Utilisation of Waste Materials for Improvement of Bituminous Mix Performances

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Abstract. Reuse of waste materials has been a general issue in all walks of life. Paving industries now face serious crunch of coarse aggregates, a by-product of natural stone resources, which constitute about 70% of bituminous paving mixes. Considering this, some researchers have already taken a cue to explore use of recycled concrete aggregates (RCA). Similarly few works show that there has been improvement in bituminous mix performance by using shredded waste plastics. Taking a note of these two facts, an attempt has been made in this study to develop bituminous mixes with RCA replacing coarse aggregate fractions, the same being modified by waste polyethylene from milk pouches (WPMP). Based on an earlier study RCA was pre-treated with bituminous emulsion (PRCA) to address the issue of higher water absorption. For comparison purposes, all material variables have been considered in preparation of dense bituminous macadam (DBM) mixes with a fixed bitumen content of 5% (including residual bitumen) and polyethylene content of 2.5%, each by weight of total aggregates. The performance characteristics studied include Marshall test, indirect tensile strength, moisture susceptibility, dynamic modulus, flow number, resilient modulus and rutting. It was observed that the mixes with PRCA and WPMP offered the best results, though all mixes satisfy the Marshall and other characteristics as per requirements.

Keywords: waste polyethylene from milk packaging (WPMP), moisture susceptibility, resilient modulus, dynamic modulus; flow number and wheel tracking test.

1 Introduction

Aggregates in the form of crushed stone are the basic raw materials used in maximum quantities in the construction industry, occupying about 70-90% of the total volume of the construction. In past few decades, due to quick growth in the infrastructure activities such as bridges, highways and buildings, the demand for such aggregates has also been increasing substantially. As a result, the natural stone resources are depleting fast. In the process, the construction industries now face serious crunch of aggregates. Therefore, administrators, engineers and researchers are more concerned about the availability of natural stone aggregates and have already taken a cue to explore alternatives for this material. Further, the utilization of alternate and waste materials in a suitable manner on the other hand, can save money for the users, create numerous business opportunities, save energy and conserve the diminishing natural stone resources protecting the ecology and environment.

In the bituminous paving industry, comparatively less number of alternative materials and technologies have been explored to replace the conventional stone aggregates in terms of their suitability for design, construction and maintenance particularly in production of bituminous mixtures. When a concrete structure either attains its expected service life or needs to be replaced, the same is demolished, which produces a large amount of debris and waste, which is commonly referred to as concrete demolition waste. This waste concrete is broken down by crushing to smaller pieces and reused as aggregates in new construction works, which are known as recycled concrete aggregates (RCA). A number of studies have been made for potential use of these materials in different types of construction. RCA has been already accepted as a substitute material for construction of various structures in place of natural aggregates in many countries including in India. In majority cases it is used either for making new concrete or as a sub-base material in road construction. It is seen that RCA has relatively different physical, chemical and mechanical properties as compared to natural aggregates. Basically, RCA is rough, porous, flat and irregular in shape. In addition, the most disadvantageous part is that it has high porosity and therefore has high water absorption value as compared with natural stone aggregates [1-2].

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To overcome this problem, many researchers have tried various pre-treatment techniques. However, these procedures appear to be cumbersome, need careful handling, and some are also expensive. As reported separately, the authors developed a simple and user friendly procedure to pretreat the RCA before using in the bituminous mixtures. As per this procedure, 8% solution (made up of 60% water and 40% MS emulsion) by weight of the mix was mixed uniformly with RCA to form the so called pre-treated recycled concrete aggregate (PRCA) to be used in preparation of the bituminous mixtures. The pre-treatment of RCA with the above solution to develop PRCA is shown in figure 1. It was observed that the water absorption value of PRCA reduced to 1.78% from its original value of 5.6% [3].

Fig. 1. Pretreatment of RCA using emulsion-water solutions

Use of polymer for modification of bituminous mixtures offers superior performances in terms of resistances to rutting, thermal cracking and fatigue damage [4-6]. Such polymers are also used in day-today life in various forms, which after their use like any other material, form wastes. Due to inadequate alternatives of these materials for recycling, large quantities of waste plastics mainly in the form of packaging materials are dumped as landfills. This procedure offers badly on the environment as these waste polymers/ plastics being non-biodegradable remain in more or less unchanged state for a considerable period of time [5]. Low density polyethylene (LDPE) in the form of carry bags is a major contributor of waste plastics in India. Therefore, potential utilization of such waste materials has a great significance in the country, particularly to reduce environmental pollution [4, 7-8]. Considering the above facts, in the present study, the waste polyethylene processed from locally available milk pouches (packaging) (WPMP) can be explored for use as a modifier of bituminous mixtures to improve the stiffness, temperature susceptibility and other engineering properties. However, studies on the use of waste polyethylene in HMA with RCA are unavailable. Hence, there is a need to consider the use of RCA as aggregate replacement in bituminous paving layers. It is expected that there will not only be proper utilization of these solid wastes effectively, but also the environmental issues concerning their disposal can be addressed up to some extent, besides bringing in possible economy in bituminous paving. For comparison purposes, in this study as usual, conventional bituminous mixes using natural aggregates (NA) in the same grading adopted, need to be prepared and tested for the same set of engineering properties.

2. Experimental Methodology and Tests

In this work, dense grade mixes such as dense grade bituminous macadam (DBM) mixtures were prepared as per Marshall method of mix design and the engineering properties used for evaluation of the mixtures have been studied. As reported earlier, RCA was processed from locally available concrete wastes such as demolished or laboratory tested concrete slab, beam, column etc. For coarse aggregate fraction in the mixtures (more than 4.75mm size), pretreated or untreated RCA has been used and for comparison purposes, the same DBM mixtures containing natural aggregates were also tried. Stone screenings of smaller size available locally (passing 4.75mm), have been used for the fine aggregate fraction, as it was difficult to obtain this fraction from RCA in required quantities in the desired sieve size ranges. The physical properties for the different coarse aggregates used in the study have been tested in laboratory and the results are presented in Table 1. Cement (CM) has been used as filler material, and commonly used as well as locally available conventional VG 30 grade bitumen has been used for preparation of all mixtures. Further, each of the resulting mixtures has been modified with WPMP (collected locally from nearby tea stalls) as per dry process. The DBM mixtures were prepared with fixed bitumen content of 5% (including residual bitumen) and 2.5% polyethylene content. For evaluation of each selected mixture, tests such as indirect tensile strength, moisture susceptibility (tensile strength ratio), dynamic modulus, resilient modulus, flow number and rutting parameter using wheel tracking device have been taken up.

Table 1. Physical properties NA, RCA and PRCA

Property	Test Method	Test Results			Recommended
		NA	RCA	PRCA	[9]
Aggregate Impact Value (%)	[10]	14	25	16	< 27%
Aggregate Crushing Value (%)		13	23	18	< 30%
Los Angeles Abrasion Value (%)		18	29	20	< 35%
Flakiness Index (%)	[11]	19	21	17	< 35%
Elongation Index (%)		21	24	20	
Water Absorption (%)	[12]	0.13	5.6	1.78	< 2%
Specific gravity		2.7	2.37	2.44	-

2.1 Marshall Sample Preparations

This experimental work has been aimed at broadly evaluating the performance of dense bituminous macadam (DBM) mixture containing three different types of coarse aggregates named as NA, RCA and PRCA; conventional crusher dust as fine aggregate; and CM as filler. According to the Ministry of Road Transport and Highways [9], the aggregate gradation recommended for a 26.5 mm nominal maximum aggregate size (NMAS) has been considered for DBM mixture. For conventional mixtures, NA as collected from the local stone crusher unit with required size was used. As mentioned earlier. Marshall mix design procedure was followed to prepare the DBM mixtures and assesses their properties according to ASTM D 1559 [13]. Six different combinations of DBM mixtures have been considered. A mix has been named based on the type of coarse aggregate fraction such as PRCA, RCA and NA; and use of waste plastics (P) if used for mixture modification. If WPMP is used to modify the mixtures, "P" follows the aggregate nomenclature PRCA, RCA and NA to identify a respective mixture. Thus six distinct bituminous mixture samples considered in this study have been represented as PRCA, RCA, NA, RCAP, PRCAP and NAP.

2.2 Tests Performed

2.2.1 Indirect Tensile Strength Test (ITS)

The ITS test has been performed at three test temperatures (20, 25 and 30˚C) according to ASTM D6931 [14], where the cylindrical Marshall samples are subjected to compressive loads through the loading strips, which act through its circumference along the vertical diametrical plane at a rate of loading 51 mm per minute. Marshall specimens prepared as described in section 2.1 have been used in the ITS test. For this test, the load has been applied till failure observed from the dial gauge of the proving ring. The loading platens and test set up used for conducting the indirect tensile strength test are shown in figure 2.

Fig. 2. ITS loading set up

The maximum load sustained by the specimen was used to calculate the indirect tensile strength using the following equation 1.

$$ITS = \frac{2000 \times P}{\pi \times D \times H} \qquad (1)$$

Where,

ITS - Indirect tensile strength (kPa)

P - Maximum load (N)

H - Specimen thickness (mm)

D - Specimen diameter (mm)

2.2.2 Tensile Strength Ratio (TSR)

The TSR result of a bituminous mixture is an indicator of its resistance to moisture susceptibility. The test is conducted according to AASHTO T 283 [15]. As per this a set of three cylindrical samples are tested at 25ºC temperature in a normal ITS test and such samples are referred to as dry or normal or unconditioned samples. On the other hand for conditioned samples, a set of three similar specimens have been tested with freeze-thaw action as per the above mentioned specification. The ratio of ITS of the water-conditioned samples to that of dry specimens is known as the tensile strength ratio and is usually expressed in percentage. The moisture susceptibility characteristics of the compacted bituminous mixtures have been evaluated by using equation 2.

$$\text{TSR (\%)} = \frac{S_2}{S_1} \qquad (2)$$

Where,

S_1 = average tensile strength of the dry subset

S_2 = average tensile strength of the conditioned subset

2.2.3 Resilient Modulus Test

In this test, a repeated load is applied to a Marshall sample and the horizontal and vertical deformations are measured. The results of this test namely, resilient modulus and Poisson's ratio are the two basic inputs required for the analysis and design of bituminous pavements. For this purpose, a repeated load customized test setup has been developed and the test is conducted according to ASTM D 4123-82 [16]. In the present experimental investigation, resilient modulus test is conducted at a temperature of 25ºC and the loading frequency was selected as 1 Hz as mentioned in the above ASTM standard. A repeated load amounting to about 25% of that contributing to static ITS, is applied for a particular mix at a particular test temperature.

2.2.4 Dynamic Modulus Test

According to AASHTO TP 62 [17], the dynamic modulus testing of bituminous mixtures was conducted using Asphalt Mix Performance Tester (AMPT). This test offers to understand the stiffness behaviour of the mixtures under dynamic traffic loading. Further, this provides a primary input required for the mechanistic-empirical pavement design (MEPD) procedure. The dynamic moduli of the mixes are normally presented in the form of master curves, which are formed using time-temperature superposition principle [18]. According to the standard protocol, these tests have been conducted for specimens of 100 mm diameter with 150 mm height, prepared with 7±1% air voids at temperatures 4, 21, 40 and 54ºC, and at load frequencies of 10, 5, 1, 0.1 and 0.01Hz under haversine loading. Such samples were prepared using a Superpave Gyratory Compactor (SGC) of larger dimensions from which the samples of required dimensions were made by coring out and trimming with the help of laboratory core cutter and diamond saw cutter respectively.

2.2.5 Flow Number Test

The flow number test indicates the start of tertiary flow in a bituminous mixture and relates indirectly to the rutting characteristics of a bituminous mixture. The flow number is considered to be that load cycle at which the rate of the change of permanent strain is minimum [19]. The behaviour of a mixture in a permanent strain test can be divided into three stages: primary, secondary and tertiary. The primary stage is characterized by rapid initial rate of increase in the permanent axial strain followed by a gradually decreasing rate of permanent strain. In the secondary stage, the permanent axial strain rate remains constant until the starting of the tertiary stage, which is indicated by a steep increase in the rate of permanent axial strain. The test is conducted for bituminous mixtures at a temperature of 54ºC in AMPT according to AASHTO TP 79 [20]. Two gyratory compacted specimens have been prepared for each mix type as described earlier under dynamic modulus test.

2.2.6 Wheel Tracking Rut Test

Laboratory wheel-tracking rut test device has been developed to simulate to the field condition by rolling a small loaded wheel repeatedly across a compacted bituminous slab having sample size of 300 × 300 ×50 mm according to European Committee for Standardization [21]. The wheel fitted in the wheel tracking device is a solid rubber tyre with outside diameter of 205 mm. In this test, two specimens were prepared and tested for each type of mix prepared at 7±1% air voids at a test temperature of 60°C. Before testing, the prepared samples have been made temperature conditioned for 4 hrs in air at same testing temperature according to CEN standard. The single wheel 'Unitracker' has been used for this test as shown in figure 3. This test is conducted till the maximum rut depth of 12.5 mm resulted or the number of load passes is 20000 cycles, whichever is earlier.

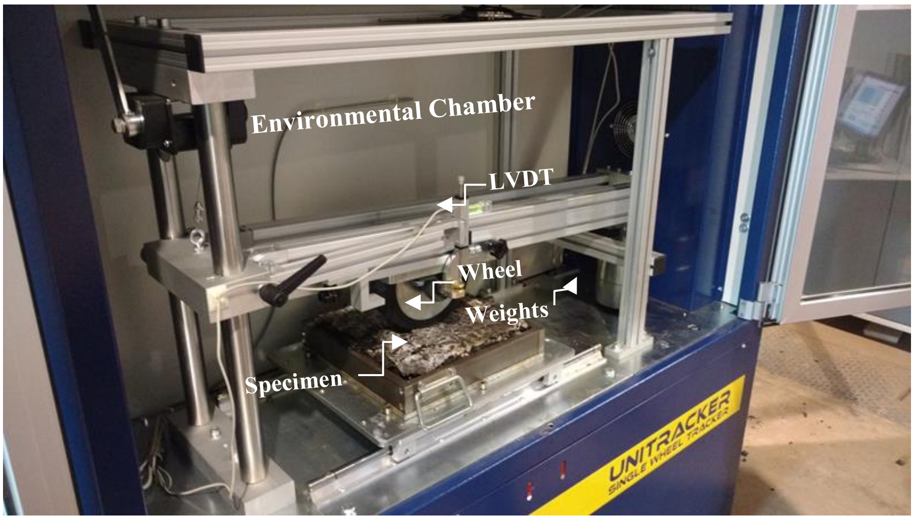

Fig. 3. Single wheel Unitracker device

3. Results and Discussion

3.1 Marshall Tests

The results of Marshall tests for mixtures prepared at 5% bitumen content (including residual bitumen) and 2.5% WPMP are presented in Table 2. From the table it is observed that, the maximum stability value is found for bituminous mixture PRCAP, though all mixtures satisfy the minimum requirement of 12kN. It is seen that RCA and waste plastics contribute to higher stability. This might be due to the better bonding between coarse particles because of the rough surface, and better adhesion provided by the waste plastics. On the other hand, percentage air voids (AV) decreased when a mixture is modified with WPMP. This may be due to WPMP filling some of the voids in the mixture. It has also been observed that all six mixtures fulfill all Marshall criteria as per MoRTH [9].

Table 2. Results of Marshall Tests

Mixture Type	Important Marshall Characteristics		
	Marshall stability, kN	Flow value, mm	Air voids, %
NA	14.83	3.3	4.2
RCA	15.71	3.2	3.7
PRCA	15.83	2.8	5.3
NAP	17.26	2.7	4.1
RCAP	18.14	2.5	3.3
PRCAP	20.03	2.3	4.8

3.2 Indirect Tensile Strength

The effects of aggregate type in the bituminous mixture on ITS value are presented in figure 4. From the figure it is observed that, as usual the ITS value decreases with increase in test temperature for each type of mixtures. It is important to note that the samples prepared with PRCA as coarse aggregate and modified with WPMP result higher ITS in all test temperatures, whereas the bituminous mixtures made with RCA as coarse fraction result in lowest ITS value as compared with other mixtures. However, addition of waste plastics for mixture modification causes a remarkable rise in ITS value even as compared to natural stone aggregates.

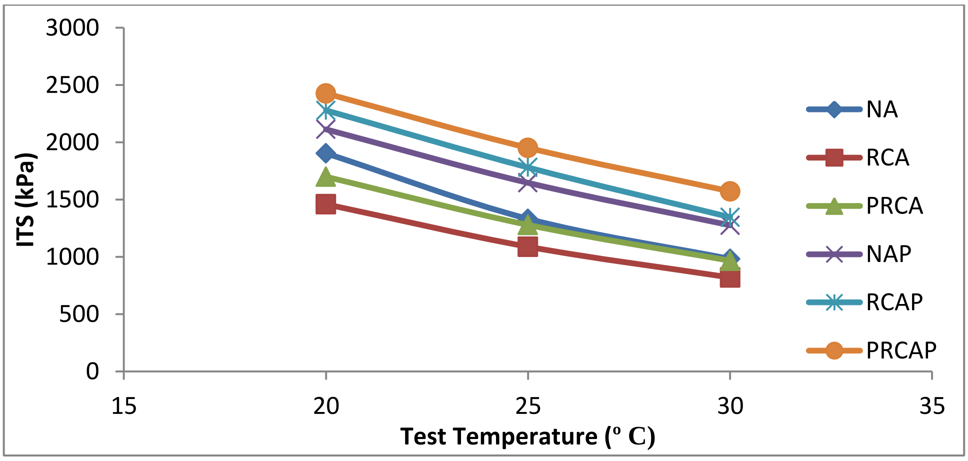

Fig. 4. ITS test results for various mixes at different temperatures

3.3 Tensile Strength Ratio

The TSR values of mixtures prepared with different aggregates and modified with waste polyethylene are presented in figure 5. Form the figure it may be observed that, the samples prepared with PRCA and waste polyethylene result in higher TSR value. On the other hand, the mixtures prepared with RCA result in the lowest TSR. However, its TSR value increases significantly when the same has been modified with WPMP. All six mixtures taken up, fulfill the TSR requirement (TSR value >80%) according to MoRTH specification [9].

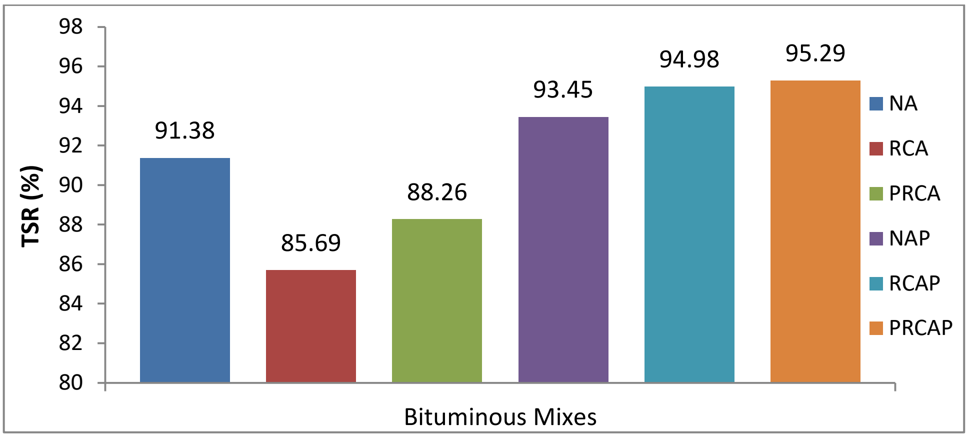

Fig. 5. TSR results for different DBM mixes

3.4 Resilient Modulus Test

The results of the resilient modulus test conducted at 25˚C test temperature have been presented in figure 6. From this, it is observed that, there is dramatic increase in resilient modulus values when the bituminous mixtures are modified with WPMP. The lowest modulus value has been observed when RCA is used as coarse aggregate. A distinct benefit is visible when RCA pretreatment is employed and modified with WPMP. PRCA as aggregates offers much higher modulus value probably due to better interlocking characteristics because of their rougher texture. Further, WPMP partially coats the aggregate (PRCA and RCA) particles and binds them resulting in better cohesion in addition to partly acting as a stabilizer in the mixture.

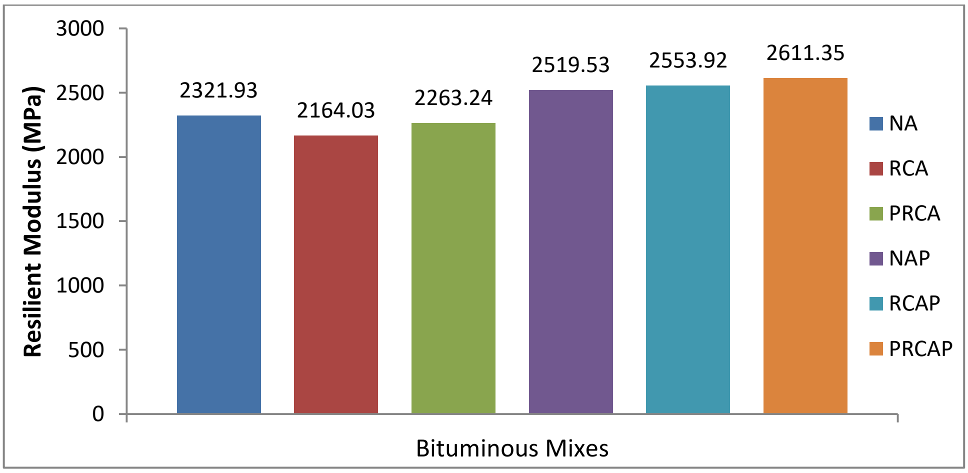

Fig. 6. Resilient moduli for various bituminous mixtures

3.5 Dynamic Modulus Test

The wide range of dynamic modulus values of bituminous mixture over varying temperatures and loading frequencies can be determined from a single dynamic modulus master curve generated at a reference temperature using time–temperature superposition principle. This temperature has been chosen as 21°C for all six DBM mixtures considered in the study. It may be observed from figure 7 that, the samples prepared with PRCA and waste polyethylene result in highest modulus values. From this figure it can be seen that, the modulus value increases when the loading frequency increases under a lower testing temperature, whereas the same decreases as the temperature increases under a low frequency. As usual, at lower temperature, the modulus value was found to be higher compared to that at higher temperature. Overall, it has been observed that, there is a significant advantage when the mixtures have been modified with WPMP at higher temperature (lower frequency). This is probably due to better cohesion between the coatings of aggregate particles with WPMP. However, the samples prepared with RCA and waste polyethylene also result dynamic moduli quite close to that with NA and PRCA modified by with waste polyethylene.

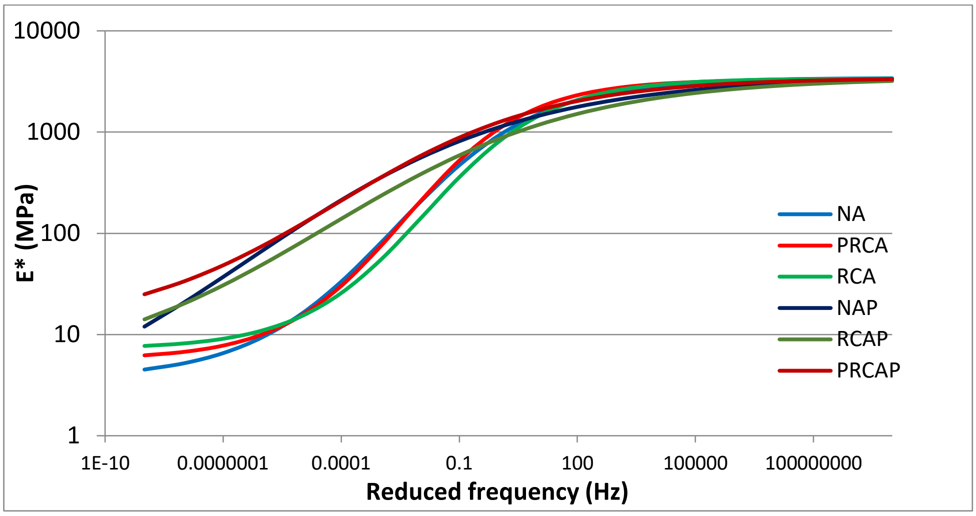

Fig. 7. Master curve for various DBM mixtures

3.6 Flow Number Test

The results of flow number test for the six different DBM mixtures evaluated in the laboratory using AMPT have been presented in figure 8. From this figure it is observed that, the mix prepared with RCA has the lowest flow number and that the mixes with PRCA and modified with WPMP have highest flow number. The notable fact is that when WPMP is used, there is a dramatic increase in flow number. This feature can be considered a very important advantage and an important contribution from this work.

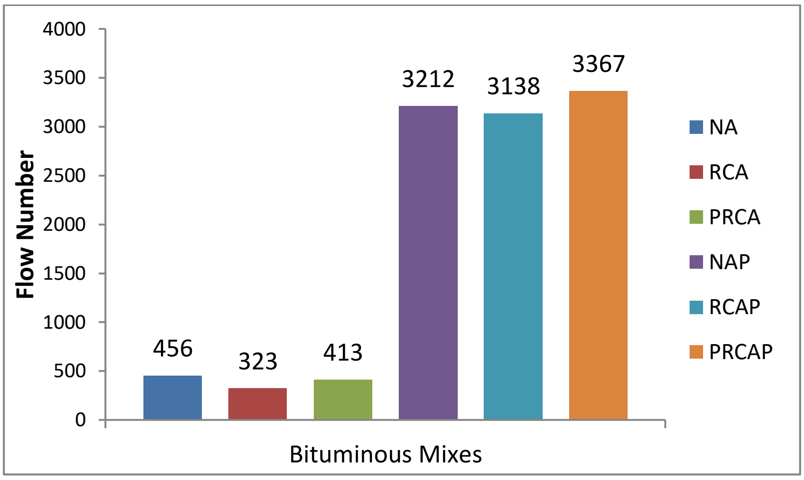

Fig. 8. Flow number of various DBM mixtures

3.7 Wheel Tracking Test for Rutting

The rutting characteristics of the six different mixtures considered in this study are presented in figure 9. All the six DBM mixtures fulfilled the criteria of maximum rut depth (i.e. <12 mm). The bituminous mixture prepared with PRCA and WPMP resulted in the lowest rut depth, whereas mixture prepared with RCA as coarse fraction result in highest rut depth as compared to others. The reasons for this effect may be attributed to the same presented earlier in respect of other parameter.

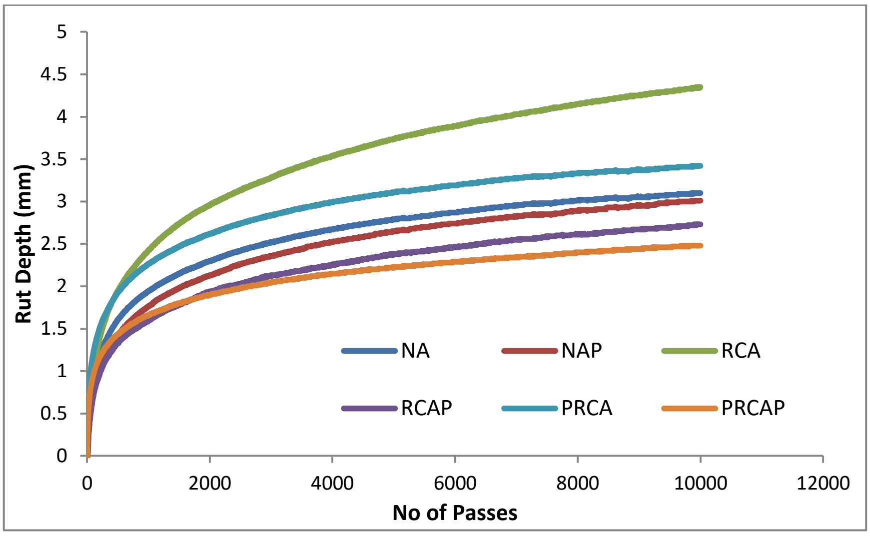

Fig. 9. Relationships between wheel track rut depth and number of cycle passes

4 Summary

Based on the investigations made in the laboratory through various tests on the DBM mixtures containing separately three types of coarse aggregates (i.e. NA, RCA and PRCA), 5% of bitumen content (including residual bitumen) and 2.5% of waste polyethylene from packaging (pouches) as a modifier, each by weight of the mixture, the following summary is drawn:

- RCA and waste polyethylene contributed to higher Marshall stability. All six mixtures considered satisfy the Marshall criteria for dense bituminous macadam mixtures as per MoRTH.
- Maximum ITS value has been observed for mixture prepared with PRCAP at all three test temperatures whereas lowest value has been observed when the mixture is prepared with RCA as compared with other combinations.
- All the six mixtures satisfied the requirement for moisture susceptibility criteria according to MoRTH (2013) as observed from the TSR results. However, waste plastics and PRCA resulted in maximum TSR value of the mixtures.
- Mixtures prepared with PRCA as coarse aggregate resulted in higher dynamic modulus values at lower temperature with higher test frequencies, whereas at higher temperature and lower frequencies, the mixtures prepared with PRCA and WPMP result higher values followed by the mixture having NA and WPMP.
- Similarly in the resilient modulus test, the maximum modulus value was observed us usual from mixtures prepared with PRCAP. However, the mixes compacted with NAP resulted nearly same modulus as with the mixes having PRCAP.
- In flow number test, highest flow number has been observed for mixture compacted with PRCAP followed by the mixtures with NAP. It has also been observed that, the addition of WPMP generally results in an extraordinary increase in the flow number.
- From the wheel tracking test for rutting, the minimum rut depth was observed for mixture containing PRCA and waste polyethylene (PRCAP) followed marginally by that with NAP. Rut depths were found to be satisfactory for all six mixtures considered in the laboratory study.

From all the tests presented in this study, it has been observed that PRCA mixed with waste polyethylene collected from milk packaging can be conveniently used in hot bituminous mixtures, particularly for lower bituminous layers (DBM layer). It is expected that the use of the abundantly available waste materials such as RCA and waste plastics can be considered as an effective and economic alternative of conventional natural stone aggregates for sustainable road infrastructure which may further assist in control of environmental pollution.

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