Influence of RAP and Waste Plastic on Cracking Resistance of Warm SMA Mixes

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Abstract  Cracking resistance of stone matrix asphalt (SMA) mixes is determined with and without reclaimed asphalt pavement materials (RAP) using coarse aggregates having elongation and flakiness index (EI+FI) of 25 and 35% respectively. The RAP at varying proportions viz 0, 10, 20 and 30% were blended with shredded plastic waste (SWP) at dosages of 4, 8, 12 and 16%. Zycotherm is used as warm mix asphalt (WMA) additive. Volumetric properties were determined at optimum binder content using Marshall mix design. Semicircular bending test was carried out to determine cracking resistance. No significant change in fracture resistance was observed for mixes prepared using aggregates having (EI+FI) of 25 and 35%. The strain energy release rate (Jc) for SMA specimen using VG-30 with varied RAP content of 10, 20 and 30% was found to be 0.55, 0.58 and 0.62 kN-mm respectively. The addition of SWP increased Jc value up to 8% for hot asphalt SMA mixes. Decrease in Jc was observed for above SMA specimens when prepared using WMA additive. It was observed that addition of WMA enables utilization of SWP up to 12% and use of SWP in SMA mix prepared with RAP increases resistance to cracking.

Keywords Cracking Resistance, Flakiness and Elongation Index, Reclaimed Asphalt Pavement, Shredded Waste Plastic, Stone Matrix Asphalt, Warm Mix Asphalt

1. Introduction

The mechanical property of asphalt mixes is influenced by the geometry of aggregates [1-3]. Aggregate geometry is defined by its form, angularity and surface texture [4]. Angularity measures the aggregate roundness that quantifies the shape of the aggregate by its edges [5] and is one of the primary aggregate properties described in the Superpave specifications [1, 6]. Since in SMA, aggregates are arranged to form stone to stone contact, leading to coarse aggregate skeleton, the geometry of aggregates influences pavement rutting and cracking. Fatigue cracking of asphalt mixture depends on aggregate structure, wheel load, test temperature, binder type and quality [7]. The addition of RAP increases fatigue cracking performance of mix [8, 9, 10]. The use of RAP at various percentages in asphalt mixes increased mechanical performance of mix [11, 12]. The percentage of RAP content could be increased by adding a softer virgin binder, use of gap graded mixes, or using warm mix additive [13]. The Fatigue cracking performance of test track study conducted by NCAT indicated that RAP content up to 45% can be utilized in open graded mixes whereas 15% RAP content in dense mixes [14, 15], indicating utilization higher RAP percentages in gap graded mixes. The addition of warm mix asphalt in SMA mix may be a viable option to incorporate higher RAP content as it contains rich binder with less ageing properties and mixes are produced at 30°C lower than conventional Hot mixes [16]. Stone matrix asphalt mixes prepared using WMA additives such as FT
wax and cellulose fibre increased service live of pavement compared to conventional mixes [17]. Waste plastic can be added during road construction either by dry or wet method. In wet process, polymers mixed with hot bitumen, whereas dry process mixed with hot aggregates and then bitumen is added. Addition of recycled or low density poly-ethylene enhances resistance to moisture susceptibility, strength and stiffness of asphalt mix [18-20]. The drain down characteristics, Marshall stability and stiffness increased with addition of waste plastic bottles [21,22]. Similar observation was made [23, 24] when waste PET flakes were added into SMA mixes in dry process. Integrating WMA, RAP and waste plastic in asphalt mixes optimizes the advantages towards sustainable pavements.

Several studies focused on utilization RAP and WMA additives at high temperature performance and moisture sensitivity [25] and influence of combined index of aggregates on rutting resistance [26]. Very limited studies are carried out on use of waste plastic for warm asphalt mixes. Present study aims to evaluate the cracking resistance of warm SMA mixes with addition of RAP with specific focus on the amount of shredded plastic waste that can be utilized at lower working temperature.

2. Experimental Work

Conventional SMA Mix was prepared using aggregates having Elongation Index +Flakiness Index (EI+FI) of 25 and 35% using VG 30 binder. The RAP materials were blended at varying proportions of 10, 20 and 30% and shredded waste plastic waste was added as stabilizer at dosage of 4,8,12, and 16% by weight of VG 30 binder for above combination. The mixes were prepared using warm mix additive. Marshall mix design was carried out and volumetric properties were determined as per Asphalt Institute MS 2 (Seventh Edition) at 4.0% air voids level. The present work primarily focused on evaluating fracture resistance of SMA mixes by utilizing shredded plastic waste and RAP for two aggregates shapes, the optimum binder content obtained for above combinations is adopted for mixes prepared with warm mix additive. Critical strain energy release rate, Jc of SMA mix was determined as per ASTM D8044-16 [27] at 25°C. A Jc value ranging from 0.5 to 0.60 kN-mm is typically recommended to ensure adequate fracture resistance of mixes.

3. Materials and Methods

3.1. Sphericity

Sphericity of coarse aggregates is determined as per Equation 1. Sphericity values range from 0.3 to 0.9 where 0 represents non spherical and 1 represents perfect sphere. The particles are classified into four categories as per Zingg shape classes [28] and are shown in Table 1.

\[
\Psi = \sqrt[3]{\frac{bc}{a^2}}
\]

Where:
\(\Psi\) = Sphericity; a, b, and c are the long intermediate and short axis dimensions, respectively.

3.2. Aggregate Shape

Shape of the aggregates is determined by flakiness and elongation index and sphericity. In SMA mix, Voids in Uncompacted Aggregates (VCA) indicate aggregate’s angularity, sphericity and surface texture (AASHTO 2003) [29]. The EI+FI is determined for sieve slots of 20-16mm, 16-12.5mm, 12.5-10mm, 10-6.3mm and obtained values are shown in Table 2

3.3. Virgin Aggregates

Aggregates were collected from two different crushing plants from same source. The elongation index + flakiness index for aggregates obtained from two plants were 25 and 35 respectively. The properties of aggregates of different combined index are presented in Table 3.
The Flakiness and Elongation index of RAP aggregates and properties of recovered binder are shown in Table 4. The binder was extracted using centrifuge extractor as per ASTM D2172M section in Bengaluru city, India. The binder was extracted 3.5. RAP Material

The RAP material was collected from arterial road section in Bengaluru city, India. The binder was extracted using centrifuge extractor as per ASTM D2172M-11 [31] and properties of recovered binder are shown in Table 4. The Flakiness and Elongation index of RAP aggregates were found to be 35. However, to obtain aggregates of less angular and flaky, RAP aggregates were fed into laboratory jaw crusher and spacing of jaw plates was adjusted by trial-and-error method to obtain Combined Index of 25. The properties of aggregates of different shape are presented in Table 5. The binder content in RAP was 3.6. Warm Mix Asphalt Additive

Zycotherm, a commercial chemical additive is used as WMA additive by 0.2% weight of asphalt binder.

### Table 2. Aggregates shape characteristics

| Size Range (mm) | Aggregate Type | FL+EI % | a (mm) | b (mm) | c (mm) | F | c/b | h/a | Shape as per Zingg | Standard Deviation |
|----------------|---------------|---------|--------|--------|--------|---|-----|-----|-------------------|-------------------|
| 20-16 | Virgin Aggregate | 16 | 27.3 | 19.5 | 14.2 | 0.72 | 0.73 | 0.71 | Equiaxial | 0.07 |
| | | 30 | 31.2 | 22.4 | 9.8 | 0.61 | 0.44 | 0.72 | Equiaxial | 0.06 |
| | RAP Aggregate | 18 | 21.2 | 15.7 | 9.7 | 0.69 | 0.65 | 0.71 | Oblate | 0.09 |
| | | 27 | 32.3 | 21.1 | 10.0 | 0.59 | 0.47 | 0.65 | Triaxial | 0.06 |
| 16-12.5 | Virgin Aggregate | 18 | 22.1 | 16.8 | 11.2 | 0.73 | 0.67 | 0.76 | Equiaxial | 0.05 |
| | | 29 | 25.6 | 18.3 | 8.5 | 0.62 | 0.46 | 0.71 | Oblate | 0.09 |
| | RAP Aggregate | 17 | 19.0 | 13.5 | 8.9 | 0.69 | 0.66 | 0.71 | Equiaxial | 0.10 |
| | | 30 | 26.8 | 18.1 | 9.0 | 0.61 | 0.50 | 0.68 | Oblate | 0.09 |
| 12.5-10 | Virgin Aggregate | 17 | 13.2 | 10.3 | 7.6 | 0.77 | 0.74 | 0.78 | Equiaxial | 0.10 |
| | | 29 | 19.6 | 10.5 | 7.9 | 0.60 | 0.75 | 0.54 | Prolate | 0.07 |
| | RAP Aggregate | 17 | 16.7 | 12.7 | 7.7 | 0.71 | 0.61 | 0.76 | Oblate | 0.04 |
| | | 28 | 21.1 | 13.9 | 7.8 | 0.62 | 0.56 | 0.66 | Triaxial | 0.10 |
| 10-6.3 | Virgin Aggregate | 15 | 13.0 | 9.5 | 7.0 | 0.73 | 0.74 | 0.73 | Equiaxial | 0.08 |
| | | 29 | 16.7 | 10.8 | 5.7 | 0.60 | 0.53 | 0.65 | Triaxial | 0.07 |
| | RAP Aggregate | 17 | 14.7 | 9.2 | 7.9 | 0.70 | 0.86 | 0.63 | Prolate | 0.05 |
| | | 29 | 17.8 | 10.4 | 8.1 | 0.64 | 0.78 | 0.58 | Prolate | 0.03 |
| 6.3-4.75 | Virgin Aggregate | -- | 9.5 | 5.8 | 4.9 | 0.68 | 0.84 | 0.61 | Prolate | 0.02 |
| | | 10.7 | 6.7 | 3.2 | 0.56 | 0.47 | 0.62 | Prolate | 0.07 |
| | RAP Aggregate | -- | 8.9 | 5.4 | 4.5 | 0.67 | 0.83 | 0.61 | Prolate | 0.10 |
| | | 11.3 | 5.6 | 4.6 | 0.58 | 0.40 | 0.50 | Triaxial | 0.05 |

### Table 3. Physical properties of conventional aggregates

| Test Properties | Conventional Aggregates- EI+FI=25 | Conventional Aggregates- EI+FI=35 | Requirement as per MoRTH Requirement |
|----------------|----------------------------------|----------------------------------|--------------------------------------|
| Impact value, % | 15.9 | 17.8 | <18 |
| Los Angeles abrasion, % | 21.4 | 24.0 | <25 |
| Specific gravity | 2.66 | 2.67 | --- |
| Water absorption % | 0.83 | 0.83 | <2 |

### Table 4. Basic properties of virgin asphalt binder VG 30 and recovered binder

| Test Properties | VG30 Binder | Requirement as per IS 73:2013 | Recovered Binder |
|----------------|-------------|--------------------------------|-----------------|
| Penetration, mm | 67 | Min.45 | 34 |
| Ductility Test, cm | 92 | Min.70 | 56 |
| Softening point, °C | 49 | 45-55 | 0.58 |
| Kinematic viscosity Pa.s | 0.400 | Min 0.350 | 1.02 |
| Specific gravity | 1.00 | --- | 34 |
3.7. Shredded Waste Plastic

Shredded waste plastic containing polyethylene and polypropylene was supplied by from KK Plastics industry, Bengaluru, India is used passing through 2.36mm and retained on 600µm is used.

3.8. Aggregate Gradation

SMA binder course prescribed as per Ministry of Road Transport and Highways, (MoRTH), Government of India V Revision 2013[32] is adopted and gradation is shown in Figure 1.

3.9. Drain Down

Drain down test was carried on SMA mix prepared using VG 30 as per IRC SP79:2008[33] and found to be more than 0.3% for mix prepared with VG 30 binder.

| Test Properties               | RAP Aggregates EI+FI=25 | RAP Aggregates EI+FI=35 | Requirement as per MoRTH (2013) |
|-------------------------------|-------------------------|-------------------------|----------------------------------|
| Impact value (%)              | 15.9                    | 18.0                    | <18                              |
| Los Angeles abrasion          | 20.4                    | 24.5                    | <25                              |
| Specific gravity              | 2.66                    | 2.67                    | ---                              |
| Water absorption (%)          | 0.76                    | 0.78                    | <2                               |

Table 5. Physical properties of conventional aggregates

Figure 1. Aggregate gradation for SMA binder course
Hence shredded plastic waste was added as stabilizer by 4, 8, 12 and 16% by weight of binder. Drain down characteristics was determined for mixes prepared for varying proportion RAP content of 10, 20 and 30% using VG 30 binders. The mixes prepared with Shredded plastic waste and RAP material fulfilled drain down conditions. However, drain down test was not conducted for RAP mixes prepared with Shredded plastic waste as existing combination has shown drain down value less than 0.3% weight of total mix. The drain down test results for above combinations is presented in Table 6.

3.10. Marshall Mix Design

Marshall Mix design was carried out as per ASTM D6927-15[34]. Marshall Properties at Optimum Binder Content for different SMA Mixes are presented in Table 7 and 8. The mixing and compaction temperature adopted for HMA and WMA mix is 160°C and 130°C, 130°C and 120°C respectively.

| Particulars                          | VG 30 | VG-30 with Shredded Waste Plastic (SWP) | 4% SPW | 8% SPW | 12% SPW | 16% SPW |
|--------------------------------------|-------|----------------------------------------|--------|--------|---------|---------|
| RAP (%)                              | 0     | 10                                     | 20     | 30     |         |         |
| Drain Down (%) at OBC                | 0.61  | 0.27                                   | 0.21   | 0.16   | 0.24    | 0.19    | 0.13    | 0.12    |
| Drain down (%) at 7% Binder Content  | 0.66  | 0.28                                   | 0.23   | 0.17   | 0.25    | 0.20    | 0.13    | 0.13    |

Table 6. Drain down test results

| Particulars | OBC (%) | VMA (%) | Stability (kN) | Flow (mm) |
|-------------|---------|---------|----------------|-----------|
|             | HMA & WMA | HMA | WMA | HMA | WMA | HMA | WMA |
| Conventional SMA | 6.4 | 17.2 | 18.1 | 7.4 | 6.6 | 5.1 | 6.1 |
| SMA+4% SWP   | 6.2 | 17.2 | 17.9 | 9.6 | 8.1 | 3.7 | 4.0 |
| SMA+8% SWP   | 6.0 | 17.3 | 18.2 | 11.0 | 9.2 | 3.5 | 4.2 |
| SMA+12% SWP  | 5.9 | 17.6 | 18.2 | 7.2 | 6.9 | 5.6 | 4.6 |
| SMA+16% SWP  | 5.8 | 18.2 | 19.1 | 8.2 | 7.4 | 6.2 | 5.9 |
| SMA+10% RAP  | 6.3 | 17.2 | 18.1 | 9.5 | 8.2 | 3.8 | 4.7 |
| SMA+20% RAP  | 6.2 | 17.6 | 18.5 | 10.4 | 9.2 | 3.5 | 4.1 |
| SMA+30% RAP  | 6.1 | 17.8 | 18.3 | 12.1 | 10.3 | 3.1 | 3.9 |
| SMA+10% RAP+4% SWP | 6.1 | 17.4 | 18.1 | 10.8 | 9.2 | 3.5 | 4.4 |
| SMA+10% RAP+8% SWP | 6.0 | 17.5 | 18.2 | 12.2 | 10.8 | 3.1 | 4.0 |
| SMA+10% RAP+12% SWP | 5.9 | 18.0 | 18.9 | 7.9 | 7.1 | 5.7 | 3.8 |
| SMA+10% RAP+16% SWP | 5.8 | 18.1 | 18.8 | 7.4 | 6.7 | 6.0 | 5.8 |
| SMA+20% RAP+4% SWP | 5.9 | 17.2 | 18.1 | 11.6 | 10.2 | 3.4 | 4.2 |
| SMA+20% RAP+8% SWP | 5.8 | 17.3 | 18.0 | 12.8 | 11.1 | 3.1 | 3.2 |
| SMA+20% RAP+12% SWP | 5.8 | 18.0 | 18.9 | 8.7 | 7.2 | 6.1 | 3.3 |
| SMA+20% RAP+16% SWP | 5.8 | 18.1 | 18.7 | 6.3 | 5.9 | 6.8 | 3.5 |
| SMA+30% RAP+4% SWP | 5.9 | 17.2 | 17.9 | 12.9 | 11.4 | 3.1 | 3.1 |
| SMA+30% RAP+8% SWP | 5.8 | 18.2 | 18.8 | 13.9 | 12.2 | 3.3 | 3.1 |
| SMA+30% RAP+12% SWP | 5.8 | 18.0 | 18.7 | 9.2 | 8.3 | 6.7 | 5.2 |
| SMA+30% RAP+16% SWP | 5.8 | 18.4 | 19.1 | 6.8 | 5.9 | 6.5 | 6.0 |

Table 7. Marshall properties of SMA mixes for aggregates having EI+FI=25
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Table 8. Marshall properties of SMA mixes for aggregates having EI+FI=35

| Particulars              | OBC (%) | VMA (%) | Stability (kN) | Flow (mm) |
|--------------------------|---------|---------|----------------|-----------|
|                          | HMA & WMA | HMA | WMA | HMA | WMA | HMA | WMA |
| Conventional SMA         | 6.6     | 18.6   | 19.0          | 6.8       | 6.7 | 5   | 6.0 |
| SMA+4% SWP               | 6.4     | 18.4   | 19.7          | 8.3       | 8.9 | 3.5 | 3.9 |
| SMA+8% SWP               | 6.2     | 19.2   | 18.8          | 9.5       | 10.5| 3.2 | 4.0 |
| SMA+12% SWP              | 6.0     | 20.2   | 19.1          | 6.7       | 7.3 | 5.6 | 4.5 |
| SMA+16% SWP              | 5.9     | 20.0   | 19.4          | 6.5       | 7.3 | 5.9 | 5.7 |
| SMA+10% RAP              | 6.5     | 18.9   | 19.1          | 9.0       | 8.6 | 3.8 | 4.6 |
| SMA+20% RAP              | 6.4     | 19.4   | 19.2          | 9.9       | 9.1 | 3.2 | 4.0 |
| SMA+30% RAP              | 6.3     | 19.6   | 19.4          | 11.1      | 11.0| 3   | 3.8 |
| SMA+10% RAP+4% SWP       | 6.3     | 19.1   | 19.8          | 10.7      | 9.8 | 3.4 | 4.2 |
| SMA+10% RAP+8% SWP       | 6.2     | 19.3   | 19.1          | 12.0      | 10.9| 3.1 | 3.9 |
| SMA+10% RAP+12% SWP      | 6.0     | 19.8   | 19.2          | 6.6       | 7.2 | 5.5 | 3.7 |
| SMA+10% RAP+16% SWP      | 5.9     | 20.0   | 19.5          | 6.7       | 6.5 | 5.8 | 5.6 |
| SMA+20% RAP+4% SWP       | 6.0     | 18.9   | 20.2          | 10.5      | 10.5| 3.3 | 4.1 |
| SMA+20% RAP+8% SWP       | 5.9     | 19.0   | 19.0          | 10.9      | 11.3| 2.9 | 3.0 |
| SMA+20% RAP+12% SWP      | 5.9     | 19.8   | 19.2          | 8.0       | 7.9 | 6.1 | 3.2 |
| SMA+20% RAP+16% SWP      | 5.9     | 19.9   | 20.4          | 5.9       | 5.7 | 6.7 | 3.5 |
| SMA+30% RAP+4% SWP       | 6.0     | 18.9   | 18.2          | 10.8      | 11.7| 3   | 3.0 |
| SMA+30% RAP+8% SWP       | 5.9     | 19.8   | 19.0          | 12        | 12.6| 3.2 | 2.9 |
| SMA+30% RAP+12% SWP      | 6.0     | 20.0   | 19.3          | 9.1       | 8.4 | 6.6 | 5.0 |
| SMA+30% RAP+16% SWP      | 6.2     | 20.2   | 20.8          | 6.0       | 5.9 | 7.1 | 5.8 |

Figure 2. Critical energy release rate/cracking resistance of SMA mixes, JckN-mm
3.10. Semi-circular Bending Test

The test is conducted to determine fatigue cracking of SMA mixes in terms of critical strain energy, Jc. The Jc values obtained for different combinations of RAP and SWP in SMA mixes are shown in Figure 2.

3.10.1 Sample preparation

The semi-circular bending (SCB) specimen was obtained by slicing modified Marshall Specimens shown in Figure 3 of dimension 150 mm diameter and 112 mm height. The numbers of blows were adjusted to achieve target air void level of 6.5±5%. Then the specimen is cut along its central axis into two equal semi-circular shapes having a thickness of 57±1 mm. Three nominal notch depths of 25, 32 and 38 mm are cut along symmetrical axis of each semi-circular specimen with a tolerance of ±1 mm. The width of notch cut specimen was <3.5 mm. Sample specimen is shown in Figure 4.

3.10.2. Experimental Procedure

The cracking resistance was determined at 25°C using SCB test as per ASTM D8044-16. A semi-circular specimen is loaded monotonically until fracture failure occurs under a constant rate of deformation of 0.05 mm/minute. The load and deformation are continuously recorded and are used to compute the strain energy for notch depth of 25, 32 and 38 mm. SCB sample and its setup in universal testing machine are shown in Figure 5.

The critical strain energy release rate (J- integral) is determined using Equation 2.

\[
JC = \frac{-1}{b} \frac{dU}{da}
\]

Where:

- Jc= critical strain energy release rate (kN-mm);
- b=sample thickness (m);
- a=notch depth (m);
- U=strain energy to failure dU/da= change of strain energy with notch depth (kN/m).

4. Results and Discussions

4.1. Volumetric Properties

4.1.1. Aggregate Shape

From Table 7 and 8, it is observed that, SMA mix prepared with aggregates having EI+FI=25 shown better stability compared to aggregates having EI+FI=35. Due to the presence of cubical aggregates, better interlocking takes places compared to irregular shape aggregates which are more susceptible to breaking. The optimum binder content increases for the mix having aggregates EI+FI=35. This may due to aggregates having EI+FI=35 have more surface area and requires additional bitumen to coat around aggregate particles.

4.1.2. Shredded Waste Plastic

The optimum binder content decreases with addition of shredded waste plastic to conventional SMA and RAP SMA mixes. This is due to waste plastic coats around aggregates thereby reducing porosity in aggregates. The increase in Marshall stability was observed up to 8% SWP content for HMA mix and 12% for WMA mix and decreased with further addition of SWP content.

4.1.3. WMA

The Marshall stability increased with addition of RAP increased for both HMA and WMA mixes. Similar trend was observed for Asphaltic concrete HMA mix with the addition of RAP [35]. This may due to presence of aged binder in RAP material which makes mix better stability compared to conventional SMA. WMA mixes exhibited lesser resistance to Marshall stability compared to HMA mixes, addition of WMA additive makes mix less ageing thereby less stiffness. However, all these mixes satisfied the requirements of Indian Roads Congress-SP 79-2008 i.e., drain down less than 0.3%, VMA above 17%.
4.2. Cracking Resistance

4.2.1. Effect of Aggregate Shape on J-Integral

From Table 1 and 2, coarse aggregates having $EI+FI=25$, sphericity varied from 0.69-0.72 indicating aggregates are Equiaxial or near to cubical/angular shape as per Zingg diagram. Similarly, shape of aggregates is oblate/prolate or more flaky/elongated for aggregates having $EI+FI=35$. From Figure 2, mix containing coarse aggregate of $EI+FI=25$ showed increase in J-Integral value by 5% compared to mix containing coarse aggregate $EI+FI=35$ for all combinations. However, increase was found to be insignificant as both combinations met ASTM specifications. This may be due to both shapes of aggregate fulfilled VMA and VCA$_{DRY}$/VCA$_{MIX}$ requirements as per MoRTH (2013).

4.2.2. Effect of RAP on J-Integral

The cracking resistance of SMA mixes is determined for varying proportions of RAP content i.e., 0, 10, 20 and 30%. Based on the results shown in Figure 2, Jc value increased from 0.54kN-mm to 0.63kN-mm with the addition of RAP due to increase in stiffness of mix.

4.2.3. Combined effect of RAP and SWP on J-Integral

In hot SMA mix, for RAP content of 10, 20 and 30% having shredded plastic waste dosage of 4 and 8%, the obtained Jc value meets requirements. However, for RAP content of 10, 20 and 30% having shredded plastic waste dosage of 12 and 16% resulted in decrease in Jc value which is below the requirements of ASTM. However, addition of shredded plastic waste up to 8% to RAP mix improves elasticity and better deformability.

4.2.4. Combined Effect of RAP and Shredded Plastic Waste and Addition of Warm Mix Additive on J-Integral

From Figure 2, it can be inferred that up to dosage of 12% shredded plastic waste in SMA specimens with WMA additive resulted in Jc value which fulfills ASTM requirements. However, increase in dosage of shredded plastic waste beyond 12% resulted in decrease in Jc values. Since mixing is done at lower temperature, only partial SWP will be absorbed by RAP binder.

5. Conclusions

From present study it is observed that

(i). The mix containing coarse aggregate of $EI+FI=25$ showed increase in J-Integral value by 5% compared to mix containing coarse aggregate $EI+FI=35$ for all combinations.

(ii). Addition of RAP in SMA mixes showed better resistance to cracking due to increased in stiffness in mix.

(iii). Addition of shredded plastic waste for hot RAP-SMA mixes showed better resistance for cracking than mix prepared with warm mix additive.

For SMA mixes prepared with addition of shredded waste plastic indicated better cracking resistance up to 8%, decrease in Jc was observed for mixes prepared using WMA additive.

The optimal dosage of shredded plastic waste for RAP-SMA specimens without WMA additive was found to be 8% and same found to be 12% for specimens prepared with WMA additive.

Studies indicate waste plastic can be utilized in warm asphalt mixes and dosage can be increased compared to hot mixes.

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