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Moisture Susceptibility of Asphalt Mixtures Modified by Recycled Polypropylene

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ABSTRACT

Moisture damage is the most commonly occurring problem, causing layers of asphalt pavements to break apart, reducing the serviceability of roads. The utilization of recycled polymer in asphalt mixtures has become popular because it may offer environmental benefits. The present study aims to investigate how the use of recycled polypropylene (RPP) can reduce the moisture susceptibility of hot mix asphalt (HMA). Asphalt binders were modified with three different concentrations of recycled polypropylene: 1%, 3%, and 5% by weight of the bitumen. The Marshall mix design method was utilized to establish the optimal asphalt content for the specific aggregate gradation both the control and modified mixtures were tested for moisture damage. Tensile and compressive strength tests were conducted to assess the moisture damage in asphalt mixtures. In the results, an optimal amount of RPP was found in asphalt mixtures, which improved Marshall properties. The same goes for their resistance to any moisture damage, which was also able to be considerably improved with this addition. The maximum tensile strength ratio (TSR) was 86.45% at 3% RPP, and the index of retained strength (IRS) of up to 81.99% by addition of 5% RPP, while the control mixture exhibited 80.25% for TSR and 75.82% for IRS. These results have shown the viability of applications with RPP in asphalt mixtures towards improved pavement performance and sustainability.

Keywords: Moistures susceptibility, Recycled polypropylene, Indirect tensile strength, Compressive strength, Asphalt mixture.

1. INTRODUCTION

Deterioration of asphalt concrete pavements is primarily due to moisture damage, which may reduce their service life **(Al-Saadi and Ismael, 2014; Wang et al., 2022; Taher and Ismael, 2023)**. The gradation of aggregate and asphalt greatly affects the the moisture susceptibility of AC and is important to avoid premature failure within one year **(Ahmed et al., 2019; Ugla and Ismael, 2024).** Water weakens the bond between asphalt cement and

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the aggregate surface, which reduces the cohesiveness of the binder and deteriorates the asphalt pavement's longevity **(Nazal and Ismael, 2019; Wiśniewski et al., 2020).** Different additives, like polymers, are added to asphalt mixes to enhance their durability against moisture-induced harm **(Jaafar et al., 2022; Mahmood and Kattan, 2023; Moghimi and Divandari, 2023).** For the construction of roads, the properties of modified bitumen might be improved by using the original polymer. However, issues with replacing recycled polymers with raw materials and the high cost of polymers mean that only a small amount can be used to improve road paving. Fortunately, studies have proven that recycled polymers can improve road performance comparable to original polymers, making them a beneficial modifier from an environmental and economic perspective **(Anwar et al.,2021; Oreto et al., 2021).** Asphalt pavement performance is enhanced by polymers that increase the mixture's resistance to fatigue, thermal cracking and permanent deformation in cold environments. In addition, it increases the shear modulus and reduces plastic deformation at high temperatures **(Al-Khateeb et al., 2020; Al-Shabani and Obaid, 2023).** Polymer waste can be used to enhance the characteristics of asphalt binders; hence, it will increase the durability and performance of asphalt mixtures, thus providing an economic and environmental benefit **(Joni and AL-Rubaie, 2022; Owaid et al., 2022; Jwaida et al., 2023; Alemu et al., 2023)**. Adding a polymer to the bitumen in amounts of 2-6% by weight improves the performance of binders, creating better roads, and thus reducing the cost of maintenance **(Emmaima et al., 2024)**. , surface roughness compared to unmodified bitumen, and they enhance both permanent deformation resistance and stress recovery. Additionally, they increase adhesion and cohesion, resulting in a better asphalt mixture **(Torres et al., 2020; Roja et al., 2021).**

The application of polymer-modified binders over asphalt in both paving and maintenance has increased. This is a result of the improvement of engineering features composing resistance against fatigue damage, rutting, thermal cracking, stripping, and temperature sensitivity (**Emtiaz et al.,2023)**. The polymer comprises 80% of waste polypropylene and the additional materials known as bitumen modifiers like styrene and maleic anhydride **(Mazurek and Buczyński, 2022)**. Because it is inexpensive to produce and readily available worldwide, polypropylene is a frequently used polymer. TSR and IRS measurements indicate that incorporating polypropylene fibers into the asphalt mixture enhances its moisture resistance **(Mohammed and Ismael, 2021).** Recycled polypropylene modified asphalt has properties similar to thermoplastic polyester-modified asphalt, especially in terms of its high-temperature performance **(Zhou et al., 2022; Polo-Mendoza et al., 2023).** However, when waste polypropylene is added to the asphalt, it reduces its ductility and makes it less resistant to fatigue cracking. In specific terms, adding 5% of waste PP to the asphalt reduces its ductility by approximately 20% **(Xiaoming and Eldouma, 2019).** Most studies incorporate polymer additives. The substitution level typically ranges from 1 to 8 percent of asphalt binder by weight of bitumen **(Veranko et al., 2018; Al-gurah et al., 2023).** The objective of the present study is to create an affordable and sustainable asphalt mixture that incorporates recycled polypropylene as an asphalt cement modifier. This would help in disposing of these wastes while also reducing the susceptibility of permanent deformation in asphalt mixtures.

2. MATERIALS AND METHODS

All materials employed are sourced locally and have undergone testing to adhere to the Iraqi Specification for Roads and Bridges **(SCRB/R9, 2003)** standards.

2.1 Asphalt Cement

The asphalt cement with a grade of 40/50 was chosen for its viscosity, which is suitable for Iraq's hot climate and is sourced from the Durrah Refinery in Baghdad. Its physical properties comply with the specifications set by Iraq **(SCRB/R9, 2003)**, which are provided in **Table 1.**

Table 1. Asphalt cement properties

Test	ASTM	Value	SCRB
Penetration (25° C,100 gm, 5 sec).	D5-2013	47	40-50
Softening Point °C	D36-2014	52	-
Ductility@ 25 °C	D113-2007	135	>100
Specific gravity at 25° C	D70-2018	1.043	-
Flash Point (Cleveland open cup) °C	D92-2018	248	>232
Retained Penetration of Residue, % (25°C, 100 g, 5 sec)	D5-2013	64	>55
Retained Ductility (25° C, 5 cm/min), cm	D113-2007	72	>25

2.2 Aggregates

Crushed coarse and fine aggregates sourced from the Al-Nibaai quarry located north of Baghdad were utilized. The coarse aggregates ranged in size from 1/2 inch to No.4 sieve, while the fine aggregates ranged from No.4 sieve (4.75 mm) to No.200 sieve (0.075 mm) **Tables 2 and 3** show the physical properties of coarse and fine aggregates according to the **(SCRB/R9 2003)** standard.

Table 2. Physical properties of coarse aggregate.

Test	ASTM	Value	SCRB
Water Absorption, %.	**(ASTM C127, 2015)**	0.48	-
Bulk Specific Gravity	**(ASTM C127, 2015)**	2.54	-
Abrasion Test (Los-Angeles), %	**(ASTM C131, 2014)**	14	≤ 30
Soundness in Magnesium Sulfate, %	**(ASTM C88, 2018)**	1.3	≤ 18
Degree of Crushing, %.	**(ASTM D5821, 2013)**	94	≥ 90

Table 3. Physical properties of fine aggregate.

Test	ASTM	Value	SCRB
Water Absorption, %.	**(ASTM C128, 2015)**	0.82	-
Bulk Specific Gravity	**(ASTM C128, 2015)**	2.59	-
Plasticity Index.	**(ASTM D4318, 2017)**	No	≤ 4
Sand equivalent.	**(ASTM D2419, 2014)**	92	≥ 45
Clay Lumps and friable particles, %.	**(ASTM C142, 2017)**	0	≤ 3

The experiment utilized limestone dust as filler, obtained from a lime factory in Karbala province. It is thoroughly dried and free of lumps or fine particle aggregations. **Table 4** demonstrates the physical characteristics of the filler. As per the Iraqi standard **(SCRB/R9 2003)**, the chosen aggregate for the wearing course type IIIA has a mid-range gradation with a maximum size of 19 mm (12.5 mm nominal size) **Fig. 1** shows the Gradation Mixes according to **(SCRB/R9, 2003**) limits.

Table 4. Physical properties of mineral filler.

Test	ASTM	Value	SCRB
% Passing Sieve No. 200	**(ASTM D242, 2019)**	96	70% min
Bulk Specific gravity	**(ASTM C188, 2017)**	2.96	-

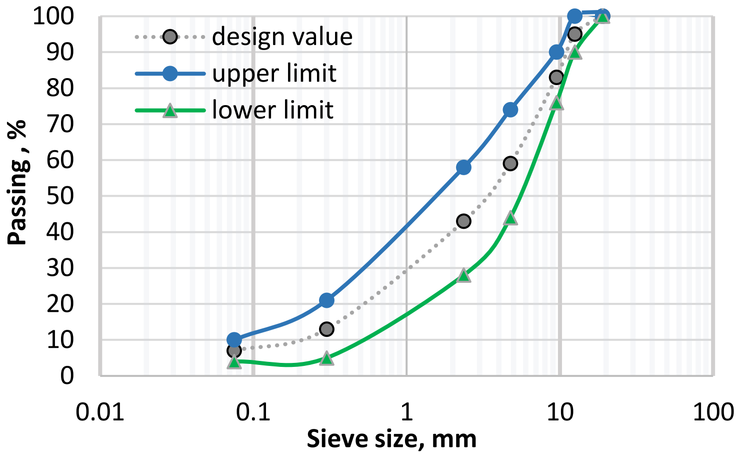

Figure 1. Gradation Mixes according to SCRB/R9 limits.

2.3 Recycled Polypropylene Polymer

The recycled polypropylene polymer was sourced from construction material remains and processed by cutting it into tiny pieces at a Bab Al-Sheikh plastic factory. These pieces were ground at 28,000 RPM, taking 10 minutes per 100 grams. The ground polymer was sieved using sieve No. 50, and the passing material was mixed in asphalt on a hotplate with an electric mixer running at 3000 rpm for 20 minutes. Monitor the temperature of the asphalt to ensure it does not exceed 165°C. Then, Since the melting point of RPP is close to the melting point of asphalt, the homogeneity of the asphalt and RPP mixture can be observed. **Fig. 2** shows the crushed and mixed of RPP.

Figure 2. Polypropylene Polymer waste crushed and mixed particles.

3. EXPERIMENTAL WORK

Initially, the purpose of the Marshall test was to identify the ideal asphalt content for asphalt cement. The tensile strength ratio and the retained strength coefficient were calculated through indirect tensile and compressive strength tests to evaluate the asphalt mixture's Susceptibility against moisture damage.

3.1 Marshall Mix Design

This method, as per **(SCRB R/9, 2003)**, involves determining the Optimum Asphalt Content (OAC) within a range of (4-6) % and increments of 0.5% in asphalt cement percentage. A set of asphalt mixture samples was prepared, and the Marshall test was conducted for each sample. The OAC was determined by calculating the average of Stability, Density, and Air Voids. Then add RPP in three proportions to the control mixture. The testing procedure outlined in ASTM D6926 involved the preparation of three cylindrical specimens for the control mix and for each percentage of the recycled polypropylene polymer-modified mixture. Each sample had dimensions of 4 inches and 2.5 inches in diameter and height respectively, with a weight of 1200 grams. The specimens were compacted on each face with 75 blows using a 4.535 kg free-dropped hammer. The density of each specimen was then determined, and its ability to withstand plastic flow was evaluated using ASTM D2726 and ASTM D6927, respectively. **Fig. 3** demonstrates Marshall specimen preparation and testing.

Figure 3. Marshall specimen Preparation and testing.

3.2 Indirect Tensile Strength

The test assessed the mixture's resistance to moisture damage following ASTM D6931. Before preparing the specimens, determine the number of blows required to achieve 7±1% air voids According to ASTM D6931 to ensure a balance between strength and durability in the asphalt mixture. The results are displayed in **Fig. 4**. Then, the samples were prepared according to ASTM D6926 for control mixture and control mixture with RPP ratios having measurements of 2.5 inches in height and 4 inches in circumference and tested following ASTM D4867. The tensile strength ratio compares conditioned to unconditioned samples and specifies that 80% is the minimal TSR value, according AASHTO M 320-2002 **(Ismael and Ahmed, 2019).**

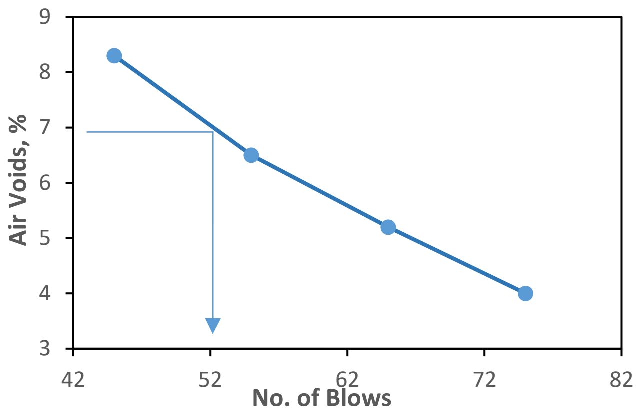

Figure 4. Correlation between Air Voids Percent and No. of Blows.

$$ITS = \frac{2\times P}{\pi\times t\times D} \quad \text{(ASTM D6931)} \quad (1)$$

$$TSR = \frac{ITS\ c}{ITS\ u} \times 100 \quad \text{(ASTM D4867)} \quad (2)$$

where:
ITS: indirect tensile strength, kPa.
P: the ultimate applied load, N.
D: the diameter of the sample, mm.
t: the thickness of the sample, mm.
ITS c: indirect tensile strength for conditioned sample, kPa.
ITS u: indirect tensile strength for unconditioned sample, kPa.
The data of these samples is analyzed to evaluate how unconditioned and conditioned mixes affect mixture performance. **Fig. 5** outlines the steps of the indirect tensile strength test.

Figure 5. The testing sequences for indirect tensile strength.

3.3 Compressive Strength Test

The Index of Retained Strength (IRS) is employed to assess how well an asphalt mixture can resist damage from moisture. 70% is the IRS's lowest allowable value, according to **(SCRB/R9, 2003)**. Mixtures that have a lower IRS are at a higher risk of being damaged by moisture. A compressive device is utilized to compact the prepared mixture. Samples with a of 4×4 inches in diameter and a height were prepared **(Raof and Ismael, 2019; Mawat and Ismael, 2020; Qian et al.,2023)** Following a 24-hour cooling period, the specimens were subjected to a compressive strength test at a loading rate of 5.08 mm/min.Then, axial force was applied to the initial surface until failure as described in **(Khaled and Ismael, 2019)**. **Fig. 6** presented the testing of compressive strength.

Figure 6. The compressive strength test.

4. RESULTS AND DESCUSION

After completing the experimental work, the following results were obtained and documented.

4.1 Results of the Marshall Test

Table 5 shows the results of the Marshall test for mixtures with different percentages of RPP, showing an increase slightly in stability as the percentage of RPP in the asphalt mixtures increases (2.69%, 7.55%, and 3.15%). The greatest stability improvement was observed at 3% RPP content. This increase in stability was accompanied by a decrease in flow values (6.93%, 12.71%, and 17.34%). The bulk density of the asphalt mixtures also decreased, while the percentage of voids in the mixtures increased slightly with higher RPP content. The addition of recycled polypropylene polymer enhances the mechanical performance of the asphalt mixture by improving stability, reducing deformation, and slightly affecting density. The void in the mineral aggregate decreases by about (1.15%, 2.04%, and 2.61%), and there is a decrease in the voids filled with asphalt by (0.05%, 0.28%, and 1.22%). This happens because adding recycled polypropylene polymer to the asphalt mixture results in a decrease in VMA due to increased aggregate packing efficiency and a decrease in VFA because the recycled polypropylene takes up some empty space that could otherwise be filled with asphalt binder **(Buruian et al., 2023)** Also, **Fig. 7** presents the test results.

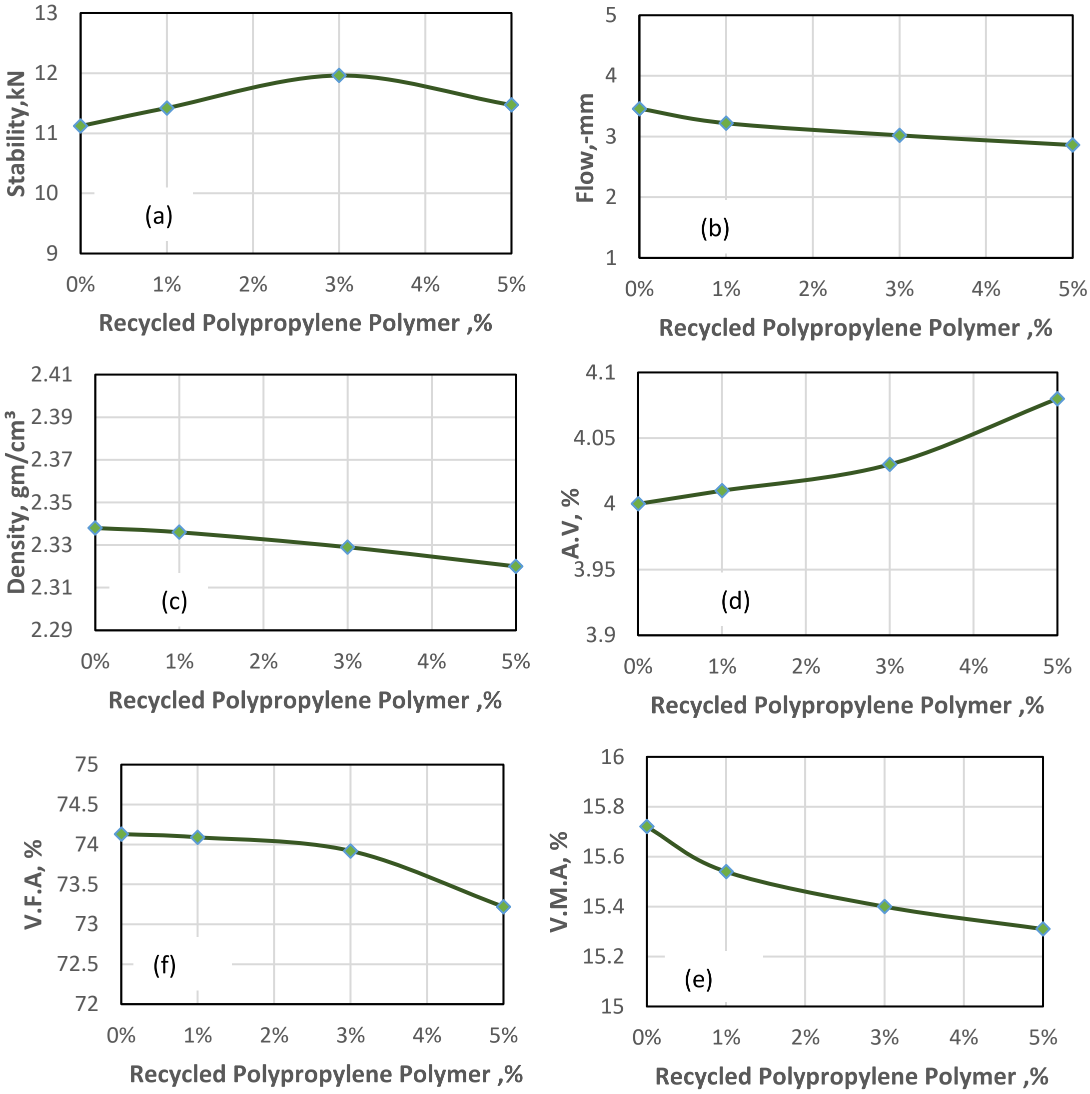

Figure 7. Effect of Recycled Polypropylene Polymer on Marshall Properties
a) Stability, b) Flow, c) Density, d) Air voids, e) V.M.A, f) V.F.A

Table 5. Marshall test results.

O.A.C	RPP (%)	Stability (kN)	Flow (mm)	Density (g/cm^3)	A.V (%)	V.M.A (%)	V.F.A (%)
4.9	0	11.12	3.46	2.338	4.00	15.72	74.13
	1	11.42	3.22	2.336	4.01	15.54	74.09
	3	11.96	3.02	2.329	4.03	15.40	73.92
	5	11.47	2.86	2.320	4.08	15.31	73.22

4.2 Results of the Tensile Strength Ratio

Adding recycled polypropylene polymer to the asphalt mixtures improved both values of tensile strength in dry and wet conditions. As a result, the TSR values increased, with the greatest increase occurring when using 3% RPP. The TSR value increased by 7.73% compared to the control mix. The increase in tensile strength may be credited to the improved adhesion between the binder and aggregate particles. Increasing the molecular weight of the RPP can improve ITS, enhance mixture properties, and make it more resistant to deterioration caused by water **(Stanic et al., 2021). Table 6** and **Fig. 8** present the test results.

Table 6. The indirect tensile strength ratio results.

RPP (%)	Dry ITS (kPa)	Wet ITS (kPa)	TSR (%)
0	1468.23	1178.31	80.25
1	1522.31	1274.64	83.73
3	1552.68	1342.33	86.45
5	1598.73	1374.28	85.96

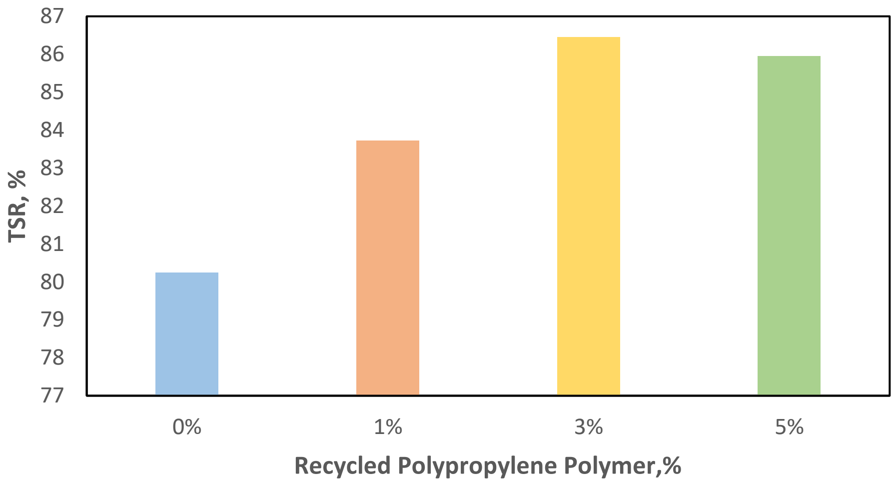

Figure 8. Effect of Recycled Polypropylene Polymer on TSR.

4.3 Results of the Index of Retained Strength

The dry and wet compressive strength values increased with an increasing percentage of RPP in the asphalt mixture, resulting an increase in IRS of 3.22%, 5.72%, and 8.14% for recycled polypropylene polymer content of 1%, 3%, and 5%, respectively. The reason for this better behavior is the same as the addition of RPP, which also improved the compressive strength of the mixture under wet conditions, as indicated by the TSR test. As a result, the increase in IRS leads to improved moisture resistance. **Table 7** and **Fig. 9** display the test results.

Table 7. Compressive strength test results.

RPP (%)	Dry Compressive Strength (kPa)	Wet Compressive Strength (kPa)	I.R.S (%)
0	4989.97	3783.39	75.82
1	5441.12	4358.22	78.26
3	5699.65	4568.84	80.16
5	6095.21	4997.46	81.99

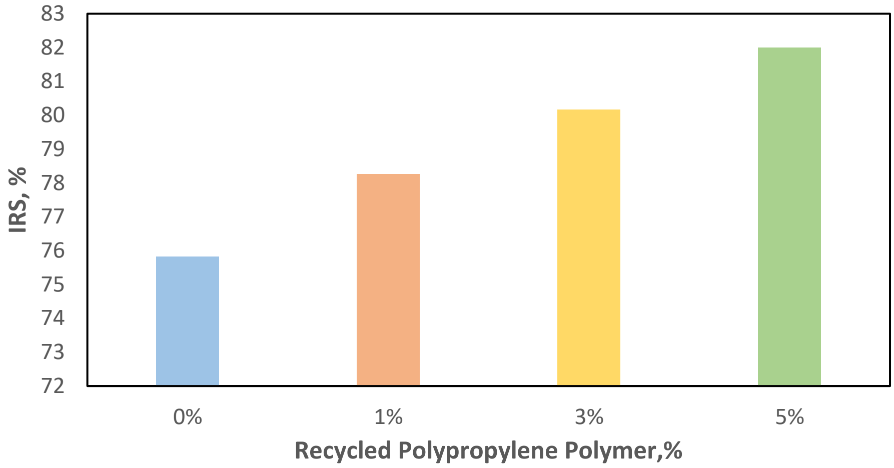

Figure 9. Effect of Recycled Polypropylene Polymer on IRS.

5. CONCLUSIONS

This study utilized the Marshall mix design and conducted moisture damage resistance tests to assess by means of indirect tensile strength and compressive strength hot mix asphalt. Based on the experimental findings, the following conclusions were drawn:

- The incorporation of recycled polypropylene polymer at ratios of 1%, 3%, and 5% by weight of bitumen determined that the optimal content is 3%. This percentage enhanced Marshall's stability by 7.55%.
- Recycled polypropylene polymer reduces Marshall flow by up to 17.34% at 5% RPP, leading to improved cohesion in the asphalt mixture.
- The addition of recycled polypropylene polymer slightly raises the air voids in asphalt mixtures, with the air voids increasing to 4.08% for 5% RPP, resulting in a decrease in density to 2.320 g/cm^3.
- Recycled Polypropylene Polymer significantly increased the values of the ratio of tensile strength The best results were achieved with a 3% RPP content, leading to TSR values 7.73% higher than the control mixtures.
- By adding recycled polypropylene polymer to the asphalt mixtures, the index of retained strength value increased. With a 5% RPP percentage, the rise in IRS value over the control mix was 8.14%.

NOMENCLATURE

Symbol	Description	Symbol	Description
AC	Asphalt concrete	P	Ultimate load failure
ASTM	American Society for testing and material	RCA	Recycled concrete aggregate
AV	Air voids, %	RPP	Recycled Polypropylene Polymer
d	Particle diameter	**SCRB**	State Corporation for Roads and Bridges
D	Diameter of specimen, mm	t	Thickness of specimen
HMA	Hot mix asphalt	TSR	Tensile strength ratio
IRS	Index of retained strength	**VFA**	Voids filled with asphalt
ITS	Indirect tensile strength	VMA	Voids in mineral aggregate

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Credit Authorship Contribution Statement

Maha M. Abdulghafour: Conducting experiments, analyzing results, compiling references, conceptualization, writing the abstract and introduction, discussion, and language review.
Mohammed Q. Ismael**:** Results verification and language review.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Ahmed, M.B., Abed, A.H., and Al-Badran, Y.M.H., 2019. Evaluation of moisture susceptibility for modified open graded friction course mixes used styrene butadiene styrene. Al-*Nahrain Journal for Engineering Sciences*, 22(2), pp.94-101.

Alemu, G.M., Melese, D.T., Mahdi, T.W., and Negesa, A.B., 2023. Combined performance of polyethylene terephthalate waste plastic polymer and crumb rubber in modifying properties of hot mix asphalt. *Advances in Materials Science and Engineering*, 2023(1), P. 6320490. http://dx.doi.org/10.1155/2023/6320490.

Al-gurah, E.R., Al-ghurabi, S.J., and Al-Humeidawi, B.H., 2023, September. Laboratory evaluation of properties of modified asphalt binder with different types of additives. In *IOP Conference Series: Earth and Environmental Science (Vol. 1232, No. 1, P. 012043)*. IOP Publishing.

Al-Khateeb, G.G., Zeiada, W., Ismail, M., Shabib, A. and Tayara, A., 2020. Mechanistic-empirical evaluation of specific polymer-modified asphalt binders effect on the rheological performance. *Science Progress*, 103(4), P. 0036850420959876. http://dx.doi.org/10.1177/0036850420959876.

Al-Saadi, A.A., and Ismael, M.Q., 2023. Improvement of moisture susceptibility for asphalt mixture with ceramic fiber. *Journal of Engineering*, 29(4), pp. 78-91. http://dx.doi.org/10.31026/j.eng.2023.04.05.

Al-Shabani, Z.J., and Obaid, I.A., 2023. Investigate the effect of using reclaimed asphalt pavement rap and polymer-modified bitumen on the moisture damage of hot mix asphalt. In *E3S Web of Conferences (Vol. 427, p. 03019)*. EDP Sciences. http://dx.doi.org/10.1051/e3sconf/202342703019.

Anwar, M.K., Shah, S.A.R., and Alhazmi, H., 2021. Recycling and utilization of polymers for road construction projects: An application of the circular economy concept. *Polymers*, 13(8), P. 1330. http://dx.doi.org/10.3390/polym13081330.

ASTM C127-15., 2015. Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate. West Conshohocken, PA: ASTM International.

ASTM C128-15., 2015. Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate. West Conshohocken, PA: ASTM International.

ASTM C131-14., 2014. Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine. West Conshohocken, PA: ASTM International.

ASTM C142-17., 2017. Standard Test Method for Clay Lumps and Friable Particles in Aggregates. West Conshohocken, PA: ASTM International.

ASTM C188-17., 2017. Standard Test Method for Density of Hydraulic Cement. West Conshohocken, PA: ASTM International.

ASTM C88-18., 2018. Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate. West Conshohocken, PA: ASTM International.

ASTM D113-07., 2007. Standard Test Method for Ductility of Bituminous Materials. West Conshohocken, PA: ASTM International.

ASTM D2419-14., 2014. Standard Test Method for Sand Equivalent Value of Soils and Fine Aggregate. West Conshohocken, PA: ASTM International.

ASTM D242/D242M-19., 2019. Standard Specification for Mineral Filler for Asphalt Mixtures. West Conshohocken, PA: ASTM International.

ASTM D36-14., 2014. Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus). West Conshohocken, PA: ASTM International.

ASTM D4318-17., 2017. Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. West Conshohocken, PA: ASTM International.

ASTM D5-13., 2013. Standard Test Method for Penetration of Bituminous Materials. West Conshohocken, PA: ASTM International.

ASTM D5821-13., 2013. Standard Test Method for Determining the Percentage of Fractured Particles in Coarse Aggregate. West Conshohocken, PA: ASTM International.

ASTM D70-18., 2018. Standard Test Method for Density of Semi-Solid Bituminous Materials (Pycnometer Method). West Conshohocken, PA: ASTM International.

ASTM D92-18., 2018. Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester. West Conshohocken, PA: ASTM International.

Buruiana, D.L., Georgescu, P.L., Carp, G.B., and Ghisman, V., 2023. Recycling micro polypropylene in modified hot asphalt mixture. Scientific Reports, 13(1), P. 3639. http://dx.doi.org/10.1038/s41598-023-30857-9.

Emmaima, A.M., Ali, S.I.A. and Gallouz, K.S., 2024. Experimental investigation of polymer and nanomaterial modified asphalt binder. *Engineering, Technology and Applied Science Research*, 14(1), pp. 12869-12874. http://dx.doi.org/10.48084/etasr.6607.

Emtiaz, M., Imtiyaz, M.N., Majumder, M., Idris, I.I., Mazumder, R., and Rahaman, M.M., 2023. A comprehensive literature review on polymer-modified asphalt binder. *Civil Engineering*, 4(3), pp. 901-932. http://dx.doi.org/10.3390/civileng4030049.

Ismael, M.Q., and Ahmed, A.H., 2019. Effect of hydrated Lime on moisture susceptibility of asphalt mixtures. *Journal of Engineering*, 25(3), pp. 89–101. http://dx.doi.org/10.31026/j.eng.2019.03.08.

Jaafar, M.A., Joni, H.H. and Karim, H.H., 2022. Assessment of the effect of nono-clay on recycled asphalt mixtures resistance to moisture. *Engineering and Technology Journal*, 40(11), pp. 1441-1447. http://dx.doi.org/10.30684/etj.2022.133022.1164.

Joni, H.H., and AL-Rubaie, A.H., 2022. Enhancement of the rutting resistance of asphalt mixtures at different high temperatures using waste polyethylene polymer. *Engineering and Technolology Journal*, 40, pp. 1-9. http://dx.doi.org/10.30684/etj.2021.131179.1008.

Jwaida, Z., Dulaimi, A., Mydin, M.A.O., Özkılıç, Y.O., Jaya, R.P., and Ameen, A., 2023. The use of waste polymers in asphalt mixtures: bibliometric analysis and systematic review. *Journal of Composites Science*, 7(10), P. 415. http://dx.doi.org/10.3390/jcs7100415.

Khaled, T., and Ismael, M., 2019. Evaluation of hot mix Asphalt containing reclaimed Asphalt pavement to resist moisture damage. *Journal of Engineering and Sustainable Development*, 23(05).

Ma, X., Wang, J. and Xu, Y., 2022. Investigation on the effects of RAP proportions on the pavement performance of recycled asphalt mixtures. *Frontiers in Materials*, 8, P. 842809. http://dx.doi.org/10.3389/fmats.2021.842809.

Mahmood, A.O. and Kattan, R.A., 2023. Experimental analysis to evaluate the impact of styrene-butadiene-styrene and crumb rubber on the rutting and moisture resistance of asphalt mixtures. *Sustainability*, 15(13), P. 10387. http://dx.doi.org/10.3390/su151310387.

Mawat, H.Q., and Ismael, M.Q., 2020. Assessment of moisture susceptibility for Asphalt mixtures modified by carbon fibers. *Civil Engineering Journal (Iran)*, 6(2), pp. 304–317. http://dx.doi.org/10.28991/cej-2020-03091472.

Mazurek, G., Šrámek, J. and Buczyński, P., 2022. composition optimisation of selected waste polymer-modified bitumen. *Materials*, 15(24), P. 8714. http://dx.doi.org/10.3390/ma15248714.

Moghimi, S., Shafabakhsh, G. and Divandari, H., 2023. Evaluation of rutting, fatigue, and moisture resistance of low-energy Asphalt mixtures modified by crumb rubber. *Advances in Civil Engineering,* 2023(1), P. 6668963. http://dx.doi.org/10.1155/2023/6668963.

Mohammed, S.F. and Ismael, M.Q., 2021. Effect of polypropylene fibers on moisture susceptibility of warm mix asphalt. *Civil Engineering Journal*, 7(6), pp. 988-997. http://dx.doi.org/10.28991/cej-2021-03091704.

Nazal, H.H., and Ismael, M.Q., 2019. Evaluation the moisture susceptibility of asphalt mixtures containing demolished concrete waste materials. *Civil Engineering Journal*, 5(4), pp. 845–855. http://dx.doi.org/10.28991/cej-2019-03091293.

Oreto, C., Russo, F., Veropalumbo, R., Viscione, N., Biancardo, S.A. and Dell'Acqua, G., 2021. Life cycle assessment of sustainable asphalt pavement solutions involving recycled aggregates and polymers. *Materials*, 14(14), P. 3867. http://dx.doi.org/10.3390/ma14143867.

Owaid, K.A., Hamdoon, A.A., Matti, R.R., Saleh, M.Y. and Abdelzaher, M.A., 2022. Waste polymer and lubricating oil used as asphalt rheological modifiers. *Materials*, 15(11), P. 3744. http://dx.doi.org/10.3390/ma15113744.

Polo-Mendoza, R., Navarro-Donado, T., Ortega-Martinez, D., Turbay, E., Martinez-Arguelles, G. and Peñabaena-Niebles, R., 2023. Properties and characterization techniques of graphene modified asphalt binders. *Nanomaterials,* 13(5), P. 955. http://dx.doi.org/10.3390/nano13050955.

Qian, G., Luo, X., Yu, H., Shi, C., Zhang, C. and Li, P., 2023. Evaluation of material composition on the shear performance of asphalt mixtures under different test conditions. *Buildings*, 13(4), P. 936. http://dx.doi.org/10.3390/buildings13040936.

Raof, H.B., and Ismael, M.Q., 2019. Effect of PolyPhosphoric acid on rutting resistance of Asphalt concrete mixture. Civil Engineering Journal, 5(9), pp. 1929–1940. http://dx.doi.org/10.28991/cej-2019-03091383.

Roja, K.L., Rehman, A., Ouederni, M., Krishnamoorthy, S.K., Abdala, A. and Masad, E., 2021. Influence of polymer structure and amount on microstructure and properties of polyethylene-modified asphalt binders. *Materials and Structures*, 54, pp. 1-17. http://dx.doi.org/10.1617/s11527-021-01683-0.

SCRB/R9, 2003. Standard Specifications for Roads and Bridges, Section R/9, Hot-Mix Asphaltic Concrete Pavement. *The State Corporation for Roads and Bridges, Ministry of Housing and Construction*.

Stanic, S., Koch, T., Schmid, K., Knaus, S. and Archodoulaki, V.M., 2021. Improving rheological and mechanical properties of various virgin and recycled polypropylenes by blending with long-chain branched polypropylene. Polymers, 13(7), P. 1137. http://dx.doi.org/10.3390/polym13071137.

Taher, Z.K. and Ismael, M.Q., 2023. Moisture susceptibility of hot mix asphalt mixtures modified by nano silica and subjected to aging process. *Journal of Engineering*, 29(4), pp. 128-143. http://dx.doi.org/10.31026/j.eng.2023.04.09.

Torres, H.P., Fernandes, S.R., Loureiro, C.D., Moura, C.F., Silva, H.M. and Oliveira, J.R., 2020. Use of polymer modified binders as rejuvenators in recycled asphalt mixtures. *International Journal of Pavement Research and Technology*, 13, pp. 654-664. http://dx.doi.org/10.1007/s42947-020-6006-5.

Ugla, S.K. and Ismael, M.Q., 2024. Evaluating the moisture susceptibility of asphalt mixtures containing aluminum dross as a filler. *Journal of Engineering*, 30(01), pp. 190-206. http://dx.doi.org/10.31026/j.eng.2024.01.12.

Veranko, V.A., Ladyshau, A.V. and Hatalski, R.K., 2018. Investigation of fatigue life for asphalt concrete modified by polymer additives of various types. *Science and Technique*, 17(6), pp. 451-457. http://dx.doi.org/10.21122/2227-1031-2018-17-6-451-457.

Wiśniewski, D., Słowik, M., Kempa, J., Lewandowska, A. and Malinowska, J., 2020. Assessment of impact of aramid fiber addition on the mechanical properties of selected asphalt mixtures. *Materials*, 13(15), p.3302. http://dx.doi.org/10.3390/ma13153302.

Xiaoming, H. and Eldouma, I.B., 2019. Experimental study to determine the most preferred additive for improving asphalt performance using polypropylene, crumb rubber, and tafpack super in medium and high-temperature range. *Applied Sciences*, 9(8), P. 1567. http://dx.doi.org/10.3390/app9081567.

Zhou, G., Li, C., Wang, H., Zeng, W., Ling, T., Jiang, L., Li, R., Liu, Q., Cheng, Y. and Zhou, D., 2022. Preparation of Wax-Based warm mixture additives from waste polypropylene (PP) plastic and their effects on the properties of modified asphalt. *Materials*, 15(12), P. 4346. http://dx.doi.org/10.3390/ma15124346.

حساسية الرطوبة لمخاليط الأسفلت المعدلة بمادة البولي بروبلين المعاد تدويرها

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الخلاصة

يعد الضرر الناجم عن الرطوبة هو المشكلة الأكثر شيوعًا التي تسبب تفكك طبقات الأرصفة الإسفلتية، مما يقلل من إمكانية خدمة الطرق. أصبح استخدام البوليمر المعاد تدويره في الخلطات الإسفلتية شائعًا لأنه قد يوفر فوائد بيئية. يهدف البحث الحالي إلى استكشاف إمكانات البولي بروبلين المعاد تدويره في تقليل حساسية الأسفلت الساخن للرطوبة. تم تعديل مواد رابطة الأسفلت بثلاثة تراكيز مختلفة من مادة البولي بروبلين المعاد تدويرها: 1%، 3%، و5% من وزن البيتومين. تم استخدام طريقة تصميم خلطة مارشال لتحديد محتوى الإسفلت الأمثل للتدرج الكلي المحدد وتم اختبار كل من الخلطات الضابطة والمعدلة للتأكد من عدم تعرضها للرطوبة. تم اجراء اختبارات قوة الشد والضغط لتقييم الضرر الرطوبي في الخلطات الاسفلتية. من النتائج، تم العثور على المحتوى الأمثل من البولي بروبلين المعاد تدويره في الخلطات الإسفلتية مع الاتجاه لتعزيز خصائص مارشال. وينطبق الشيء نفسه على مقاومتها لأي ضرر بسبب الرطوبة، والتي تحسنت أيضًا بفضل هذه الإضافة. وكان الحد الأقصى للزيادة في نسبة قوة الشد 86.45% عند نسبة 3% من مادة البولي بروبلين المعاد تدويره، وأعلى معدل نمو لمؤشر قوة القص المحتفظ بها يصل إلى 81.99% بإضافة 5% بينما أظهرت خلطة التحكم 80.25% لنسبة مقاومة الشد و 75.82% لمؤشر القوة القص. من مادة البولي بروبلين المعاد تدويره. وقد أظهرت هذه النتائج جدوى التطبيقات مع البولي بروبلين المعاد تدويره في الخلطات الإسفلتية من أجل تحسين أداء الأسطح وزيادة الاستدامة.

الكلمات المفتاحية: تحسس الرطوبة، البولي بروبلين المعاد تدويره، خلطة مارشال، مقاومة الشد غير المباشر، مقاومة الانضغاط