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Effect of Polypropylene Fibers on moisture Susceptibility of Warm Mix Asphalt

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Abstract

Warm Mix Asphalt (WMA) is a modern energy-saving process that uses environmentally friendly materials, has lower mixing and compaction temperatures, and uses less energy and releases less contaminants than conventional hot mix asphalt. Moisture damage poses one of the main challenges of the material design in asphalt pavements. During its design life, the asphalt pavement is exposed to the effect of moisture from the surrounding environment. This research intends to investigate the role of the polypropylene fibres for modifying the moisture susceptibility for the WMA by using different percentages of polypropylene (namely 2, 4, and 6%) by weight of the binder of the control mixture (WMA). In this paper, the physical characteristics of the asphalt cement, Marshall properties, Tensile Strength Ratio (TSR) and Index of Retained Strength (IRS) were determined to establish the effect of the polypropylene on the moisture susceptibility of the WMA. The results displayed that the modification of the AC with polypropylene caused an increase in the optimum asphalt content by 1.03, 3.09, and 11.3%, with the addition of 2, 4 and 6% of the P.P., respectively. The moisture resistance of the asphalt mixture was enhanced by adding the P.P., according to the rise in the Tensile Strength Ratio (TSR) and Index of Retained Strength (IRS) values. The TSR value showed 9.4, 18.2 and 19.5% increase when the P.P. increased from 0.00 to 0.02, 0.04, and 0.06, respectively; besides, the IRS showed improvement with the addition of the P.P. to the WMA.

Keywords: Warm Mix Asphalt (WMA); Indirect Tensile Strength (ITS); Tensile Strength Ratio (TSR).

1. Introduction

Warm mix asphalt (WMA) used in road construction is a new energy saving method and provides an environmentally friendly protective step via reduced mixing and compaction temperatures and relatively lower energy consumption and exhaust emission compared with the use of the conventional Hot Mix Asphalt (HMA) [1]. The production of WMA differ than that of (HMA) since the mixing temperature as well as compaction temperature approximately lower than that of HMA by 15-40 degree Celsius depending on the type of additives adopted to produce WMA [2]. Over the recent years, environmental protection is gaining recognition as an important factor in transport engineering, particularly in asphalt production. Even with the popular use of HMA in different countries, some researchers recommend switching to a different technology that involves lower temperature production for the manufacture of asphalt mixtures via the use of WMA; this technology is currently being employed in the United States and European Union countries [3].

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A key durability issue associated with the ability of asphalt pavement to resist the effects of water, without significant deterioration in the pavement. The moisture damage is commonly referred to as loss of the adhesion bond at the asphalt-aggregate interface or loss of the cohesion of asphalt binder [4]. Susceptibility of moisture in asphaltic pavement might be considered as a serious defect that caused stripping, and development of other problems including fatigue cracking and permanent deformation [5]. Stripping issues are the main problems related to the WMA, as the lower production temperature will cause incomplete drying of the water entrapped in the aggregate, which subsequently will weaken the interface and adhesive characteristics between the aggregate and asphalt binder, resulting in the separation of the aggregate from the asphalt after the application of traffic loads on the asphalt mixture [6]. In spite of some moisture damage issues being reported, particularly those associated with foaming and some chemical technologies in case of WMA. In last years, different additives types have been used by researchers to improve the moisture resistance, one of which is polypropylene (P.P.) [7].

Polypropylene fibres are used extensively as a reinforcing agent in the AC. The P.P. fibres provide (3) dimensional reinforcement to concrete, ensuring that the concrete becomes tougher and more durable. These fibres can't substitute the mesh of wire reinforcement. P.P. fibres function of the secondary reinforcement and thus makes it more economical by partially replacing the steel fibers. P.P. fibres are a vital component of high-performance concrete. In the United States, P.P. Fibres were also employed as a modifier in the AC [8]. These P.P. fibres are hydrophobic, meaning they do not absorb water. Therefore, when mixed with the concrete they need to be mixed only long enough to ensure dispersion within the concrete mixture. The fibre length normally recommended is linked to the nominal maximum size of the mixture aggregate [9]. Polypropylene is one of the polymers that finds the most extensive use across the world because of its widespread availability and low manufacturing cost. Polymers can improve the properties of the mixture because it offers the possibility of producing mixtures that can resist rutting, cracking and moisture damage [10].

2. Materials and Methods

The first stage in the experimental plan was to determine the optimum asphalt content of the control mix (WMA) without the addition of the polypropylene, and the second stage was to determine the optimum asphalt content of the WMA with polypropylene for each percentage of polypropylene, depended on the Marshall characteristics. The OAC specified from these tests were then used to produce mixtures for the indirect tensile tests to evaluate the TSR and compression strength tests to evaluate the IRS. The test program of this work is presented by a flow chart as shown in Figure 1.

2.1. Asphalt Cement

One type of AC of (40-50) obtained from the Al-Durrah Refinery can be used in this research. The tests conducted on the AC confirmed that its properties complied with the specifications of the SCRB [11] .Table 1 shows the physical properties of this type of AC.

Table 1. Physical Properties of AC

Property	ASTM Designation No.	Value	SCRB Specification
Penetration, 1/10 mm, 25° C, 100 g, 5 sec	D5	44	40-50
Softening Point, ° C (ring & ball)	D36	50	-
Ductility, cm (25° C, 5 cm/min)	D113	125	>100
Specific Gravity, 25° C	D70	1.04	-
Flash Point, ° C, Cleveland open cup	D92	269	>232
After Thin-Film Oven Test ASTM D 1754			
Retained Penetration of Residue, % (25° C, 100 g, 5 sec)	D5	60%	>55
Ductility of Residue, cm (25° C, 5 cm/min)	D113	83	>25

2.2. Aggregate

In this work the aggregate was obtained from the Asphalt Plant of Hammurabi in the city of Ramadi, which was basically a large rock broken using the company crushers to obtain the required gradation. The sizes of the coarse aggregate were in the range from ¾ in to No. 4. The fine aggregate size was in the range from No. 4 to No. 200, as clearly defined, in accordance with the requirement of the SCRB (2003) [12]. The physical properties of the aggregate are listed in Table 2.

Table 2. Physical properties of the aggregate

Property	ASTM Designation No.	Coarse Aggregate	Fine Aggregate	SCRB R/9 2003
Bulk specific gravity	ASTMC127 and C128	2.647	2.635	-----
Percent water absorption	ASTM C127 and C128	0.13	0.524	-----
Percent wear (Los-Angeles Abrasion)	ASTM C131	19.7	------	30 Max

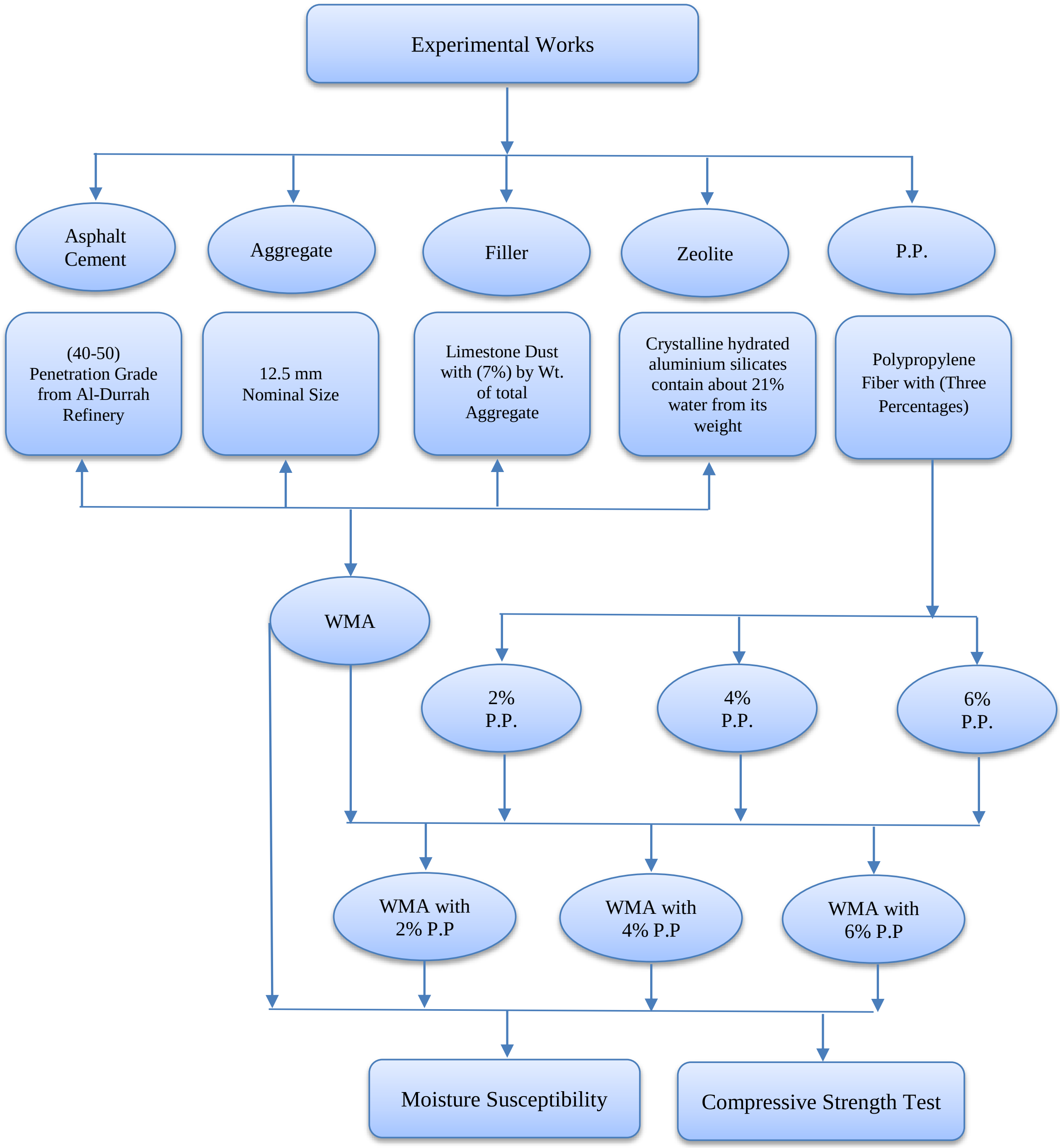

Figure 1. Flow Chart of Experimental Work

2.3. Mineral Filler

The filler is a material that can pass through sieve No. (0.075 mm), and is usually used to enhance the properties of mixture by reducing the plasticity, increasing the viscosity and decreasing the change of volume. In this work, limestone was the filler used. It was sourced from the lime factory in the governorate of Karbala (Iraq). Table 3 represent the physical properties of the mineral filler that used in this work.

Table 3. Physical Properties of Mineral Filler

Property	Test Result	SCRB Specification
Specific gravity	2.73	-
Passing Sieve No. 200 (0.075 mm), %	94	70-100

2.4. Zeolite

Aspha-min powder was used as the additive for the WMA production in the laboratory. Aspha-min is industrialized synthetic sodium aluminium silicate, or enhanced, known popularly as zeolite. This zeolite is hydrothermally crystallized. Eurovia's Aspha-min® retains about 21% water by mass and is released at temperatures above 100° C. The chemical characteristics for the Aspha-min are presented as shown in Table 4.

Table 4. Chemical composition of zeolite

Chemical composition	Result %
SiO2	32.2
Al2O3	28.5
Na2O	15.3
L.O.I.	24.0

2.5. Polypropylene (P.P.)

Polypropylene is a commodity polymer extensively used and known for its good process ability, integral hinge property, low cost, high softening point, low density and good properties of mechanical. Polypropylene fibres are manufactured by the polymerization of P.P. as a linear polymer and termed by its abbreviated form, P.P. The physical and mechanical characteristics of the P.P. according to the manufacturing company are listed in Table 5.

Table 5. Physical Properties of Polypropylene Fibre

Type of Properties	Specification of Polypropylene
Raw material	Virgin Polypropylene
Fibre type	Monofilament
Melting point (°C)	160-170
Acid and alkali resistance	Strong
Length (mm)	12
Break elongation	5%
Fibre diameter	(20 – 30) µm
Density (gm/cm³)	0.01
Tensile strength (MPa)	450
Water absorption	No

3. Selection of Aggregates Gradation

According to General Specification for Roads and Bridges (SCRB/R9, 2003), the nominal maximum size of aggregate is 12.5 mm for the wearing course. Selected aggregates gradation for the wearing course can be showed in Figure 2.

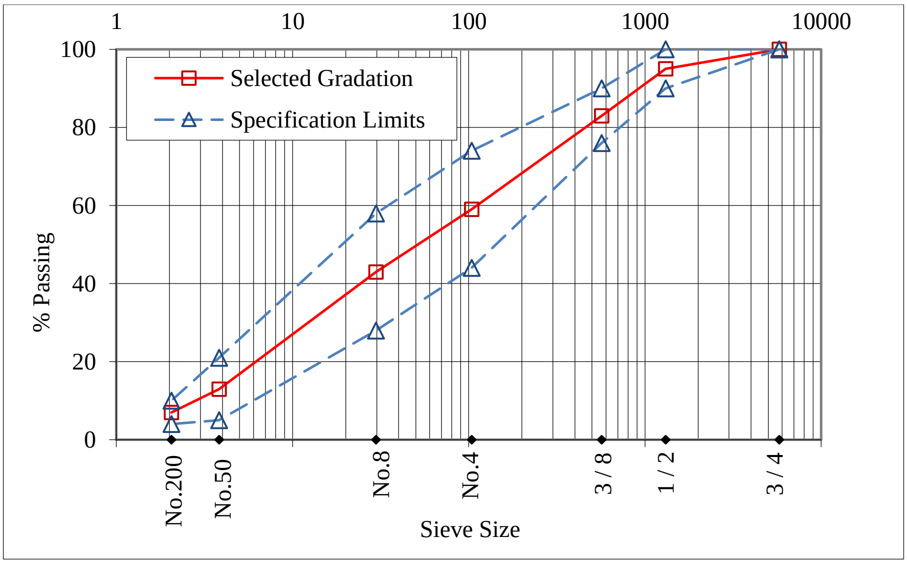

Figure 2. Specification Limits and Selected Gradation for Wearing Course

4. Marshall Mix Design

The procedure includes the preparation, compaction and testing of the 101.6 mm diameter and 63.6 mm height cylindrical bituminous specimens of paving mixture using the Apparatus of Marshall, in accordance with ASTM 6926-04 (2010) [13].

4.1. Preparation of WMA

Sieve No. 4 functions as the boundary between the coarse and fine aggregates. This is where the materials retained for this sieve form the coarse aggregate, while the materials passing through it, form the fine aggregate. These materials are washed and at 110°C dried, and separated into sieves after cooling. The mineral filler such as (Limestone dust) was used, that could pass through sieve No. 200. To prepare the WMA, according to the Iraqi standard specifications, the material was recombined with the filler to meet the required gradation**.** The aggregate mix was heated to 125°C. Also, the asphalt was added to the aggregate directly after adding the zeolite. Figure 3 shows the addition of the zeolite to the aggregate, while Figure 4 indicates the addition of the binder to the prepared warm mix asphalt.

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Figure 3. Shows the process of the addition of the binder to the prepared warm mix asphalt.

Figure 4. Binder addition to the aggregate and zeolite blend

4.2. Preparation and Testing of ITS Specimens

For evaluating the susceptibility of moisture in asphalt concrete, specimens with dimensions of 101.6 mm diameter and 63.6 mm height are used. Specimens are prepared according to AASHTO, T.283 (2007) [14], left to cool at room temperature for (24 hours) and then extracted from the moulds. The desired No. of blows is determined to obtain test specimens with approximately 7±1% of A.V. using different No. of blows for each face. Figure 5 shows the No. of blows versus percentage of A.V. for the control mixture (WMA).

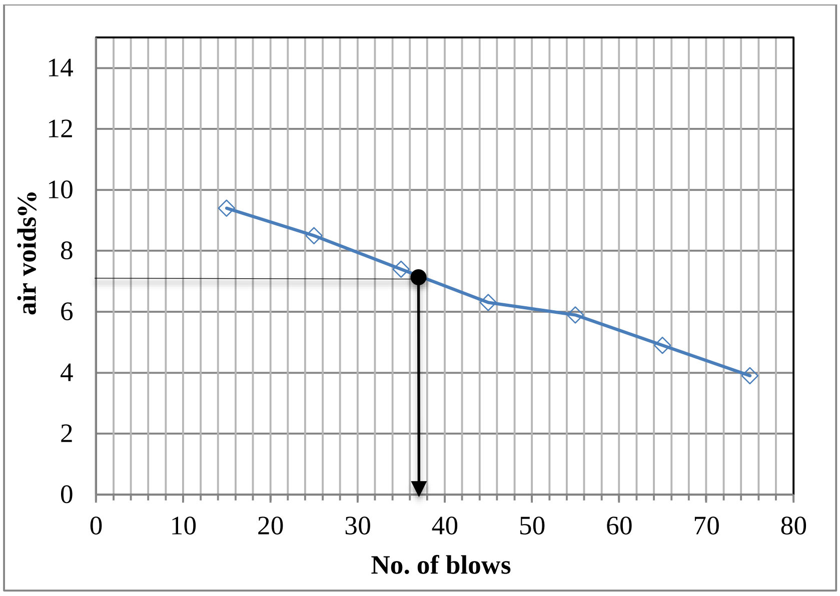

Figure 5. Relationship between the number of Blows and Air Void Percentage for WMA

The indirect tensile strength has been determined by applying the following Equation 1:

$$ITS = 2000\, Pult \,/\, \pi\, t\, D \quad (1)$$

Where; ITS = indirect tensile strength (kPa); $Pult$ = maximum load (N); t = specimen thickness (mm); D = specimen diameter (mm).

The TSR is computed as Equation 2;

$$TSR = (S1/S2) \times 100 \quad (2)$$

Where; TSR = tensile strength ratio (%); $S1$ = mean indirect tensile strength of the wet subset (kPa); $S2$ = mean indirect tensile strength of the dry subset (kPa).

5. Index of Retained Strength Test (IRS)

This test method includes the measurement of the loss of compressive strength due to the action of water on the compacted bituminous mixtures containing the asphalt cement. This test method is useful as an indicator of the susceptibility to the moisture of the compacted bitumen-aggregate mixtures and fully covered [9]. Four sets of cylindrical specimens of 4 inches height and 4 inches diameter 101.6×101.6 mm were prepared by compressing the asphalt mixture until the specimen achieved the required height 101.6 mm. The first set was used as the control mixture (WMA) without the added polypropylene fibre, while the other three sets included the added 2, 4 and 6% of the polypropylene fibres by weight of the bitumen in the control mixture, respectively, and each set comprised 6 specimens. The (IRS) was calculated according to AASHTO; and according to SCRB/R9 (2003). The minimum IRS value should be 70%.

$$IRS\,\% = (S2/S1) \times 100 \quad (3)$$

Where; $S1$ = compressive strength of dry specimens (kPa); $S2$ = compressive strength of immersed specimens (kPa).

6. Results and Discussion

6.1. Marshall Stability

Stability is a property for a mixture of asphalt, which indicates its resistance to rutting, while the high stability refers to the increased stiffness of the mixture. High stiffness of the mixture of asphalt indicates good resistance under loadings of traffic. for long-term performance, the lower flexibility of the bitumen mixture is essential, the high stiffness is not recommended because of the potential of the thermal the Marshall stability of the mixtures containing polypropylene was the higher degree of cracking in the future [15], as shown in Figure 6, than that of the control mixtures. The specimens containing polypropylene of (0.02, 0.04, and 0.06 by weight of the binder) had higher values of stability than did the mixtures control by 3.81, 18.1 and 23.8%, respectively. Significant improvement in stability was noted with the increase in the polypropylene content. The scientific interpretation for the increase in stability was the functioning of the polypropylene as "reinforced concrete" when cracks appeared in the asphalt mixture, thus offering resistance to the propagation of the developing cracks.

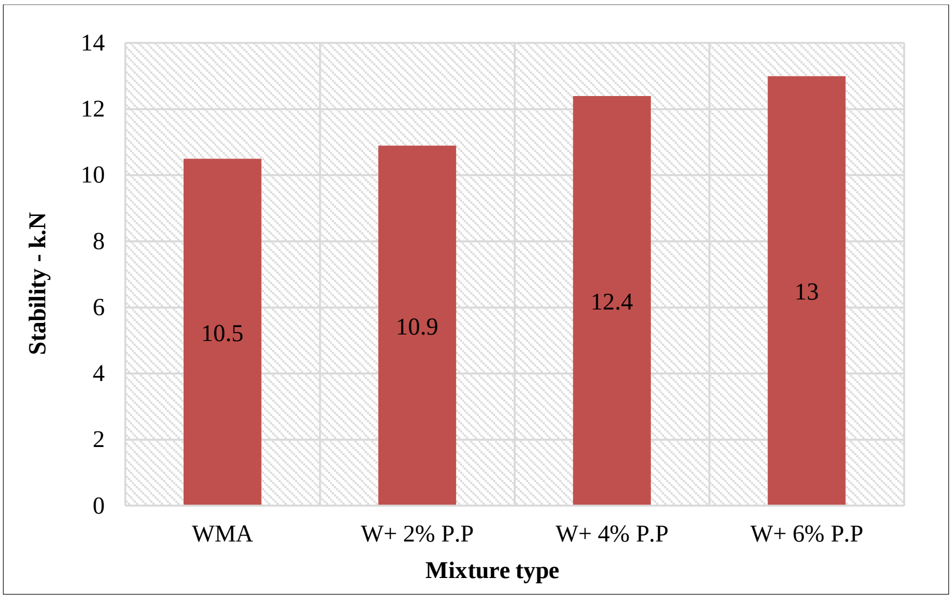

Figure 6. Effect of polypropylene content and on Marshall stability

6.2. Voids in Total Mixture (A.V.)

The A.V. in the total of mixture are an important parameter that can influence the mixture durability of asphalt. According to Tapkın (2007) [8], (3-5%) of the A.V. is sufficient to avoid the bleeding, which occurs due to the low A.V. content less than (3%) in the mixture of asphalt; however, when the high A.V. content is present (exceeding 5%) the mixture of asphalt becomes less durable against the effects of fatigue and moisture. Air voids is the ratio (expressed in %) between the volume of small A.V. between the coated particles and total volume of the mixture [16]. The results showed that the air voids increase in the mixtures that contain polypropylene by 31.6% after the addition of 2% polypropylene; by 31.9% after the addition of 4% polypropylene; and by 0.88% after the addition of 6% polypropylene, compared with the control mixture. The change in the A.V. with the addition of P.P. is shown in Figure 7.

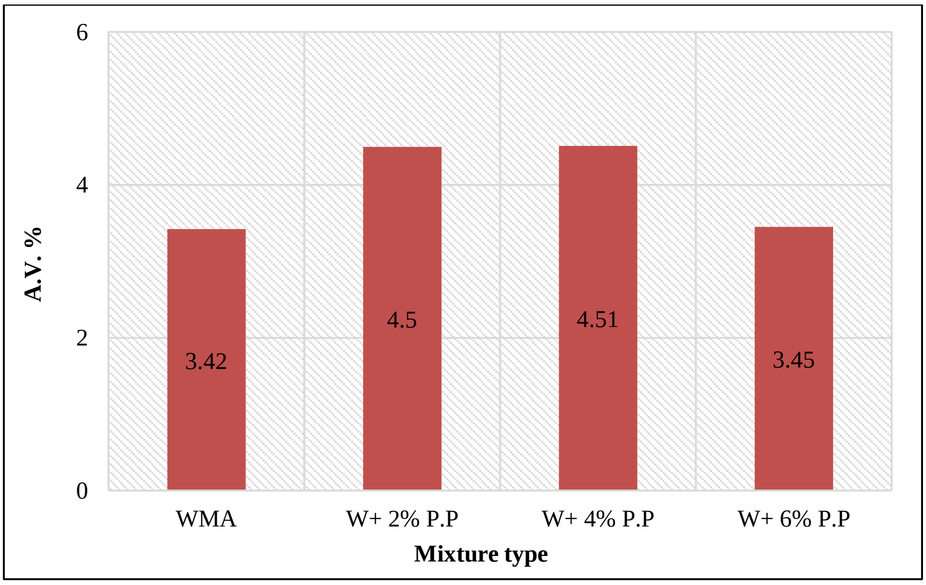

Figure 7. Influence of polypropylene content on the A.V. (%)

Air voids volume is seen to rise with the increase in the polypropylene content because a large percentage of the asphalt need to coat the polypropylene particles leads to an increase in the air voids. This property is important for pavements designed to serve in hot regions where the asphalt is suspected to experience bleeding, flushing and where the increased void ratio can be a solution for these problems.

6.3. Tensile Strength Ratio

This test used to evaluate the susceptibility of moisture damage in the AC, only samples having the dimensions of

101.6 mm diameter and 63.6 mm height were selected. The desired No. of blows was determined to obtain test specimens possessing approximately (7%) of air voids, using different numbers of blows per face. The TSR was used to predict the susceptibility of moisture. The recommended limit 80% for the TSR is used to distinguish between the moisture susceptible mixtures and moisture resistant ones. High (TSR) values indicate that the mixture will probably perform better in resisting susceptibility of moisture.

All the results of the TSR comply with the reported findings of earlier researchers, where the rise in (% P.P.) improved the moisture resistance, concurring with Hamedi et al. (2018) and [17]. Also, these results are consistent with the findings of some researchers, such as Mawat (2019) and Ali (2020) [18, 19], as they found that when other types of fibres, such as (carbon fibres and ceramic fibres) are used, the resistance of the asphalt mixtures to moisture damage significantly improved. Furthermore, another researcher showed that the AC modification with nano-clay with montmorillonite led to increase moisture resistance of mixture of asphalt according to the increase in IRS and TSR [20]. Moreover, other local materials were used, such as (Reed Netting Reinforcement) these materials, which increased the resistance of the asphalt mixture to stripping, and thus increased its resistance to moisture damage [21].

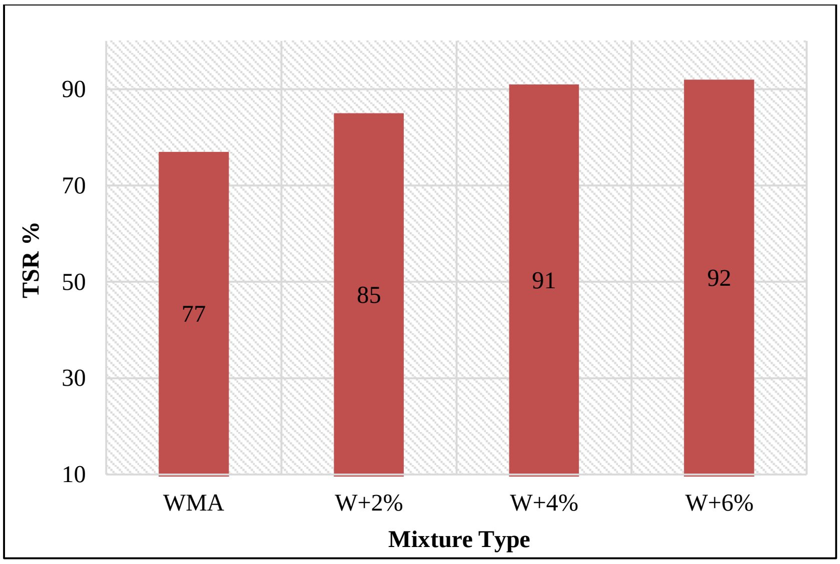

Figure 8. Tensile strength ratios for the different mixture types

The results of the addition of the P.P. reveal that this additive material exerts a positive effect on the amount of the TSR in all of the percentages used in this research. The addition of (2 and 4) % of these materials significantly increases the TSR. While this increase is not significant after 6% of the additive is added (in comparison to the addition of 4% of the additive), it represents that an increase of higher than 4% of this material is not logical because it will only raise the cost of running the mixture; another reason is that no positive effect in terms of increasing resistance against susceptibility of moisture is observed when compared with the samples made with 4%. Consequently, an additional 4% of the P.P. can be considered as the optimal dosage of incorporation. The results showed in this work suggest that the addition 4% of the P.P. material significantly improves the asphalt mixtures resistance against susceptibility of moisture, in comparison with the control samples. The Using additional 4% of the P.P. induced the TSR index, considered the practical index for susceptibility of moisture in executive projects, to exceed the minimum recommended value in most regulations 80%, and thus problem of susceptibility of moisture in the samples could be removed from in terms of regulations.

Although addition 6% of P.P. has also further improved resistance of asphalt mixture against susceptibility of moisture, the difference between the samples with added 4 and 6% P.P. is not significant. Otherwise, the material costs and issues with modification of asphalt are higher in the specimens with the added 6% P.P. Therefore, it appears that the addition of 4% P.P. can be recommended as the optimum concentration of this substance as an anti-stripping additive in the mixtures of asphalt.

6.4. Index of Retained Strength Test (IRS)

IRS was used to evaluate the Compressive Strength (CS) of the mixture of asphalt under the effect of moisture to assess the resistance of the mixture of asphalt to moisture damage. According to SCRB/R9 (2003), the minimum permissible value of IRS is 70 %, which is considered to be the value that indicates whether the mixture is susceptible to moisture or not. The IRS obtained is the percentage of the (CS for conditioned specimens to that of the un-conditioned ones). The (ISR) increased by 8.3, 16.7, and 19.4% with the addition 2, 4, and 6% of the P.P., respectively, compared to the control mixture. For the same reasons recorded in the test of the (TSR), the addition of the P.P. raised the resistance of the asphalt mixture for compression under the effect of moisture, which resulted in the increased I.R.S and enhanced the resistance to moisture, where the resistance to moisture of the mixture of asphalt rises with the increase in the I.R.S. All the results of the I.R.S agree with the reported findings of some researchers, where the rise in P.P. % improved the moisture resistance, agreeing with Mawat (2019) [5].

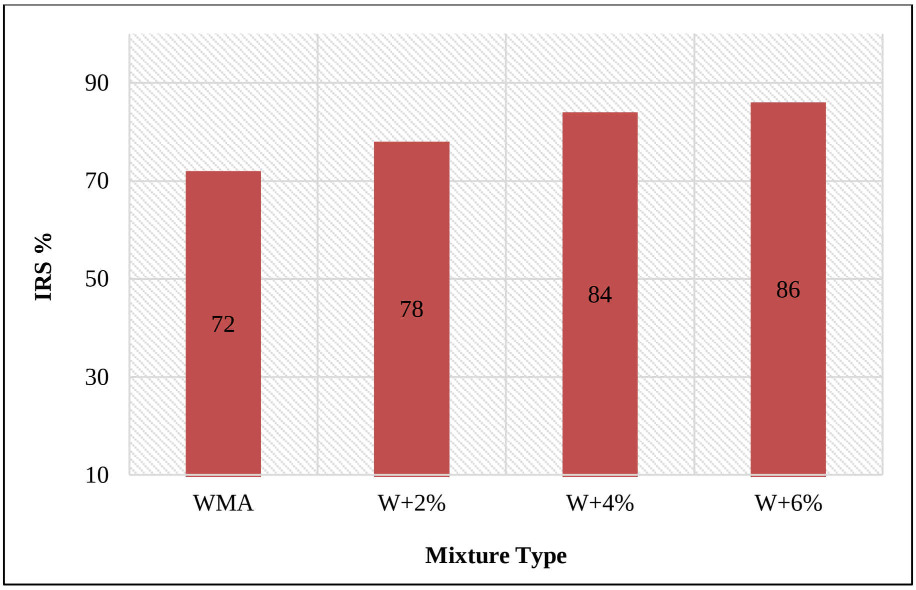

Figure 9. Index of Retained Strength for the different mixture types

7. Conclusions

- The properties of the asphalt cement are improved through the use of the WMA at lower temperatures by the adding the zeolite additive.
- Reductions in the compaction temperatures and mixing are important for lowering energy expenditure, as well as the emissions.
- The Marshall stability improved with the addition of the P.P., where it escalated by 3.81, 18.1 and 23.8% after adding the polypropylene (0.02, 0.04, and 0.06%) by weight of the binder.
- The tensile strength ratios improved after the addition of the P.P., which indicated that the added P.P. reduced the moisture susceptibility of the asphaltic mixtures. The TSR values increased by 9.4, 18.2, and 19.5% when the P.P. was increased from 0.00 to 0.02, 0.04, and 0.06, respectively.
- The addition of 2 and 4% of the P.P. significantly raised the TSR. While this increase after adding 6% of the additive when compared with adding 4% of the additive is not significant, it implied that any increase exceeding 4% of this material is not logical, because it will only raise the cost of running the mixture.
- The IRS improved after the P.P. was added, indicating that the use of the P.P. reduced the moisture susceptibility of the asphaltic mixtures.

8. Declarations

8.1. Author Contributions

Conceptualization, S.F.M. and M.Q.I.; writing—original draft preparation, S.F.M. and M.Q.I.; writing—review and editing, S.F.M. and M.Q.I. All authors have read and agreed to the published version of the manuscript.

8.2. Data Availability Statement

The data presented in this study are available in article.

8.3. Funding

The Ministry of Higher Education and Scientific Research, as well as Civil Engineering Department, College of Engineering, Baghdad University, sponsored this study.

8.4. Conflicts of Interest

The authors declare no conflict of interest.

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