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Utilization of production shingle waste in hot mix asphalt and warm mix asphalt

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ABSTRACT

Shingle material can appear as an excess usage due to defective production problems or at the end of their service life. Especially the reuse of shingle materials in bitumen has brought a different approach in terms of sustainability. In this study, the utilization of production shingle waste material in asphalt pavement were investigated. Mechanical properties of hot mix and warm mix asphalt samples involving different amount of production shingle waste (1-6% by weight of the aggregate) were evaluated. Following the determination of optimum rate of shingle waste bitumen content is reduced to decrease both hazardous effects of bitumen and production cost. Marshall Mix Design criteria was employed on determination of maximum reduction on bitumen content and the amount of shingle utilization within the asphalt pavement. As a final analysis, indirect tensile tests were performed on the specimens prepared with determined bitumen content and shingle waste. As a result, it is concluded that, utilization of waste shingles within the asphalt mixture not only benefits the environment and cost but also improves Marshall stability and Marshall quotient of the mixtures.

Keywords: Shingle; Waste; Warm mix asphalt; Hot mix asphalt.

INTRODUCTION

Environmental consciousness has been increasing rapidly in recent years. Common measures such as the Kyoto protocol, which is being implemented by the European Union and air pollution reduction, targets encourage efforts in this direction (Polo-Mendoza et al., 2022). Warm Mix Asphalt (WMA), a new pavement technology that emerged first in Europe, is among the efforts that support the environmental consciousness (Kristjansdottir, 2006). WMA is a bituminous mixture prepared with the appropriate method to reduce the mixing temperature by at least 20-30ºC and help to save energy in production and reduce emissions that are harmful to the environment and worker health (Pasetto et al., 2017). During the WMA production process, various additives such as organic, chemical or foaming etc. are used to reduce the viscosity of the bitumen and ensure that the aggregate is completely covered at low temperature and the mixture is compressible (Zhao et al., 2021).

Due to increasing world population, the limited amount of raw material resources is decreasing day by day and waste materials are emerging. Incineration of wastes or creating landfills and burying them are in the most common dealing ways (Bocci et al., 2020 & Ochepo et al., 2014). In recent years, studies have been carried out to recycle waste materials and use them in various fields. The pavement sector is among the first application area that comes to mind at the need for raw materials and the evaluation of the wastes (Huang et al., 2007 & Tapkin et al., 2018). Shingle is a roofing material with fiber glass (glass wool) carrier, covered with mineral stones in various colors and shaped in decorative patterns (Nam et al., 2014). Use of shingle material as a coating is becoming increasingly common in order to insulate the roofs of the buildings and to protect the structure against environmental effects. Around 90 million roof shingles are produced every year all over the world. (Krivit, 2007). Generally, these wastes are disposed of by being stored in storage areas. The storage or disposal area requirement of the resulting wastes constitute the importance of the recovery of these materials due to their environmentally pollutant properties (Waller, 2013). As a solution to this, effective evaluation of shingle waste material in the modification of asphalt pavement can be ***brought*** into usage (Grodinsky et al., 2002; Sengoz et al., 2002 & Deniz et al., 2009).

In this study, the utilization of production shingle waste material in both HMA and WMA pavement production were investigated. Following the determination of optimum rates of shingle waste regarding HMA and WMA, optimum bitumen content has been reduced to evaluate the reduction on the mechanical properties of the samples. As a final analysis, indirect tensile tests and indirect tensile strength ratios were performed on the specimens prepared with determined bitumen content and shingle waste to investigate the strength and stiffness characteristics of the mixtures.

EXPERIMENTAL STUDIES

Materials

The base bitumen with 60/70 penetration grade has been obtained from Dere Group/Asphalt plant. Some of the properties of base bitumen as follows; penetration: 62, softening point: 51^{o}C, penetration index (PI): 0.35, change of mass after rolling thin film oven test (RTFOT): 0.160%, retained penetration after RTFOT: 82%, softening point after RTFOT: 58^{o}C, viscosity @ 135°C: 0.412 mPa.s, viscosity @ 165°C: 0.104 mPa.s, specific gravity: 1.030. It was manufactured by blending crude oil from various sources in Middle East countries. The organic WMA additive is used on the production of WMA samples. Sasobit®, which is the most widely used organic additive today, is a long-chain aliphatic hydrocarbon additive produced by the South African company Sasol by the Fischer-Tropsch method (Singh et al., 2022 & Ge et al., 2017). In this study, Sasobit® content was chosen as 3% by the aggregate weight depending on the previous studies in the literature (Jamshidi et al., 2012 & Qin et al., 2014). Asphalt mixtures was produced with limestone aggregates procured from Dere Group/Izmir quarry. Table 1 summarizes the properties of the aggregates as well as gradation. Aggregate gradation was chosen in conformity with the Type 1 wearing course specification of General Directorate Turkish Highway. In this study, shingle waste was provided by BTM Isolation A.S., a local company in Izmir/Turkey. Shingle particles are supplied in smaller parts than 9.5 mm using shredding machines from BTM Isolation A.S. (the shingle supply was screened to limit the 9.5 mm. to 4.75 mm) and directly added to the HMA. The properties of shingle are as follows; bitumen (10/20) content: 32.5%, fiberglass (glass felt): 2.5%, filler ($CaCO_3$): 30%, aggregate (basalt): 35%. Before the production of HMA, the shingle waste was placed in the oven with the aggregates at 175-185^{o}C until it reaches mixing temperature (160-165^{o}C). The shingle was added between 0% (control sample) to 6% by the weight of aggregate with 1% incremental rates. Three uniform samples were produced for each mixture type. Following the determination of optimum rates of shingle waste regarding HMA and WMA, optimum bitumen content has been reduced to evaluate the reduction on the mechanical properties of the samples.

Table 1. The properties of the aggregates as well as gradation.

Test	Specification used	Actual value	Specification limits
Gradation		100	
3/4 in.		100	100-10
1/2 in.		92.1	88-100
3/8 in.		76.7	72-90
No. 4		47.1	42-52
No. 10		30.2	25-35
No. 40		11.9	10-20
No. 80		7.4	7-14
No. 200		4.9	3-8
Specific gravity (coarse aggregate)	TS EN 1097-6		
Bulk		2.697	
Apparent		2.727	
Specific gravity (fine aggregate)	TS EN 1097-6		
Bulk		2.689	
Specific gravity(filler)		2.734	
Los Angeles Abrasion (%)	AASHTO T-96	26.0	Max 45
Flat and elongated particles (%)	ASTM D 4791	7.5	Max 10

Test Methods

Marshall Stability Test

Both WMA and HMA samples were produced by following Marshall mix design method (ASTM D1559). Depending on the previous study conducted by the same authors in which the identical penetration grade bitumen, aggregate type and gradation was used, the optimum bitumen content was chosen as 4.7% and 4.3% of aggregate weight for HMA and WMA, respectively (Musawi et al., 2021). The shingle was added between 0% (as control sample) to 6% by the weight of aggregate with 1% incremental rates at optimum bitumen contents for both HMA and WMA mixtures. Three uniform samples were produced for each mixture type. Marshall Mix Design parameters of the samples such as void results, stability and flow rates were investigated. Following the determination of optimum shingle waste amount on for both HMA and WMA samples produced with the optimum bitumen content, the effects of waste shingle content on the reduction of required bitumen content was evaluated. Since WMA mixtures can be produced with lower bitumen content compared to HMA mixtures, the bitumen ratio in HMA mixtures is reduced by 1%, while in WMA mixtures it is reduced by 0.5%. Hence, the HMA samples involving 3.7% bitumen content and WMA samples involving 3.8% bitumen content with the shingle wastes (1-6%) were again subjected to Marshall mix design criteria and the results were investigated for each mixture. On the other hand; waste shingle samples added at different rates to WMA and HMA samples (as presented in the materials part) contain 32.5% bitumen. Therefore, although the bitumen rate is reduced, the total bitumen amount within the mixture will increase by the addition of waste shingle. Marshall Quotient (MQ) value, which is defined as the ratio of stability to flow value of the mixtures, were also investigated for each sample in order to evaluate the stiffness properties of the mixtures.

Indirect Tensile Test

It is important to evaluate the permanent deformation characteristics of the mixture when investigating the mechanical properties of the samples. Previous studies depicted that, Indirect Tensile Strength (ITS) value of the sample can be used to obtain the fatigue cracking and rutting properties of the mixture (Ahmedzade et al., 2007 & Sarsam et al., 2014). In this study, ITS values of the samples were evaluated as a parameter of low temperature susceptibility and rutting resistance characteristics of asphalt pavements. ITS test was conducted following the ASTM D6931 standard and can be calculated according to Equation 1.

$$St = 2000*P/\pi*t*D \qquad (1)$$

Where;

St = Indirect tensile strength (ITS), Mpa; P = Maximum applied load, N; D = Diameter of sample, mm; t = Thickness of the sample, mm

RESULTS AND DISCUSSIONS

Marshall Stability Test Results

The Marshall test results in terms of Marshall stability, flow, air void and Marshall quotient for HMA mixtures produced with optimum and reduced bitumen amounts containing different shingle content are presented in Figure 1-4. Marshall mix design limits are depicted on the figures to evaluate whether the samples meet the criteria or not.

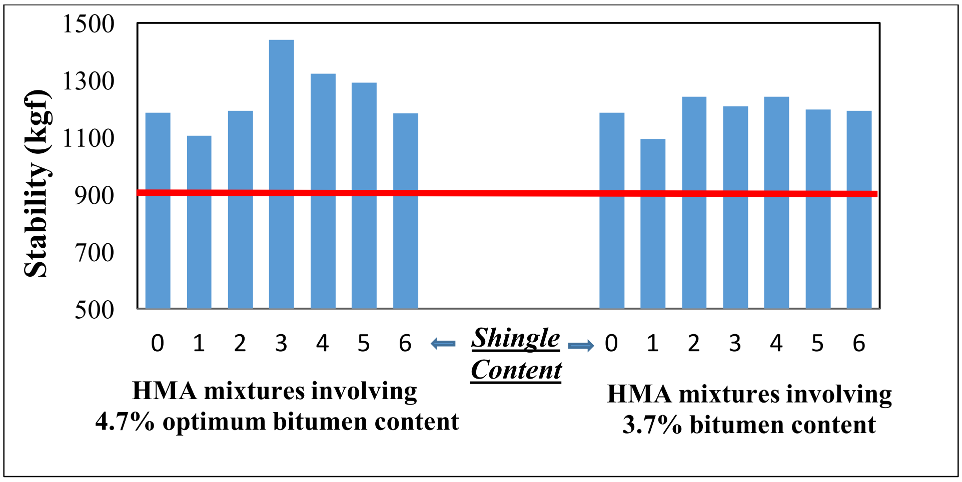

Figure 1. Marshall stability values for HMA mixtures containing different shingle content.

Considering Figure 1; Marshall stability of all HMA mixtures including optimum bitumen content (4.7%) and reduced bitumen content (3.7%) was found to be above the specification limit of 900 kg. For the samples with optimum bitumen content, the highest stability result was provided from the samples having 3% shingle content. However, a decreasing trend was obtained beyond that amount of shingle waste existence within the asphalt mixture. On the other hand, for the samples having reduced bitumen content, the Marshall stability values did not variate considerably by the increment of the shingle waste. Overall, asphalt mixtures (produced by both optimum and reduced bitumen content) involving different amount of shingle wastes provided higher stability value compared to the control mixtures (without shingle waste).

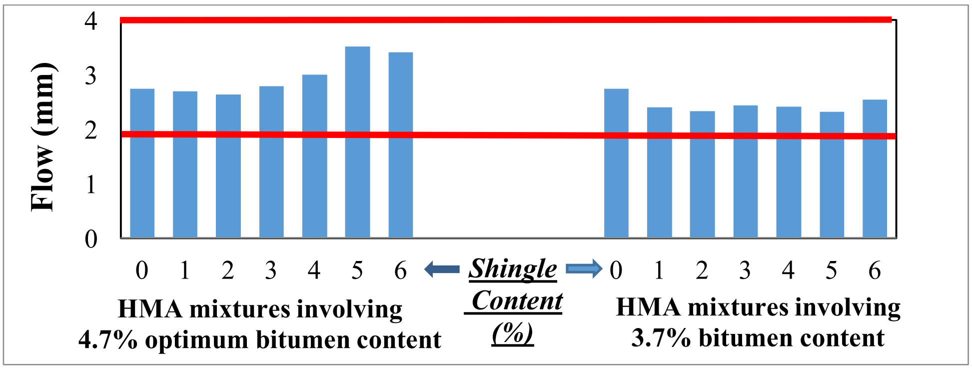

Figure 2. Marshall flow values for HMA mixtures containing different shingle content.

Based on Figure 2, it has been observed that the flow value of all HMA mixtures is between 2-4 mm, which satisfies the specification limit. For the mixture produced with optimum bitumen content, the flow rates increased by the increase on the shingle amount within the mixture. The increase was more significant when the shingle content was 5%. Regarding the samples including reduced bitumen content, the modification of the mixture with shingle waste decreased the flow values of the samples, which can be evaluated by improved resistance against the permanent deformations. However, the amount of shingle utilization did not bring considerable differences.

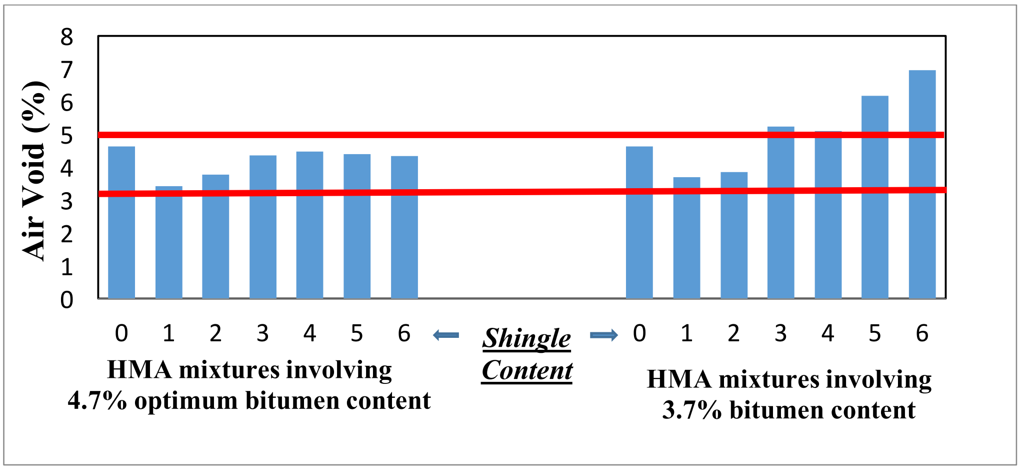

Figure 3. Air void values for HMA mixtures containing different shingle content.

As can be seen in Figure 3, the air void results of all HMA mixtures, produced by optimum bitumen content, were within the specification limits independent of the shingle waste rate. On the other hand, although the more the shingle waste content within the mixture increased the air void value, the shingle waste modified mixtures provided decreased air void results compared to unmodified (control) mixture involving optimum bitumen content. For the samples having reduced bitumen content, up to 3% shingle waste modification, decreased air void values were obtained, however, a significant increase was observed when 3% and more amount of shingle waste utilized. As a result, 3% and beyond that amount of shingle waste usage were failed to meet the specification criteria on the air void results.

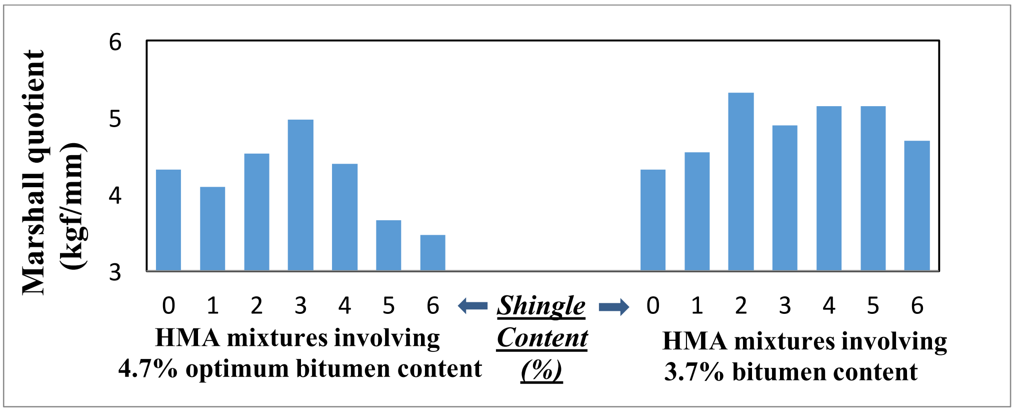

Figure 4. Marshall Quotient for HMA mixtures containing different shingle content.

Marshall quotient, known as the ratio of stability to flow, represents the stiffness of the mixture. As can be seen in Figure 4, the stiffness of the mixtures having optimum bitumen content were increased up to 3% shingle waste utilization. However, the Marshall quotient value of the mixtures decreased by the increase of shingle waste amount within the asphalt mixture. On the other hand, when the bitumen content in the mixture reduced, the modification of HMA mixtures with shingle waste increased the stiffness of the unmodified (control) mixture. The mixture involving 2% shingle waste had the highest stiffness properties among the all mixtures produced by reduced bitumen content. Considering Figure 1-4, it was concluded that, the optimum shingle waste content is 3% for HMA samples produced by optimum bitumen content (4.7%), and it is 2% for samples produced by reduced bitumen content (3.7%).

Marshall stability test was applied on the WMA samples prepared with optimum bitumen content of 4.3% and bitumen content of 3.8% (bitumen ratio reduced by 0.5%) involving shingle waste at the rate of 0%-6% by weight of the aggregate to investigate the effects of shingle waste on the mechanical properties of the WMA mixture. The Marshall test results in terms of Marshall stability, flow, air void, and Marshall quotient for WMA mixtures prepared with optimum bitumen content (4.3%) containing different shingle waste contents are given in Figure 5-8. On the other hand, the air void results of WMA mixtures involving reduced bitumen content (3.8%) and different shingle waste amounts is presented in Figure 9.

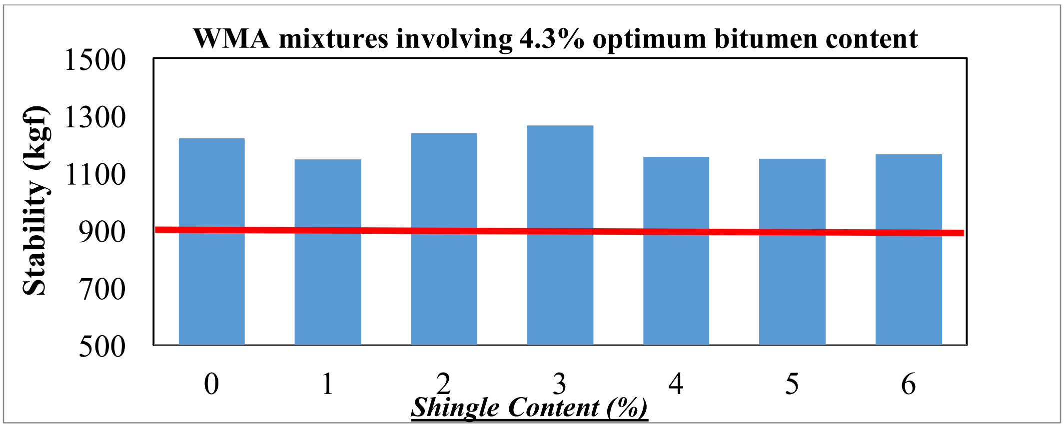

Figure 5. Marshall stability values for WMA mixtures containing different shingle content.

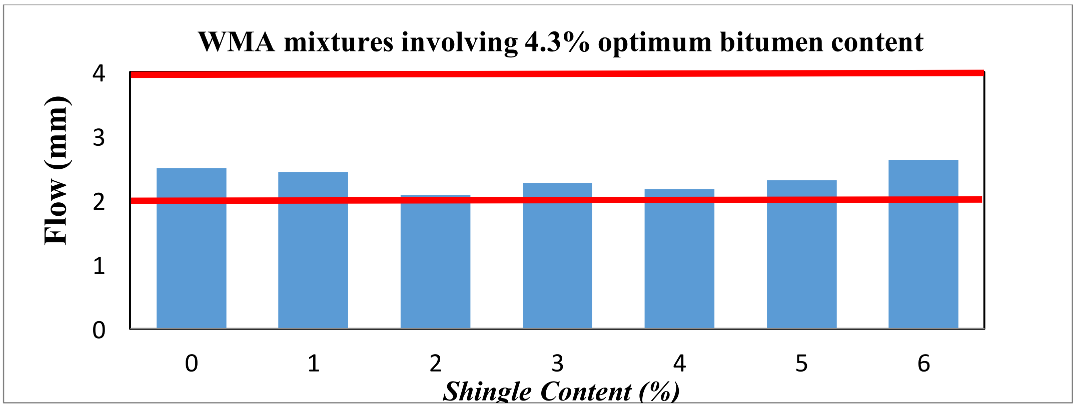

Figure 6. Marshall flow values for WMA mixtures containing different shingle content.

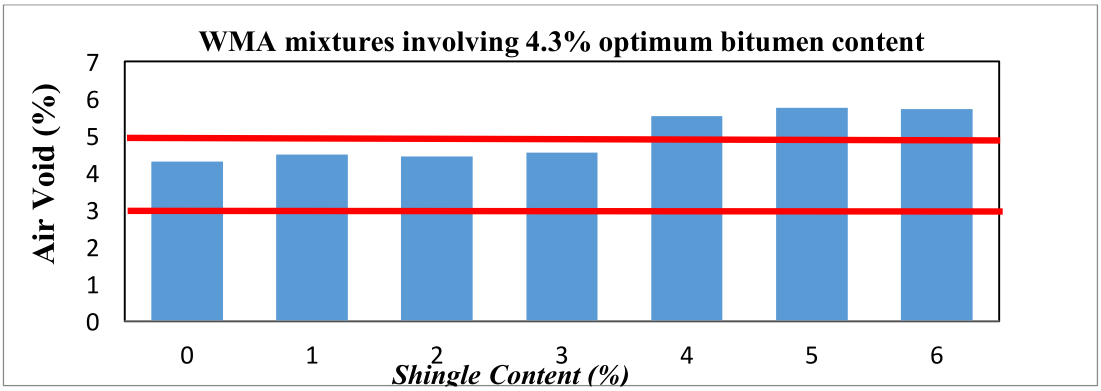

Figure 7. Air void values for WMA mixtures containing different shingle content.

As can be seen in Figure 5, each WMA mixtures prepared with organic WMA additive provided the stability values above the specification limit (900 kgf). Additionally, even though the amount of the shingle utilization on the modification process did not yield significant changes on the stability values of the WMA mixtures, the one with 3% had the highest stability value similar with the HMA results.

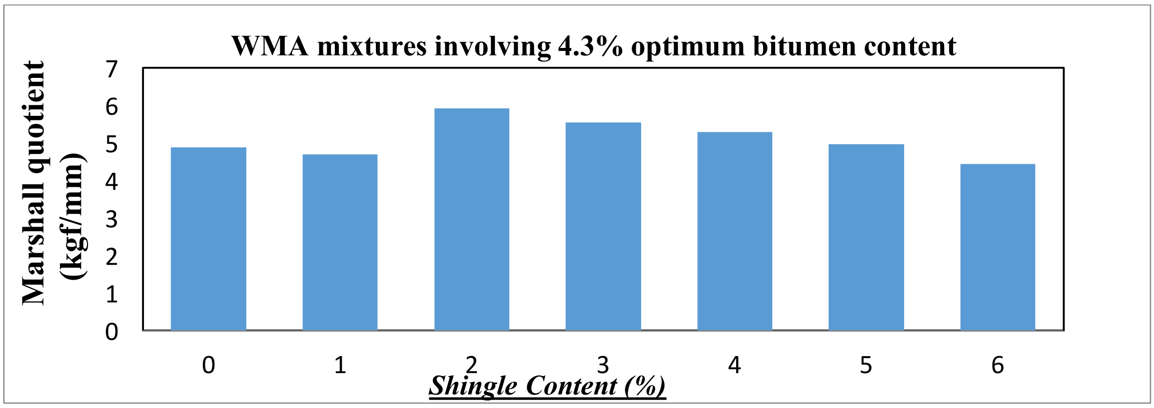

Figure 8. Marshall Quotient for WMA mixtures containing different shingle content.

According to Figure 6; it has been observed that the flow value of all WMA mixtures is between 2-4 mm, which is the specification limit. Again similar with the HMA mixture results, the WMA mixture involving 2% shingle waste resulted in having the lowest flow rate, which is associated with better permanent deformation resistance. Air void results have been the determinative criteria on the amount of shingle waste utilization, since not the all samples met the Marshall mix design air void criteria.

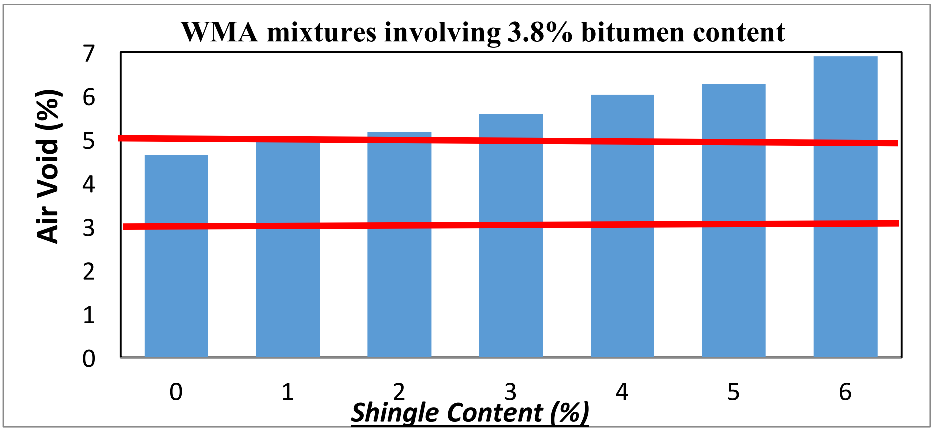

Figure 9. Air void values for WMA mixtures with bitumen content of 3.8% containing different shingle content.

As can be seen in Figure 7, the WMA samples can be modified with maximum 3% shingle waste considering beyond that amount the samples tent to have higher air void values than the specification can let. As illustrated in Figure 8, Marshall quotient results depicted that, samples having 2% shingle waste resulted in providing the highest stiffness properties among all WMA mixtures. As presented in Figure 9, the air void results of the WMA mixtures, produced by reduced bitumen content (3.8%), could not satisfy the specification limits range of 3%-5% independent of the shingle waste addition. Hence, considering the air void values, shingle waste modification is not possible for the WMA samples prepared with bitumen content of 3.8%.

Indirect Tensile Test Results

The indirect tensile (ITS) test was conducted on the HMA and WMA samples including optimum shingle contents obtained by the Marshall test results. ITS values were investigated to evaluate the characteristics of the samples in terms of mixture stiffness. WMA samples prepared with a bitumen content of 3.8% (by reducing the optimum bitumen rate 0.5%) could not allow the addition of shingle waste at any rate with respect to the air voids ratio, so ITS test was not performed on these samples. The higher the ITS value, the more would be the capability of the mixture to withstand tensile strains prior to crack initiation and vice versa. The ITS results and ITS ratios of both HMA and WMA samples involving optimum amount of shingle waste together with the control samples are given in Figure 10.

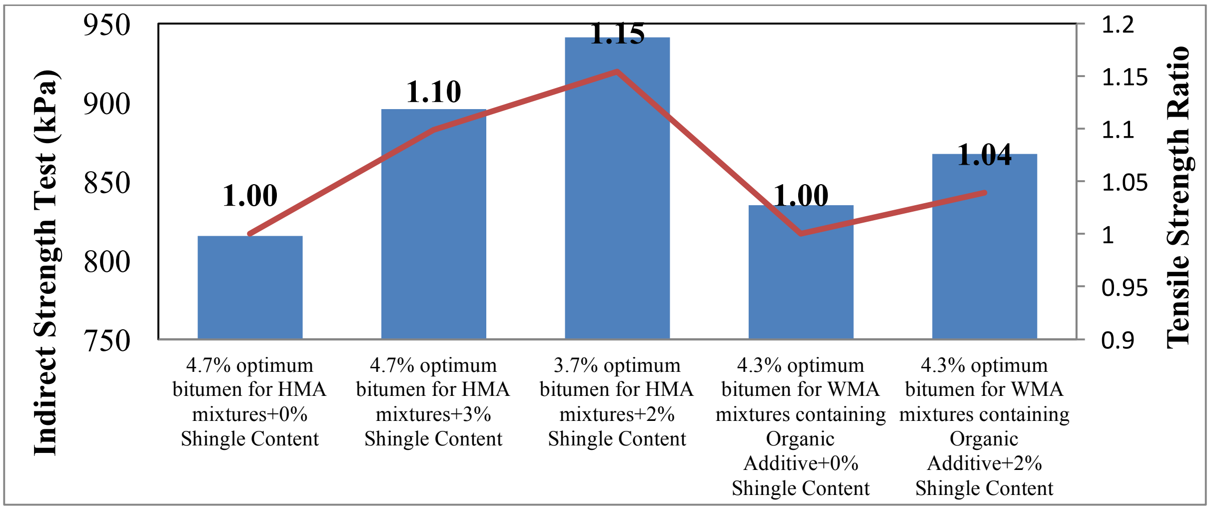

Figure 10. ITS results and ITS ratios for optimum mixtures and control samples.

As can be seen in Figure 10, shingle waste modification revealed higher ITS values for both HMA and WMA mixtures. Therefore, it is possible to say that mixtures having shingle waste can endure higher tensile strains before having permanent deformation. In other word, shingle modification provides asphalt mixtures to be more rigid, brittle and more resistant to bending. For HMA samples, the mixture produced by the reduced bitumen content yielded higher ITS value compared to the one having optimum bitumen content. On the other hand, WMA samples had lower ITS values compare to the HMA mixtures, which means WMA mixtures cannot withstand the strains level of HMA mixtures before initiation of permanent deformation.

CONCLUSIONS AND RECOMMENDATIONS

In this study, the usability of shingle waste in HMA and WMA mixtures was investigated. Mechanical properties of HMA and WMA samples that are prepared with various bitumen contents and involving different amounts of production shingle wastes were evaluated through Marshall and ITS tests. The main findings of the study are as follows:

• Considering the HMA mixtures, the highest stability value was provided from the samples having 3% shingle waste content. However, a decreasing trend was obtained beyond that amount for the mixtures produced by optimum bitumen content. On the other hand, 2% shingle waste utilization yielded the highest stability value when the bitumen content was decreased (3.7%).

• Regarding the flow results, HMA mixtures involving both optimum and reduced bitumen contents met the criteria independent from the shingle amount within the mixture. However, the highest flow value was obtained by the control mixture for the samples involving reduced bitumen content. Additionally, although the control mixture had the highest air void value, the increase of shingle waste addition yielded higher air void results for each bitumen content. As a result, it was concluded that, the optimum shingle waste content is 3% for HMA samples produced by optimum bitumen content (4.7%), and it is 2% for samples produced by reduced bitumen content (3.7%).

• The Marshall quotient values, in other word the stiffness properties of the HMA samples, increased with shingle waste addition until meeting the optimum shingle content. After that amount, Marshall quotient values decreased depending on stability values. Consequently, it is possible to say that, shingle waste utilization on HMA mixture modification yielded a decrease on bitumen content which provides economic and environmental benefits.

• For WMA samples, the 2% and 3% shingle waste usage in the mixtures produced by optimum bitumen content resulted in higher stability values compared to the control mixture. Although, all mixtures met the flow rate criteria, the utilization of 4% and more shingle waste provided higher air void values than the specification limits. Marshall quotient results depicted that, samples having 2% shingle waste resulted in providing the highest stiffness properties among all WMA mixtures.

• As a result, optimum shingle waste content was determined as 2% for WMA mixtures. Additionally, depending on the air void results, it was concluded that, the reduction of bitumen content by shingle waste utilization is not possible for WMA samples.

• Depending on the ITS results, it was obtained that, HMA and WMA mixtures modified by shingle waste can endure higher tensile strains before having permanent deformation.

This study could be improved by conducting further research in order to evaluate the fatigue cracking properties and rutting resistance for HMA and WMA mixtures including various contents of shingle.

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