performance along with decrease in cost of road as well as saving of environment degradation in terms of reduced pollution.

The uses of plastic in common practice are increasing all over the world. However, the disposal of this plastic after its use in huge amount has been a problem, particularly in metro cities. The mixing up of these wastes with other bio-degradable organic waste materials in the garbage of the urban areas generates problem. Therefore, attempts are being made in some areas to limit or even to prohibit the use of plastic for packing and other common use, so as to control this "undesirable waste material" from getting mixed up with the other organic garbage. Being, a non- biodegradable material, waste plastic does not decay over time. After dumped in landfills, it reaches back to environment through air and water erosion, which choke the drains and drainage channels and can be eaten by unsuspecting grazing animals causing them illness and death. Identification of waste plastic salvage value and development of waste plastic so that its economic potential can be explored. This will reduce the disposal problems as well.

So, there is a need to use plastic waste in environmental and eco-friendly way for its safe disposal. The prime significance of this study is to find out an alternate for disposal of plastic waste, that too with value addition in road construction along with economy.

Classification of Plastics

Depending upon chemical composition, plastics are known as thermoplastic and thermosetting material. Thermoplastic material can be shaped into desired shapes under controlled heat and pressure and become solid on cooling. They can be remoulded by applying same conditions of heat and pressure. Thermosetting materials shaped once cannot be softened / remoulded. Types of thermoplastic and thermosetting resins are given in Table 1.1.

Table 1.1: Thermoplastic and Thermosetting Resins

Sr. No.	Thermoplastic	Thermosetting
1	Polyethylene Terephthalate	Bakelite
2	Poly-Vinyl Acetate	Melamine
3	Poly-Vinyl Chloride	Urea - Formaldehyde
4	Polypropylene	Epoxy
5	Low - Density Polyethylene	Polyester
6	High - Density Polyethylene	Alkyd
7	Polystyrene	-

Scenario of Waste Plastic

“Production of waste plastic reached an unprecedented record of about 299 million metric tons in year 2013, which was increased 498% as compared to generated in year 1976 as shown in Figure 1.1. Annual globally plastic waste estimated in 2015 was 15 million metric tons and expected to reach 85 million tons by the year 2020. World over , top five exporters United State of America, Japan, Germany, United Kingdom and Hong Kong have effective waste plastic collection systems. Global plastic trade which utilized about 29-33% of the post-consumer plastic wastes is not sufficient to extract its resource value” (Sojobi et al., 2016). India consumed 8 million tonnes plastic per year and converted 15342 tonnes per day as waste.

Objectives of the Research Work

The objectives of the study “Experimental Investigation on Bituminous Mixes using Plastic Waste” aims to investigate the behavior of bituminous mixes with addition of waste plastic.

The main objectives of the study are:

- a) To study the physical properties of materials used for bituminous mixes.
- b) To determine optimum bitumen content and optimal dose of waste plastic (PET) in bituminous concrete (G-II) and dense bituminous macadam (G-II) bituminous mixes.
- c) To develop correlation between various properties of bituminous mixes and dependent variables.

Methodology for Present Study

The detailed methodology adopted in the present study is expressed in the form of a flow chart, Figure 3.1. The objectives of present study is to characterize the materials used for making bituminous mixes and mix designing of bituminous mixes with and without waste plastic using dry process, satisfying the requirements of strength and durability.

The methodology followed in the present research was decided with aim to—

- a) Study the information about the existing and possible future use of plastic waste in bituminous mixes.
- b) Study the effects of varied percentages of Polyethylene Terephthalate (PET) on mechanical and volumetric properties of Bituminous Concrete (Grade -II) and Dense Bituminous Macadam (Grade -II) mixes.
- c) Discuss the suitability of waste plastic (PET) in flexible pavement with special reference to India

Materials Used

In order to achieve the defined objectives material comprising of aggregate (coarse and fine), filler, bitumen and waste plastic bottle (PET) was procured and tested for basic engineering properties as under:

Bitumen

Bitumen is a petroleum product obtained through fraction distillation of crude. It is hydrocarbon material of pyrogenous origin, found in gaseous, liquid, semisolid form and is completely soluble in carbon disulphide and in carbon tetra chloride. Bitumen has mainly four grades depending upon viscosity such as VG-10, VG-20, VG-30 and VG-40. Bitumen sample of VG-30 grade. The sample was tested for various engineering properties required for bituminous mixes as per Indian Standard. Test results are summarized.

Aggregates

Aggregates constitute bulk of the total volume of bituminous mixes. Hence, it is very important to study the quality of aggregates. The durability and performance of road are influenced by characteristics of aggregates used in bituminous mixes. Aggregates are broadly classified in to two types, i.e. Coarse aggregate and fine aggregate. The properties of both the coarse and fine aggregates such as size, shape, specific gravity, hardness, surface texture, water absorption and gradation affect the quality of bituminous mixes.

Coarse Aggregates

“The coarse aggregates used in bituminous mix design shall consist of crushed rock, crushed gravel or other hard material retained on the 2.36 mm sieve. They shall be clean, hard, durable, of cubical shape, free from dust and soft or friable, organic or other deleterious matter”(MoRT & H, 2013, India). The locally available aggregates of size 19mm, 13.2mm and 6mm, complying Ministry of Road Transport and Highways specifications were used in the present study. Test results on aggregates along with permissible limit and test standard code are compiled.

Fine Aggregates

“Fine aggregates shall consist of crushed or naturally occurring material, or a combination of the two, passing 2.36 mm sieve and retained on the 75 micron sieve. They shall be clean, hard, durable, cubical shape, free from dust and soft or friable, organic or other deleterious matter. Natural sand shall not be used in binder and wearing course” (MoRT & H, 2013, India). Stone dust was used as fine aggregate with properties given in study.

Mineral Filler

“Filler may originate from fines in the aggregate or be added in the form of cement, lime or ground rock. Filler has an important effect on the voids content and the stiffness of the bitumen-fines matrix. It should have a plasticity index not greater than

4. This requirement does not apply, if filler is lime or cement” (MoRT&H, 2013, India). The grading requirement for the mineral filler as per Ministry of Road Transport and Highways specifications is given. Hydrated lime of specific gravity 2.25 was used as mineral filler.

Modifier

The waste plastic bottle (Polyethylene Terephthalate (PET)) was used as a modifier. The plastic bottles were cut in uniform size, passing through 2.36mm sieve and retaining through 600 μ sieve, so that the process of coating over aggregates could be carried out with ease. Properties of waste plastic (PET) are given

Bituminous Mix Design

Bituminous mix designing is a process to determine optimum bitumen content along with appropriate proportioning of aggregate to fulfil the requirement of an ideal mix. The desirable properties of an ideal bituminous mix are stability, durability, flexibility, skid resistance and workability. Four mix design methods namely Marshall, Hveem, Hubbard-Field and Smith Triaxial are commonly used for mix designing of bituminous mix. The same have been described in the section on literature review. The requirements of bituminous mixes are explained as below:

- Sufficient stability to satisfy the service requirement so pavement without undue displacement.
- Sufficient amount of bitumen to ensure durable pavement by coating and bonding of aggregate and water proofing of mix.
- Sufficient voids for slight amount of additional compaction due to traffic load
- Sufficient flexibility to prevent racking due to repeated application of loads.
- Sufficient workability during placing and compacting
- Sufficient resistance of pavement against skidding and a function of surface texture and bitumen content.

Designation of Bituminous Mix

Bituminous Concrete (Grade -II) and Dense Bituminous Macadam (Grade -II) mixes were used for study with varying percentage of PET and designated as BC_xP_y and DBM_xP_y given.

Where, BC=Bituminous Concrete, DBM= Dense Bituminous Macadam, x =Percentage of Bitumen Content, P=Polyethylene Terephthalate (PET) y = Percentage of PET Content

Proportioning of Material

Proportioning of material affects the mechanical and volumetric properties of bituminous mixes. So, it is essential to decide the best proportion of constituting materials for bituminous mixes. In the present study analytical method of proportioning was used for proportioning of aggregates.

Optimum Bitumen Content

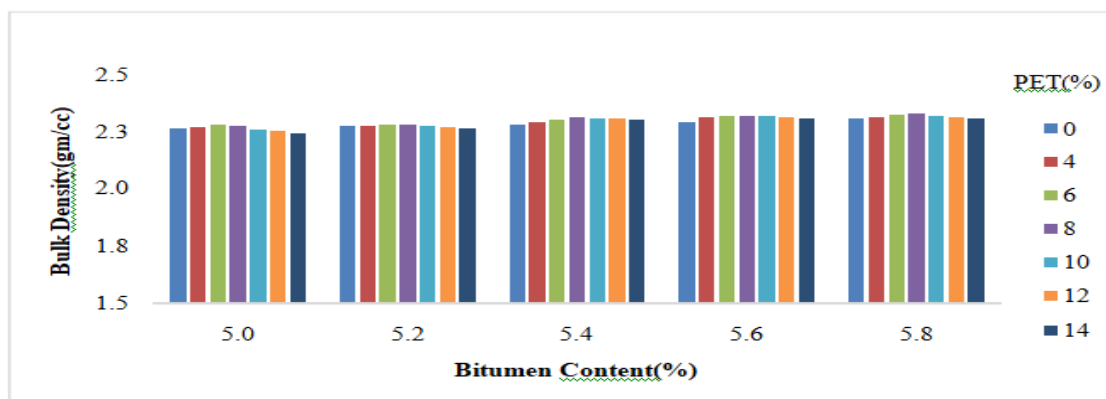
The amount of bitumen that fulfils the requirements of an ideal bituminous mix is known as optimum bitumen content. The durability of the bituminous pavement can be enhanced by the impermeability achieved. A minimum amount of bitumen is essential to prevent the aggregates from being pulled out by the abrasive actions of moving vehicles on the carriageway. At the same time it should not be too high because it would reduce stability.

The optimum bitumen content for conventional bituminous concrete and dense bituminous macadam achieves the best performance (fulfil the minimum requirements) at 5.66% and 4.82% respectively. PET modified mixes $BC_{5.4}-P_8$ and $DBM_{4.5}-P_{10}$ also achieves the best performance and fulfils the minimum requirements as per IRC SP-98, 2013 specifications. Use of PET waste plastic reduces the optimum bitumen content by 4.59% for bituminous concrete mixes and 6.64% for dense bituminous macadam

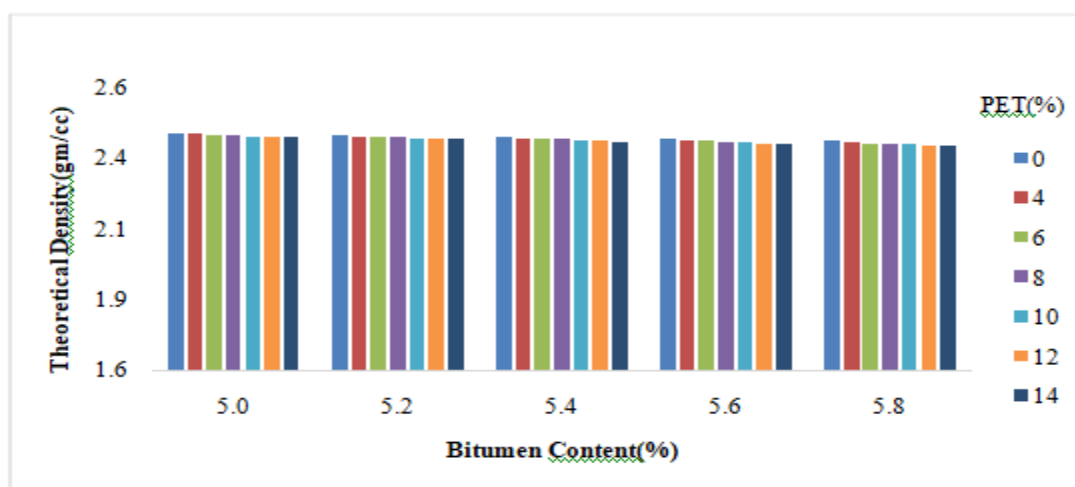
Modeling and Analysis

This section contains the results of various tests which include Marshall Stability, Indirect Tensile Strength conducted on conventional and modified bituminous concrete and dense bituminous macadam mixes. The results of various mechanical properties like stability, flow, marshall quotient, retained stability, indirect tensile strength, tensile strength ratio and volumetric properties like bulk density (G_m), theoretical density (G_r), volume of air voids (V_v), volume of

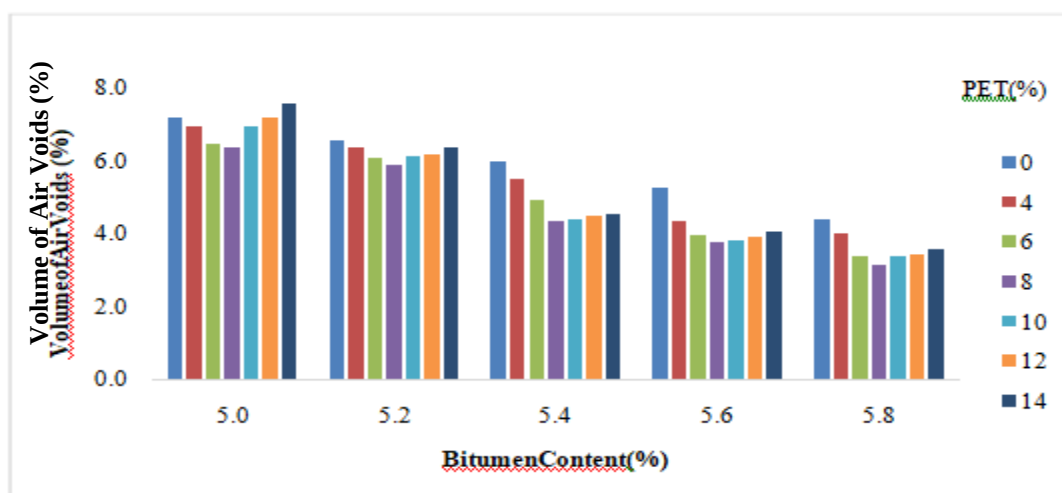
bitumen (V_b), voids in mineral aggregates (VMA), voids filled with bitumen (VFB) required for bituminous mixes are analysed.



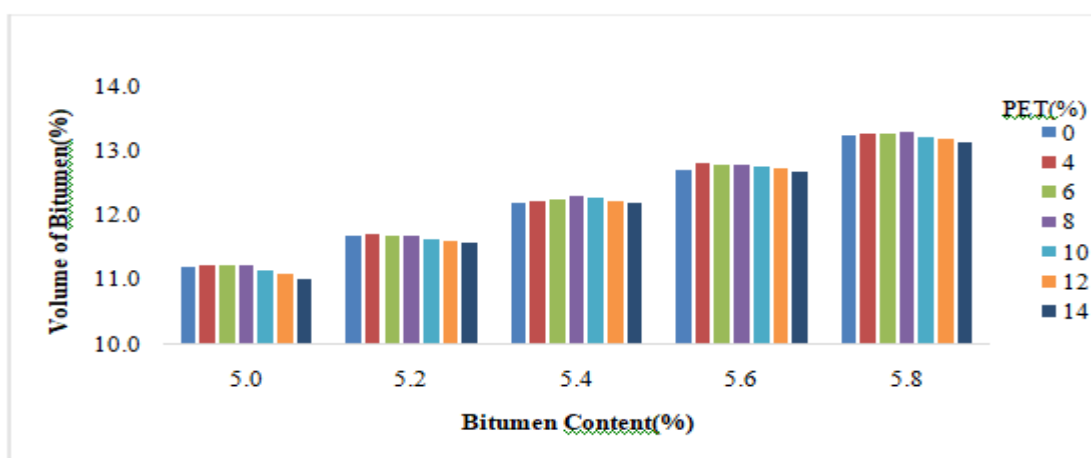
Graph 1: Bulk Density of Bituminous Concrete Mixes at different PET Content



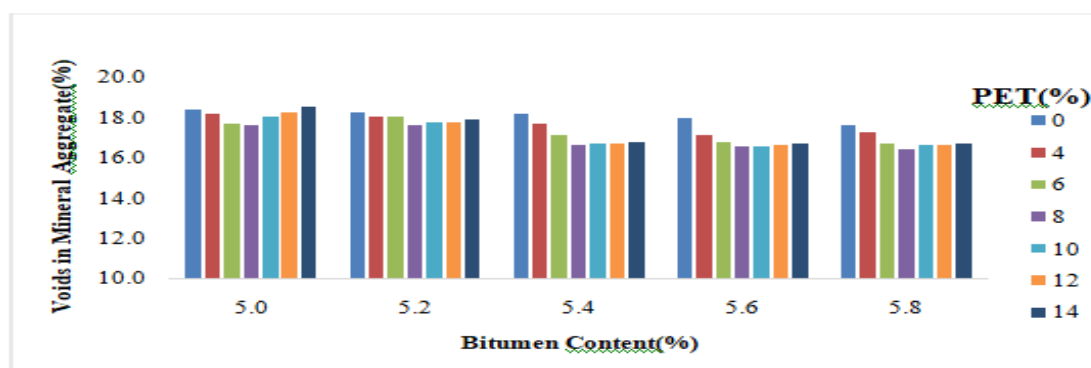
Graph: 2. Theoretical Density of Bituminous Concrete Mixes at different PET Content



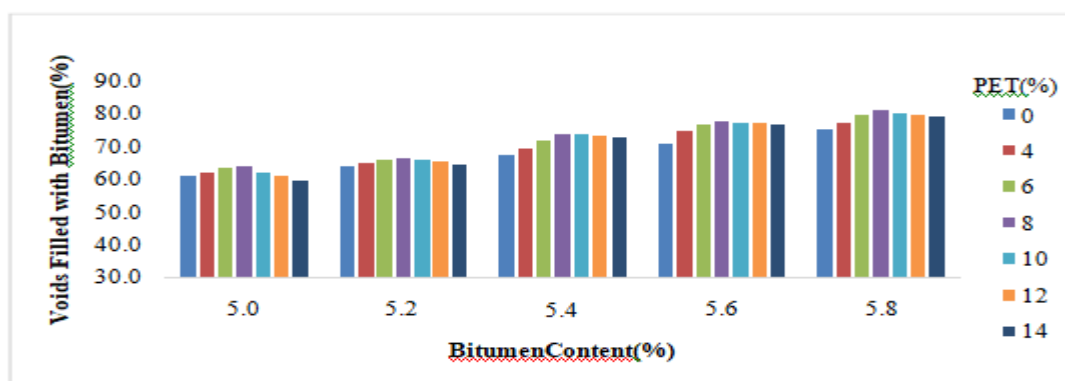
Graph: 3. Volume of Air Voids for Bituminous Concrete Mixes at different PET Content



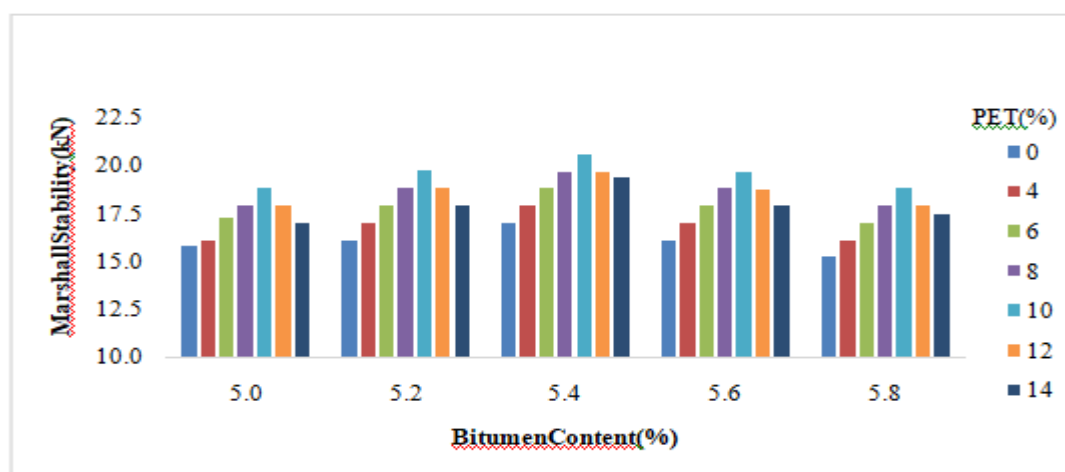
Graph: 4 Volume of Bitumen for Bituminous Concrete Mixes at different PET Content



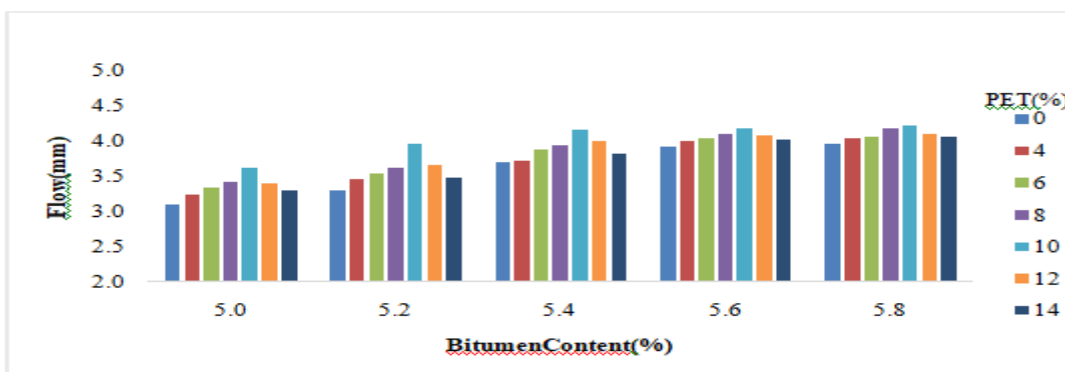
Graph: 5. Voids in Mineral Aggregate for Bituminous Concrete Mixes at different PET Content



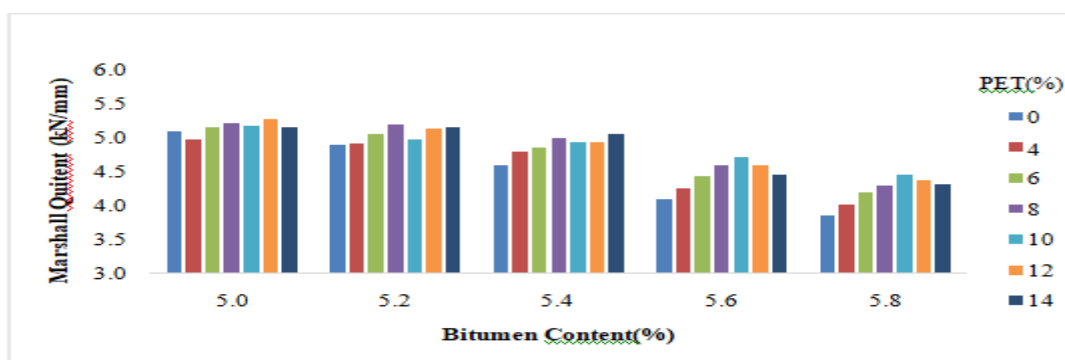
Graph: 6. Voids Filled with Bitumen for Bituminous Concrete Mixes at different PET Content



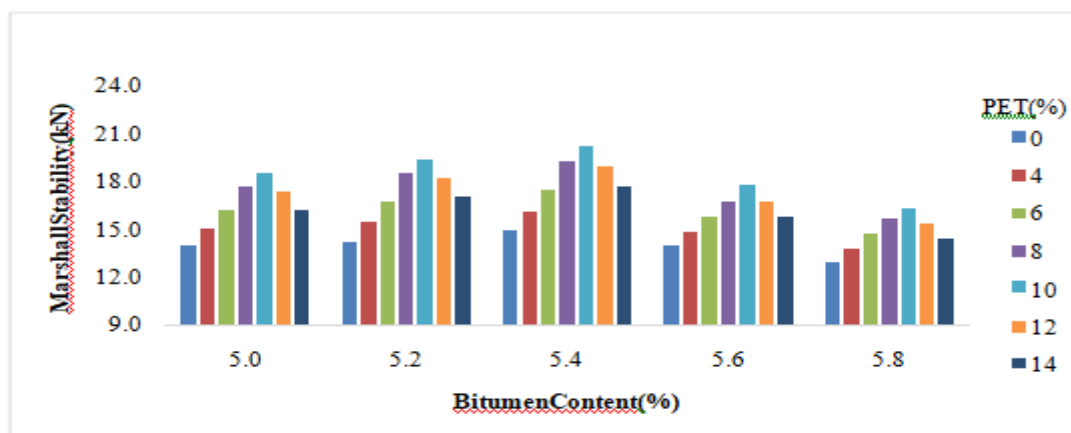
Graph: 7 Un-conditioned Marshall Stability of Bituminous Concrete Mixes at different PET Content



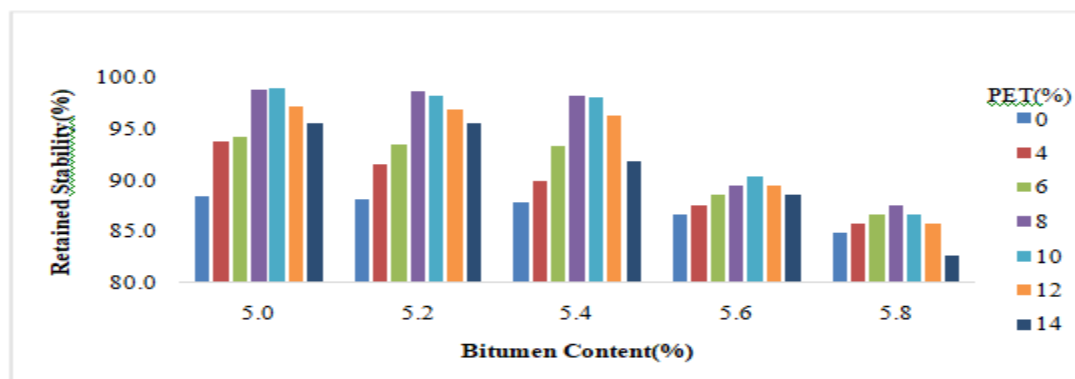
Graph:8. Flow Value of Bituminous Concrete Mixes at different PET Content



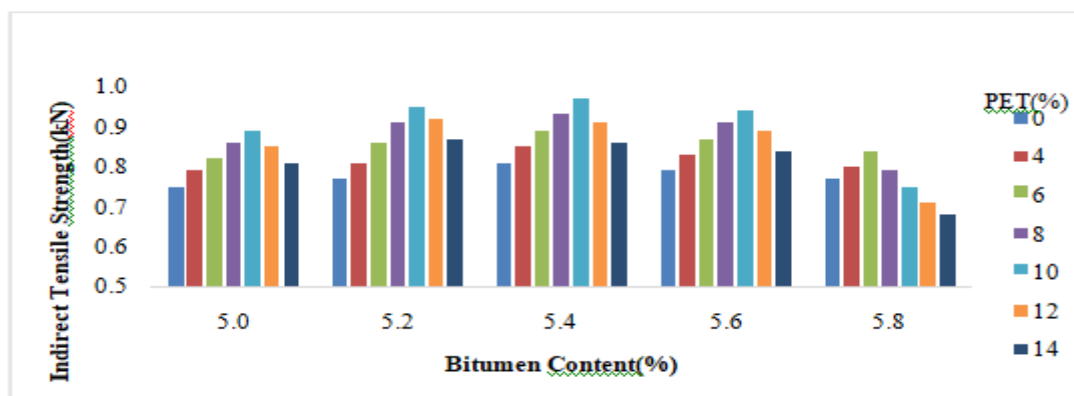
Graph: 9. Marshall Quotient of Bituminous Concrete Mixes at different PET Content



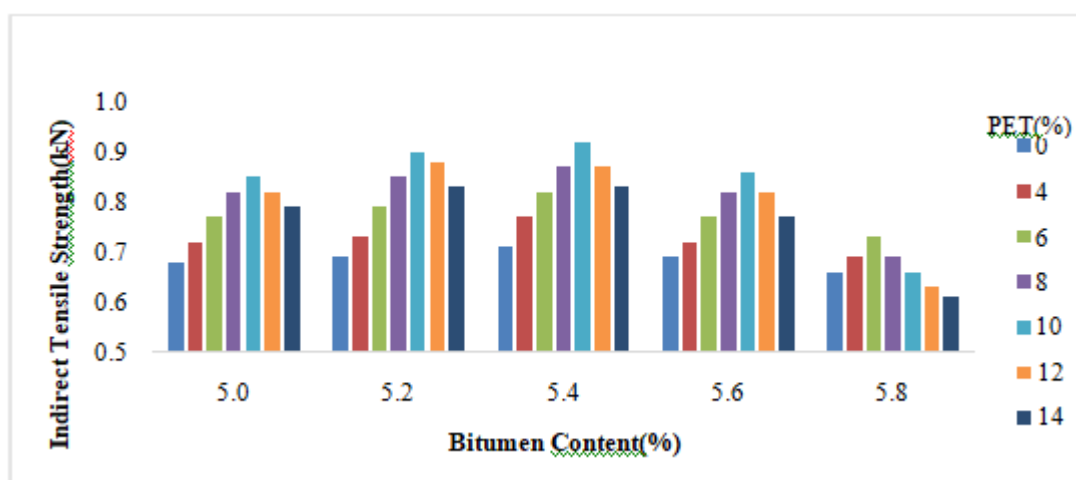
Graph: 10 Conditioned Marshall Stability of Bituminous Concrete Mixes at different PET Content



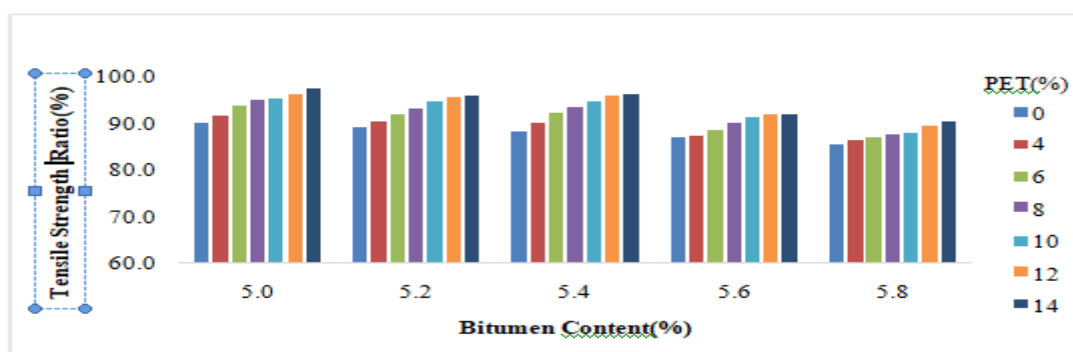
Graph: 11 Retained Stability of Bituminous Concrete Mixes at different PET Content



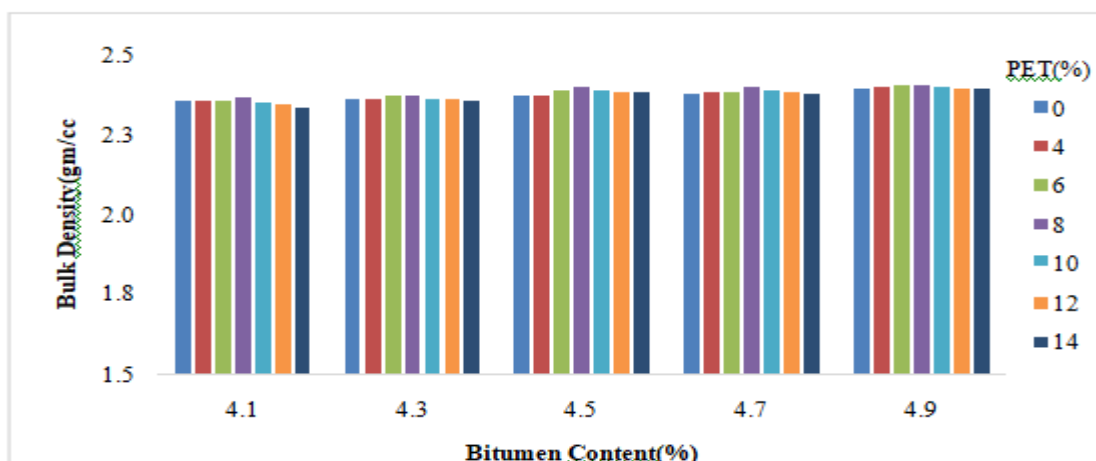
Graph: 12 Un-conditioned Indirect Tensile Strength of Bituminous Concrete Mixes at different PET Content



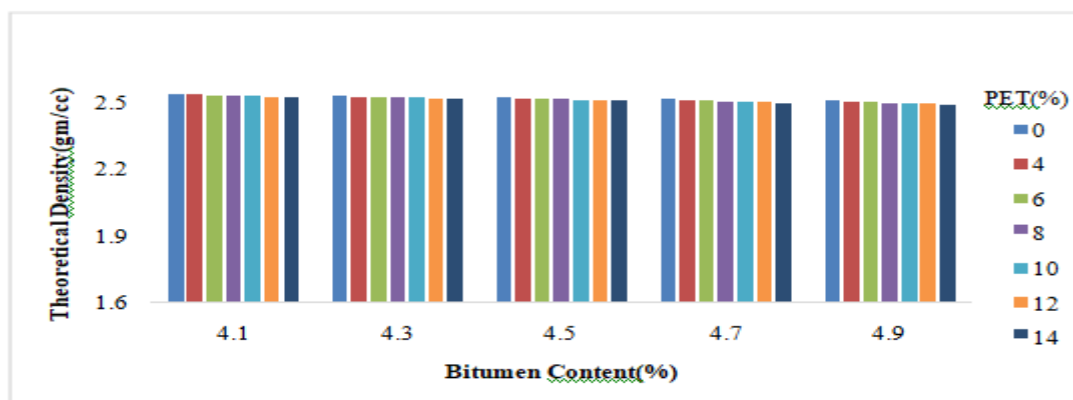
Graph: 13 Conditioned Indirect Tensile Strength of Bituminous Concrete Mixes at different PET Content



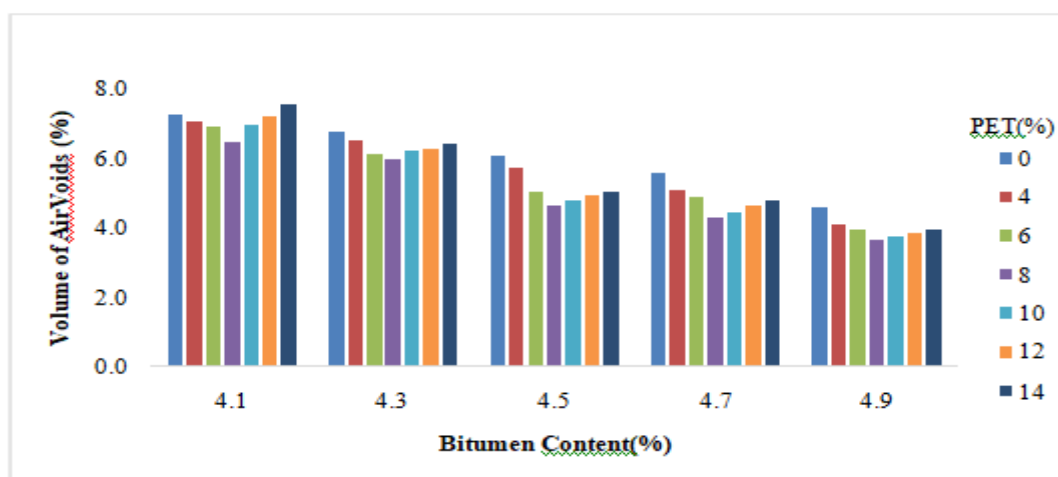
Graph: 14 Tensile Strength Ratio of Bituminous Concrete Mixes at different PET Content



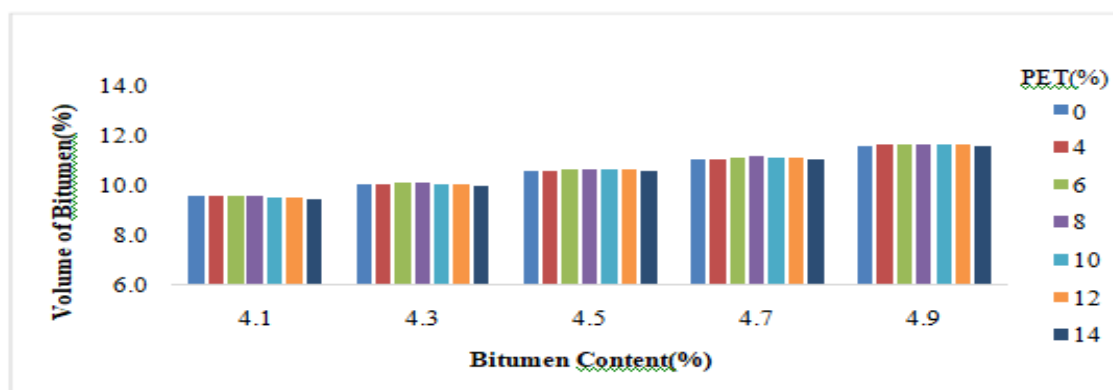
Graph: 15 Bulk Density of Dense Bituminous Macadam Mixes at different PET Content



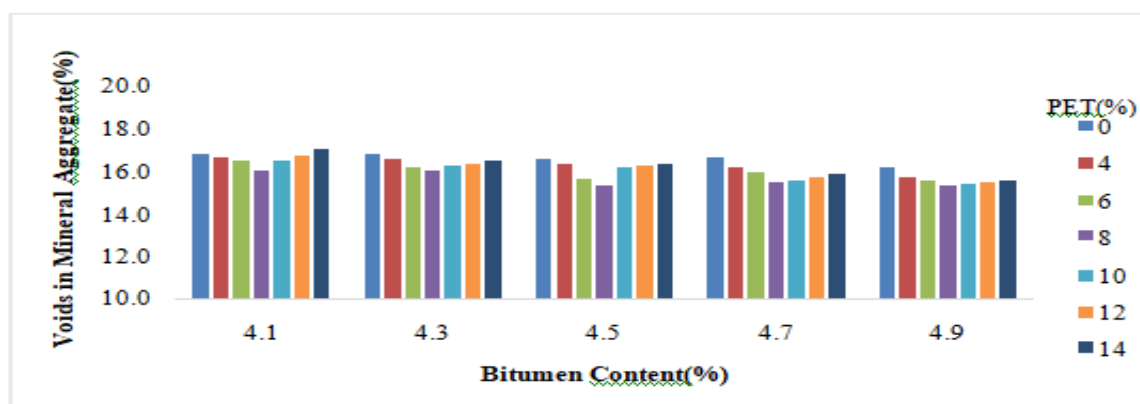
Graph: 16 Theoretical Density of Dense Bituminous Macadam Mixes at different PET Content



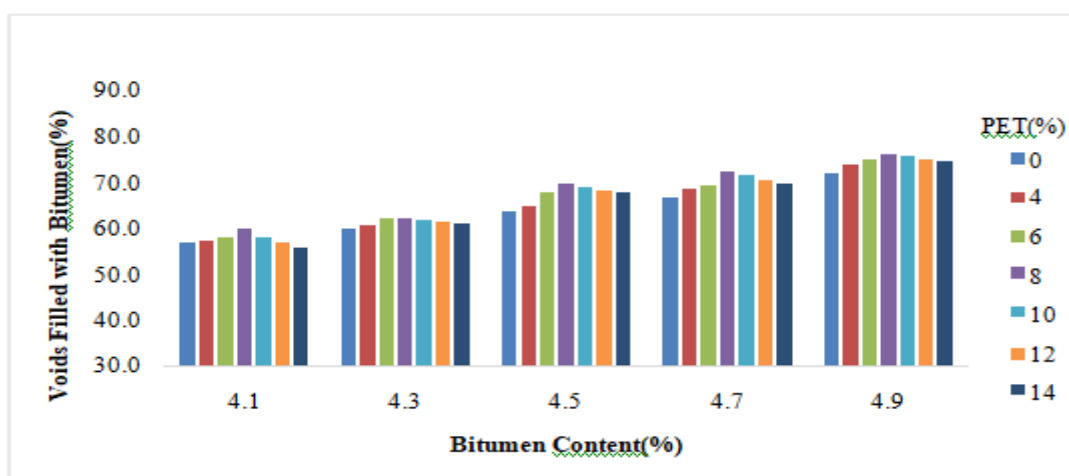
Graph: 17 Volume of Air Voids for Dense Bituminous Macadam Mixes at different PET Content



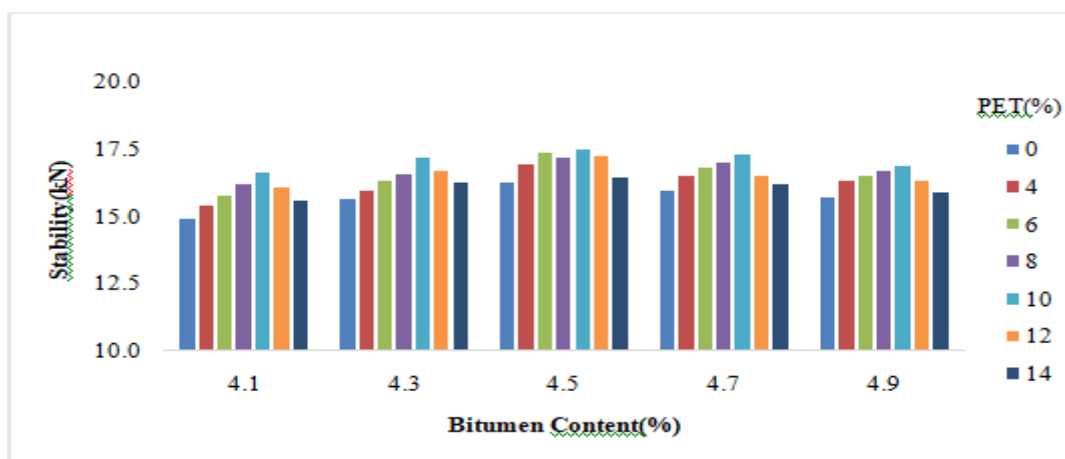
Graph: 18 Volume of Bitumen for Dense Bituminous Macadam Mixes at different PET Content



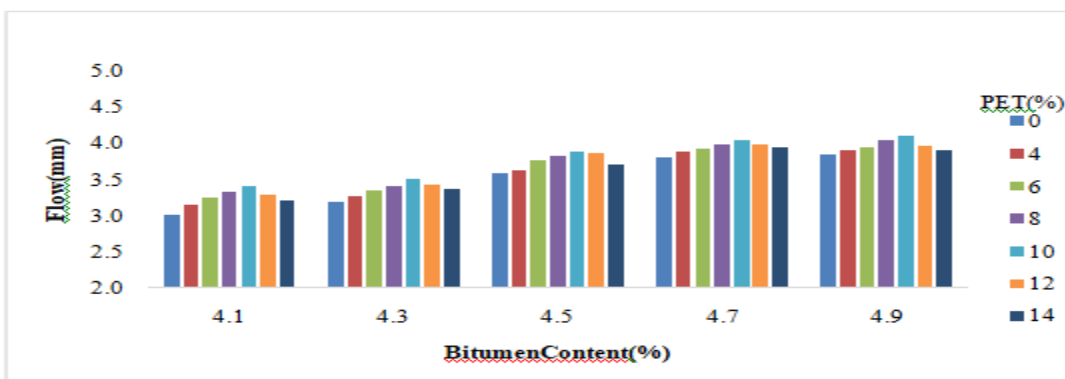
Graph: 19 Voids in Mineral Aggregate for Dense Bituminous Macadam Mixes at different PET Content



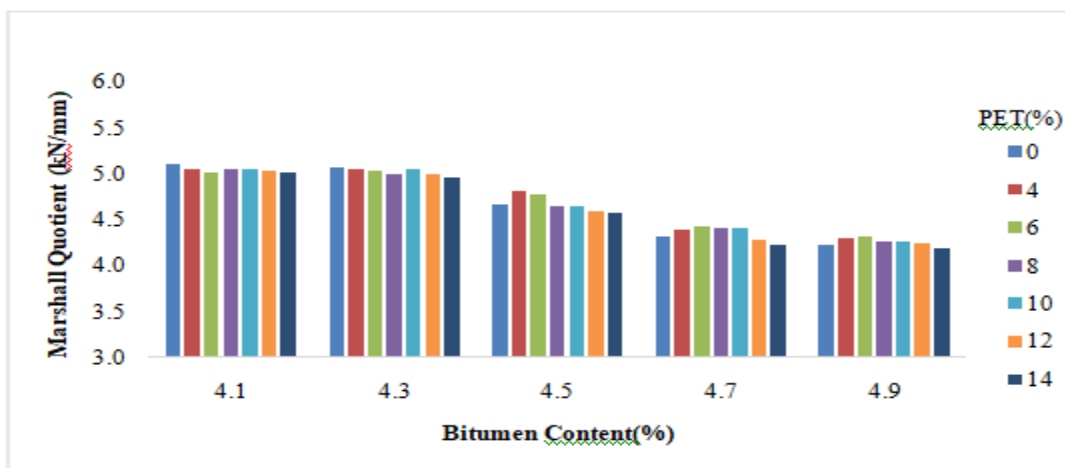
Graph: 20 Voids Filled with Bitumen for Dense Bituminous Macadam Mixes at different PET Content



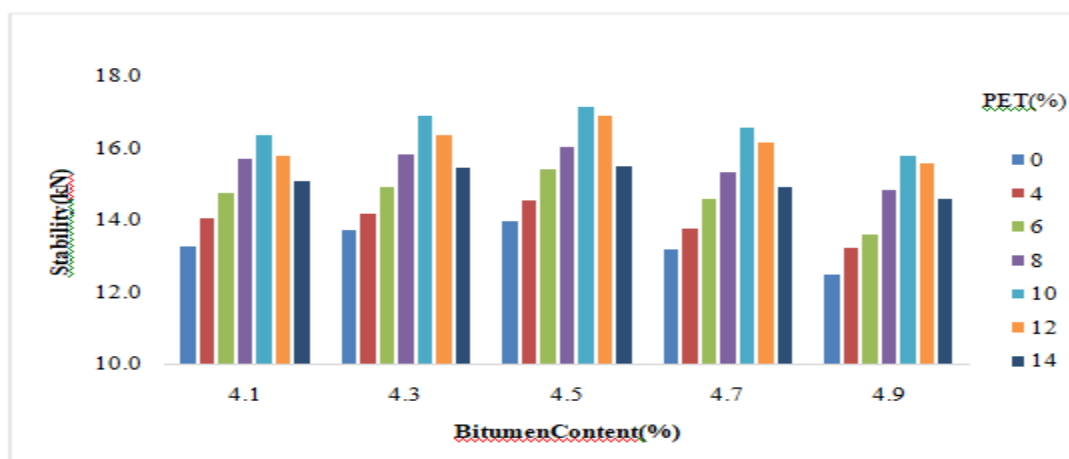
Graph: 21 Un-conditioned Marshall Stability of Dense Bituminous Macadam Mixes at different PET Content



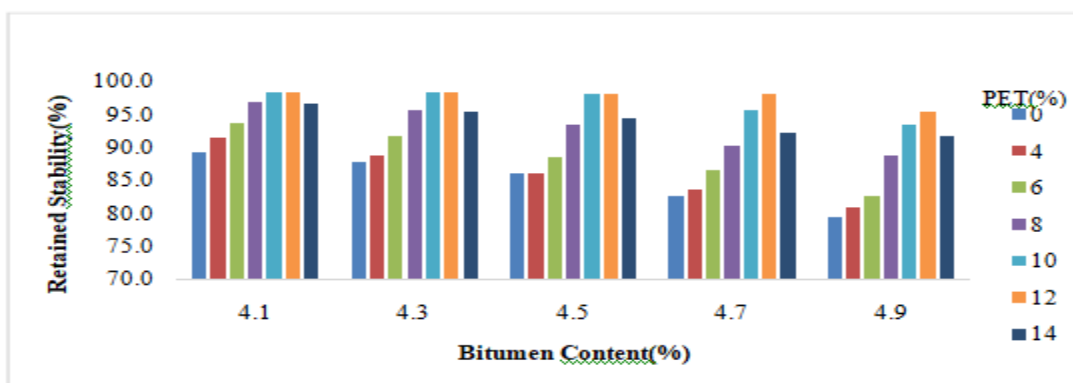
Graph: 22 Flow Value of Dense Bituminous Macadam Mixes at different PET Content



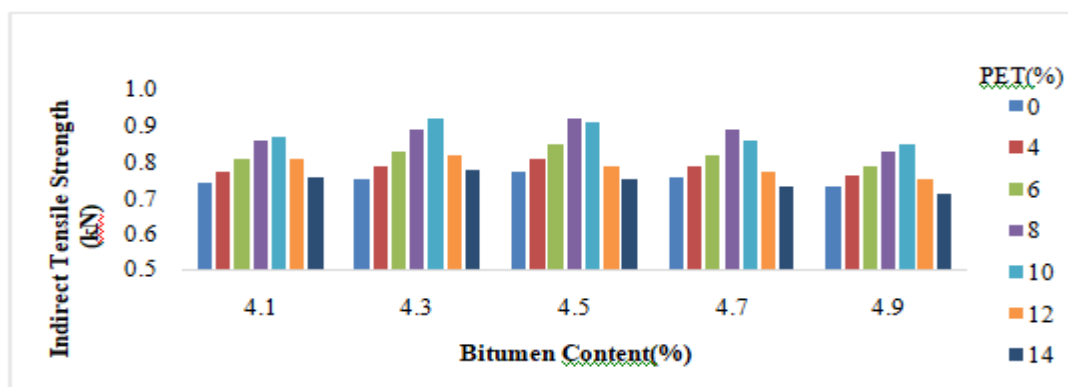
Graph: 23 Marshall Quotient of Dense Bituminous Macadam Mixes at different PET Content



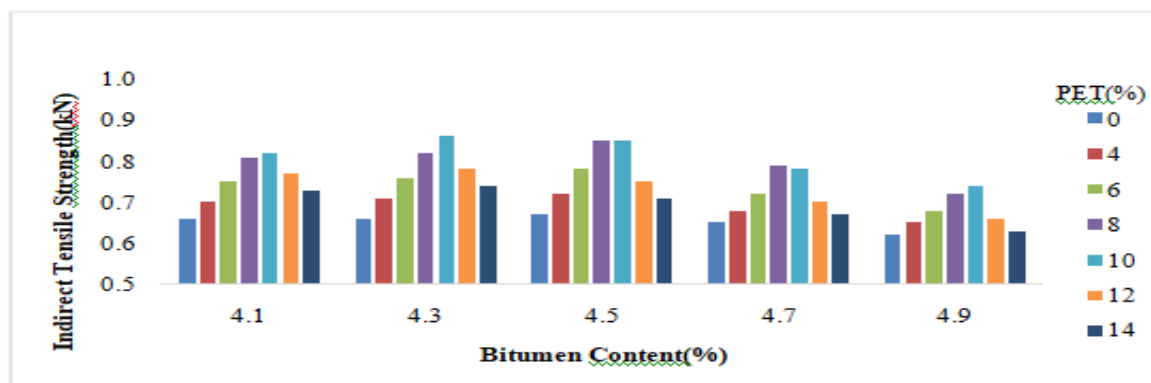
Graph: 24 Conditioned Marshall Stability of Dense Bituminous Macadam Mixes at different PET Content



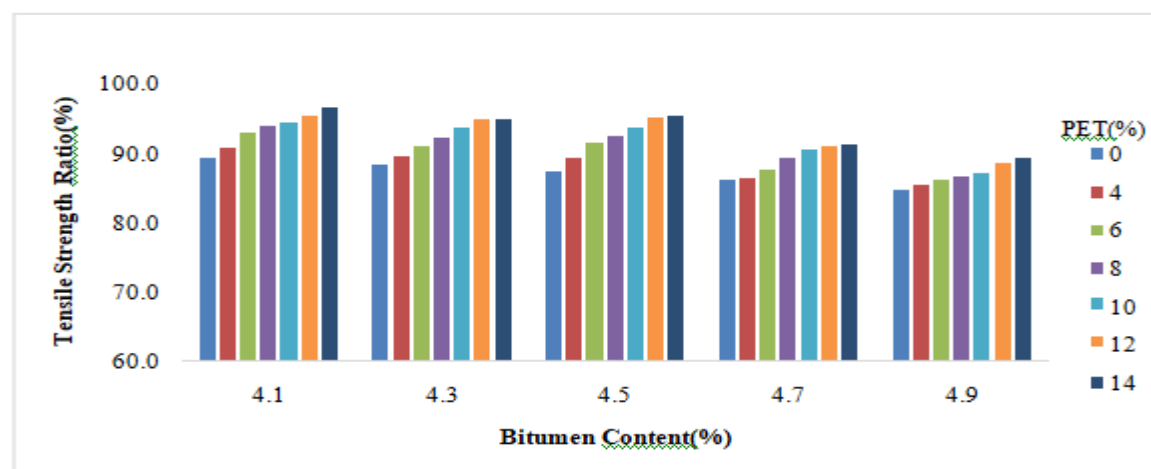
Graph: 25 Retained Stability of Dense Bituminous Macadam Mixes at different PET Content



Graph: 26 Un-conditioned Indirect Tensile Strength of Dense Bituminous Macadam Mixes at different PET Content



Graph: 27 Conditioned Indirect Tensile Strength of Dense Bituminous Macadam Mixes at different PET Content



Graph: 28 Tensile Strength Ratio of Dense Bituminous Macadam Mixes at different PET Content

Conclusions

On the basis of experimental and analytical observation on conventional and modified mixes following conclusions are drawn. Stability value of bituminous mixes increases with addition of PET – waste plastic. An increase of more than 24% and 10% was observed in case of BC and DBM respectively, at optimal dose of PET content, as compared to conventional mixes. Higher value of Marshall Quotient in case of PET modified bituminous mixes reveal stiffer bituminous mixes, more suitable for heavily trafficked roads. Tensile strength ratio (tsr) for conventional bituminous concrete and dense bituminous macadam (at optimum bitumen content) was 86.50% and 85.19% respectively. Pet modified mixes have higher tsr i.e. 93.45% and 93.70% for bc and

dbm respectively. This indicates that pet modified mixes are less susceptible to moisture damage as compared to conventional mix.

- a) Optimum bitumen content for conventional bituminous concrete and dense bituminous macadam mix was observed as 5.66% and 4.82% respectively. a reduction in optimum bitumen content was observed with use of waste plastic (pet), which is 4.59% in case of bituminous concrete and 6.64% in case of dense bituminous macadam mix.
- b) Optimal dose of waste plastic (polyethylene terephthalate (pet)) was observed as 8% and 10% for bituminous concrete and dense bituminous macadam mix.
- c) Utilization of waste plastic (pet) in bituminous mixes, using dry process, is a cost effective solution for safe disposal of waste plastic with improved engineering properties of bituminous mixes.

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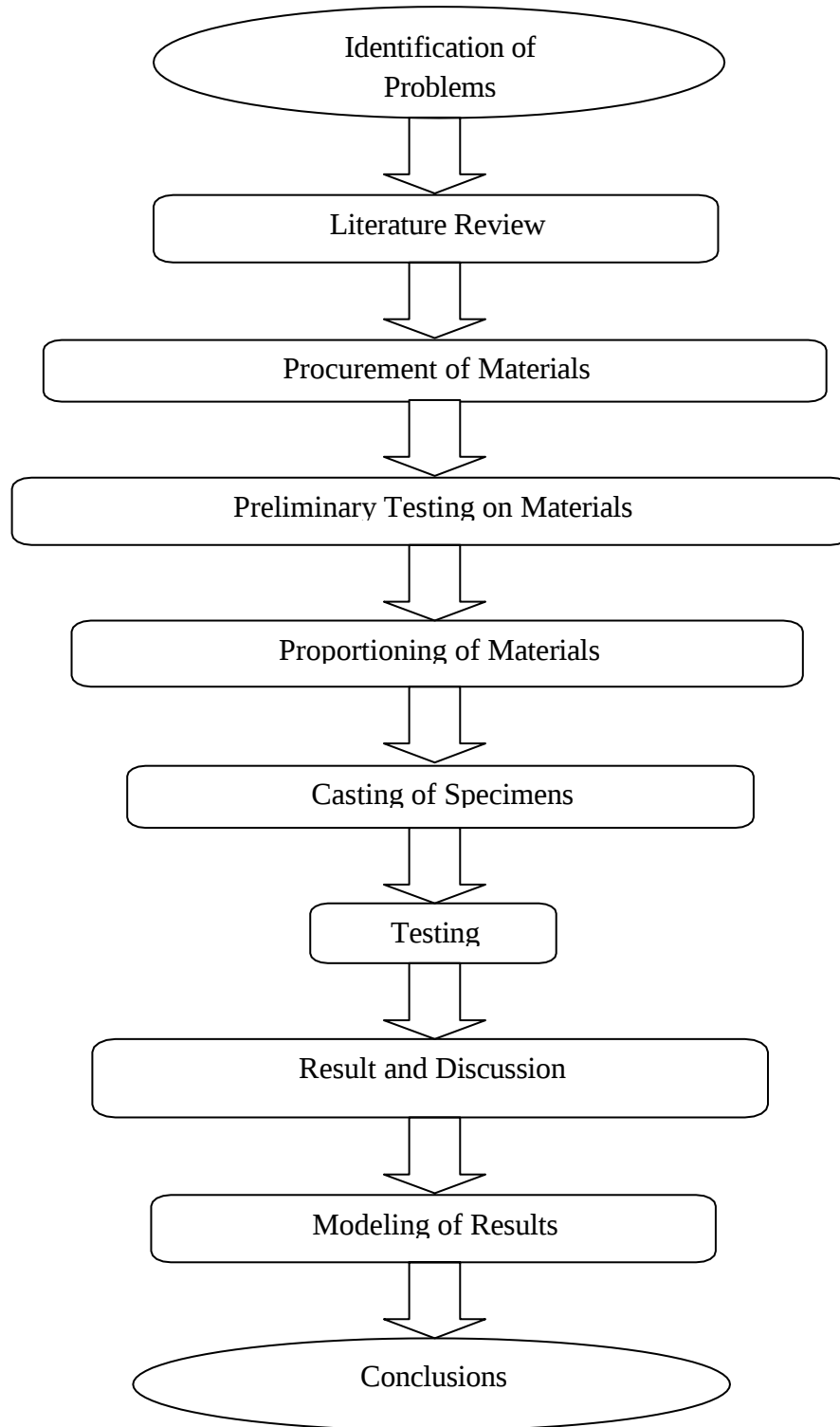


Figure 1: Methodology for Present Study