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Performance Evaluation of Asphalt Mixture Modified with Medical Plastic Waste

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Abstract

Moisture presents a significant challenge for flexible pavements, as it can cause a range of issues, including asphalt stripping, leading to decreased durability and service life of the pavements. This, in turn, results in higher construction and maintenance costs. The primary objective of this research is to examine the moisture sensitivity of hot asphalt mixtures by incorporating medical plastic waste (MPW) as an asphalt mix modifier. The study involved blending asphalt 60/70 with varying concentrations of MPW (ranging from 2% to 8% by weight of bitumen). the asphalt mixtures were designed according to Egyptian specifications using the Marshall method. The moisture susceptibility of both the conventional and MPW-modified asphalt mixtures was assessed through indirect tensile strength (IDT) and loss of stability tests. The test results demonstrated that adding 4% MPW yielded superior performance across most parameters. incorporating MPW significantly improved the hardness of the asphalt mixture and reduced susceptibility to moisture damage. Incorporating MPW significantly improved hardness of the asphalt mixture and reduced susceptibility to moisture damage.

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Keywords: Medical Plastic Waste, Binder, Marshall Test, Moisture Susceptibility, TSR, Loss of stability.

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1. INTRODUCTION

Hospitals are confronting a massive plastic waste crisis, with each patient producing an astounding 1.4 to 2.2 kg of waste per day [1]. Surprisingly, 55% of this rubbish is plastic. These persistent toxins pose a double threat: poor treatment can infect regular trash, causing a disposal nightmare and disease such as COVID-19 [2-5]. Traditional options, like incineration and landfills, appear easy but are far from ideal, as they harm the air and soil. Clearly, novel measures are required to reduce the growing mountain of medical plastic waste. Current techniques are unsustainable, with significant environmental repercussions. Addressing this issue requires a comprehensive plan that prioritizes waste reduction, increased recycling, and the development of environmentally acceptable medical supplies and disposal technologies.

Egypt is a developing country with a rapidly growing population that needs to stabilize its economy, which means that its healthcare system needs to be expanded. To accommodate these demands, a plethora of private practices, clinics, and hospitals thrive. But this advancement has a hidden cost: an increasing amount of medical plastic waste (MPW), which endangers public health and the environment [6-9]. Scientists, engineers, researchers, and governments all have an important responsibility: to develop cost-effective and sustainable garbage disposal solutions. Recycling discarded plastic is an excellent example. These solutions should not just focus on environmental benefits, but also on new ways to repurpose waste materials in projects such as road building [10-14]. This technique provides a win-win situation by reducing waste while producing significant resources for infrastructure development [15-18].

Lately, numerous investigations have been conducted on recycled plastic waste. It is also common knowledge that plastic waste pollutes the environment over time due to the lengthy decomposition process [19,20]. Squander plastics can be utilized as black-top modifiers in various structures through additional cycles. Waste plastics were initially processed into pellets with the intention of directly incorporating them into the asphalt production plant [21]. Shredding has begun to be done with waste plastics in recent years [22].

Researchers are looking for practical ways to repurpose waste plastic into a profitable resource. One interesting option is to incorporate recycled plastic types such as PET, LDPE, HDPE, and PE as additives in asphalt pavements [23]. Using modified asphalt instead of raw asphalt is a recommended way to improve the

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longevity and reliability of asphalt pavements to fulfill various criteria, such as climatic conditions and traffic loads [24].

Virgin polymers have been demonstrated to enhance asphalt performance, particularly in terms of high-temperature stability [25]. However, virgin polymer materials can be challenging to obtain and costly to utilize as modifiers [26]. To address these concerns, the usage of discarded plastics for asphalt modification has gained traction, as it helps reduce building costs and mitigate environmental impacts. Researchers are actively exploring the use of waste plastics in asphalt manufacturing. This includes studies on the properties of this modified asphalt, how it works, and potential environmental impacts [27]. A key goal is to find ways to incorporate more waste plastic without sacrificing the performance of the asphalt [28]. Early research suggests that using waste plastic could significantly reduce construction costs and help protect the environment from pollution [29].

The addition of polymers to asphalt pavements can significantly enhance performance [30-31]. While virgin polymers often achieve this improvement, recycled polymers may provide comparable benefits [32]. However, careful waste plastic selection and controlled production methods are critical to success [33].

There are two primary approaches to incorporating polymers: directly modifying the bitumen (wet process) or adding solid polymers to the mix (dry process). The wet procedure is the most prevalent method [34]. According to previous studies, altering bitumen with polymers or recycled plastics improves asphalt performance, including higher resistance to rutting, enhanced stiffness in hot weather, and reduced temperature sensitivity [25,34]. The choice of polymer has a considerable impact on asphalt fatigue resistance because it changes bitumen's rheological properties (such as flow and deformation behavior) [35,37]. Several studies have investigated the use of recycled plastic trash for bitumen modification. Common alternatives include low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), ethylene-vinyl acetate (EVA), acrylonitrile-butadiene-styrene (ABS), and polyethylene terephthalate. García-Morales' research on recycled EVA showed encouraging results. Incorporating up to 9% EVA increased the binder's viscosity at high temperatures, improving rutting resistance while maintaining workability during manufacture and application [38]. Other research has revealed some shortcomings. Fuentes-Auden discovered that, while recycled polyethylene improves rutting resistance and lowers cracking, concentrations greater than 5% can have a negative effect on workability. Similarly, Casey et al. found that HDPE and LDPE outperformed recycled PET, PVC, ABS, and MDPE. While ABS showed some potential, the ideal concentration for recycled HDPE and LDPE was around 4%.

2. OBJECTIVES OF STUDY

a) Reusing medical plastic waste to improve the properties of the asphalt mixture while avoiding environmental pollution or the spread of infection.
b) Determining the optimum ratio of medical plastic waste.
c) Evaluating the properties of the modified HMA (Marshall design, parameters, moisture sensitivity).

3. RESEARCH METHODOLOGY

This study work investigates different areas, the main scope of this research work includes:

a) Selecting the types of aggregate (coarse and fine) and mineral filler to be used in composing control HMA.
b) Selecting the type of asphalt to be used in this study.
c) Reviewing the benefits of plastic waste material additives on pavement performance.
d) Characterizing and classifying medical plastic wastes.
e) A conventional control mix designed using Marshall method was used with amounts of additives to evaluate the rheological and mechanical properties of control and modified asphalt mixtures.
f) Carrying out Marshall, Indirect Tensile Strength (ITS).

4. MATERIALS AND EXPERIMENTATION METHODS

4.1. Materials

An asphalt binder of 60/70 penetration grade obtained from the Suez refinery, Egypt, was used in the present investigation. Its properties are summarized in Table 1.

TABLE 1 THE PHYSICAL PROPERTIES OF THE BITUMEN USED IN THIS STUDY.

PROPERTY	**Test method**	**Quantity**	**Specification limit**
Penetration at 25 °C, 100 g. 5 s (deci-mm)	ASTM D-5	63	60-70
Softening Point, ring and ball (°C)	ASTM D36	51	49-56
Flash Point, Cleveland open cup (°C)	ASTM D-92	264	Min 232
Ductility at 25 °C at 5 cm/min (cm)	ASTM D-113	106	Min 100
Solubility in trichloroethylene, (%)	ASTM D2042-76	99.8	Min 99
Loss on heating. (%)	ASTM D	0.09	Max 0.8

Coarse and fine aggregates are both used to prepare asphalt mixture samples, the coarse aggregate used is crushed granite having a maximum nominal size of 19 mm. Table 2 presents their physical properties. Medical plastic wastes (MPW) are brought sterilized from government hospitals in Sohag Governorate, Egypt as shown in Fig.1.

TABLE 2 AGGREGATE PROPERTIES.

Property (unit)	Specification	Standard
Abrasion loss (%) (Los Angeles)	21.8	AASHTO T96
Flakiness index (%)	15	BS 812
Two or more crushed faces (%)	91	ASTM D5821
Coarse aggregate water absorption (%)	2.1	AASHTO T85
Fine aggregate water absorption (%)	2.6	AASHTO T84
Coarse aggregate specific gravity (g/cm³)	2.57	ASTM C127
Fine aggregate specific gravity (g/cm³)	2.31	ASTM C128

4.2 Experimental Methods

4.2.1 Conventional asphalt mixture

The design of a Conventional Hot Mix Asphalt (HMA) wearing surface course, commonly known as 4C, used in the construction of pavements in Egypt, was performed using the Marshall method [39]. The composition of the aggregates in this mixture consisted of 25% aggregate #2, 43% aggregate #1, 32% sand, and 5% mineral filler. Fig.2 depicts the gradation curve of the aggregate blend in comparison to the specifications outlined in the Egyptian guidelines [40,41]. Table 3 provides a comparison between the properties of the Marshall mixture and the requirements specified for the asphalt wearing surface mix in Egypt.

TABLE 3 CONVENTIONAL ASPHALT MIXTURE PROPERTIES PARAMETER

Parameter	Quantity	Egyptian requirements
Marshall bulk density (t/m³)	2.32	-
Stability (kg)	1150	Min 1100
Flow (mm)	3.45	2-4
Air voids (AV) (%)	4.65	3-5
Voids in mineral aggregates (VMA)	13.8	Min 13
Voids filled with binder (VFB)	70	-
Asphalt Cement (%)	5.2	-

Fig .1 Medical plastic wastes (MPW).

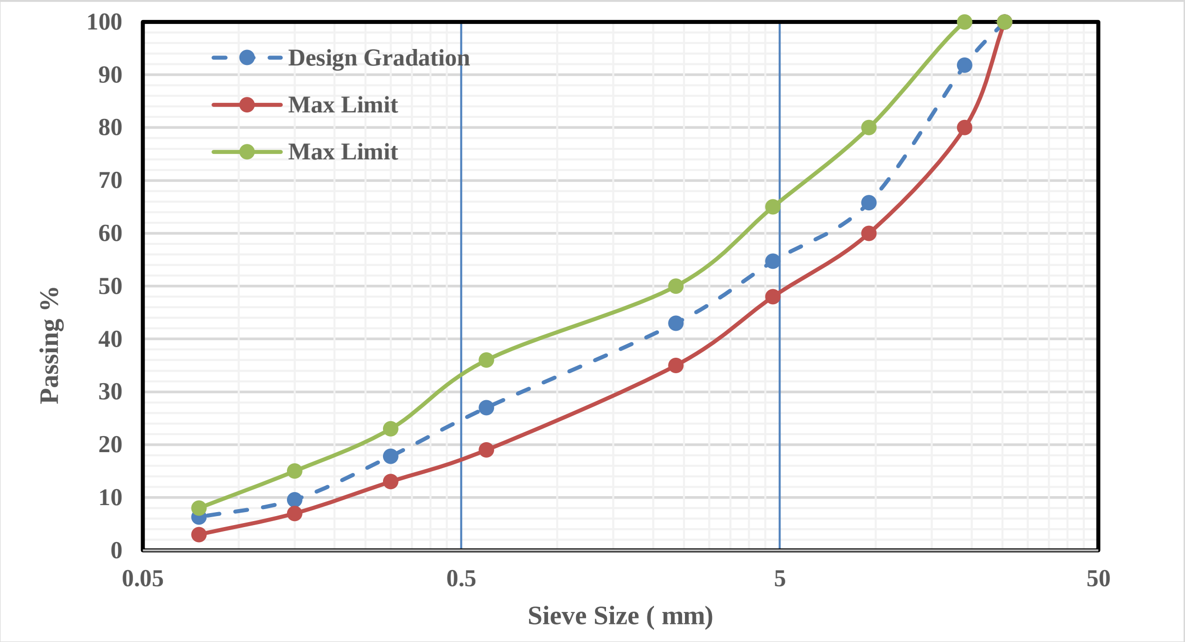

Fig .2 Gradation curve of the wearing surface asphalt mixture.

4.2.2 Preparation of modified asphalt mixture

Asphalt mixtures are prepared by adding (2%, 4%, 6%, 8%) of the MPW by weight of binder using the dry process. The dry process, MPW are firstly added to the preheated aggregates and mixed properly until uniform mixing is ensured. After that, asphalt binder is added to this blend to form an asphalt mixture [42,43].

4.2.3 Moisture Susceptibility

Two tests were conducted to evaluate the moisture susceptibility of conventional and MPW-modified mixtures: the indirect tensile strength (IDT) test and the loss of stability test. The IDT test, performed according to (AASHTO T283-14) [44], aimed to examine how moisture impacts the tensile strength of the asphalt mixture. Samples were prepared for each concentration of MPW, following the dimensions of Marshall samples. The specimens' air void ratios were determined to be between 6% and 8% through multiple trials. The samples were divided into two sets. In the first set, the samples were subjected to the IDT test in a dry state at a temperature of 25°C, with a loading rate of 50.8 mm/minute, until they reached failure. The failure load was recorded for each sample. In the second set, the following steps were performed on the samples:

- The saturation percentage of the samples was increased to a range of 55% to 80% using vacuums, following (AASHTO T283-14) [44].
- The saturated samples were immersed in a water tank at a temperature of 60°C for 24 hours, followed by 2 hours at 25°C.
- The samples were then loaded onto a testing machine at a rate of 50.8 mm/minute, and the load at which failure occurred was measured.

The indirect tensile strength (ITS) can be calculated using Eq. 1, while the tensile strength ratio (TSR), which indicates moisture susceptibility, can be determined as the ratio of the tensile strength of wet samples to that of dry samples using Eq. 2.

$$ITS = 2P/\pi HD \qquad \text{Eq. 1}$$

$$TSR\% = 100(ITS_{wet}/ITS_{dry}) \qquad \text{Eq. 2}$$

Where:
P = Failure load (measured in kilonewtons, KN).
H = Thickness of the sample (measured in millimeters, mm).
D = Diameter of the sample (measured in millimeters, mm).

ITS_{dry} = the mean indirect tensile strength of the samples in the first group, measured in kilopascals (kPa).
ITS_{wet} = the average indirect tensile strength of the samples in the second group, also measured in kilopascals (kPa).

As per references [40,45-51], the loss of stability test, referred to as the immersion Marshall test, was employed to assess the moisture damage resistance of asphalt mixtures. Six samples of regular and MPW-modified mixes were prepared for the test. The samples were divided into two groups. In the first group, the samples were subjected to examination in a Marshall apparatus after being immersed in a water bath for 30 minutes at a temperature of 60 C^{o}. On the other hand, the second group of samples was evaluated after being immersed in a water container for 48 hours at the same temperature of 60 degrees Celsius. The loss of stability (LOS) is defined as the percentage decrease in Marshall stability (MS) between the first and second group samples, and it can be calculated using Eq. 3:

$$LOS\% = 100 * (1 - Ms_1 / Ms_2) \qquad \text{Eq. 3}$$

Here, Ms_1 represents the average Marshall stability of the second group samples, while Ms_2 represents the average Marshall stability of the initial group samples.

5. RESULTS

5.1 Marshall tests

Three samples of each of the control and modified asphalt mixtures were made with an optimal asphalt concentration of 5.2%. These samples were then put through the Marshall test to determine the parameters of the modified asphalt mixtures. The stability and flow parameters were computed after the samples were immersed in a 60°C water bath for 30 minutes and loaded at a rate of 50.8 mm/min. Fig. 3 shows that using 4% MPW as modifiers increased the Marshall stability of the unaltered asphalt mixture by 44.4%. In contrast, Fig. 4 demonstrates that the flow value fell with the inclusion of the modifiers for all MPW items.

Fig. 5 depicts the variation of bulk density values with varied MPW levels, revealing that the 4% MPW modified mixture had the highest bulk density. Fig. 6 illustrates how varied percentages of MPW affect key volumetric parameters of conventional and MPW-modified asphalt mixtures. These characteristics include the percentage of air voids (AV%), voids in mineral aggregate (VMA%), and voids filled with aggregate (VFA%). In general, the air void content ranged from 3% to 5% across all samples. Adding MPW to the combination reduced the VMA% somewhat as compared to the traditional mixture. The percentages of voids filled with aggregates (VFA%) in modified asphalt mixtures rose with the addition of MPW.

The Marshall Quotient (MQ) indicates how well an asphalt mix resists getting deformed. A higher MQ value means the mixture is stiffer and less likely to bend under pressure [52,53]. Fig. 7 shows that the Marshall Quotient (MQ) Value increased by 39.14% after 4% MPW was applied. This suggests that the asphalt mixtures treated with MPW were more resistant to persistent deformation because of their high MQ value and improved Marshall strength. As a result, asphalt mixtures containing MPW can be considered for paving areas that require low asphalt concentrations while maintaining high stiffness.

5.2 Moisture Susceptibility

5.2.1 Indirect tensile strength

This investigation aimed to assess the influence of MPW on the tensile strength and moisture resistance of asphalt mixtures. The correlation between MPW content and tensile strength ratio (TSR) is depicted in Fig. 8. The data presented in Fig. 8 demonstrably reveals a statistically significant enhancement in tensile strength for mixes incorporating 4% MPW relative to the control mix, under both conditioned and unconditioned conditions. This translates to noteworthy improvements of 46% and 78% for dry and wet mixes, respectively.

Furthermore, the incorporation of MPW demonstrably improves moisture resistance. The 4% MPW mix exhibits a superior TSR of 91.6%. However, exceeding this optimal MPW content has a demonstrably detrimental effect on both tensile strength and TSR. This decline can be attributed to the increased stiffness of the mix resulting from excessive MPW concentration. This heightened stiffness compromises workability and reduced the amount of asphalt coating the aggregate particles, consequently rendering them more susceptible to water ingress. It is noteworthy that despite this decline, mixes with MPW content exceeding 4% still exhibit demonstrably improved moisture resistance compared to the control mix, as evidenced by Fig. 8.

5.2.2 Loss of Stability

The moisture damage susceptibility of the asphalt mixtures was determined using a modified Marshall Stability test based on [54]. For 24 hours, specimens of compacted asphalt mixture were immersed in a water bath heated to 60°C. The Loss of Stability Ratio (LSR%) was calculated by measuring Marshall Stability and comparing it to dry samples. Fig.9 illustrates the LSR% values for all mixes. The findings show that modified asphalt mixtures outperformed the control mix in terms of moisture resistance. Notably, the MPW-modified mixture had the lowest LSR % level. Importantly, all mixes kept their LSR% below 25%, which is the maximum allowed limit set by the Egyptian code of practice [40].

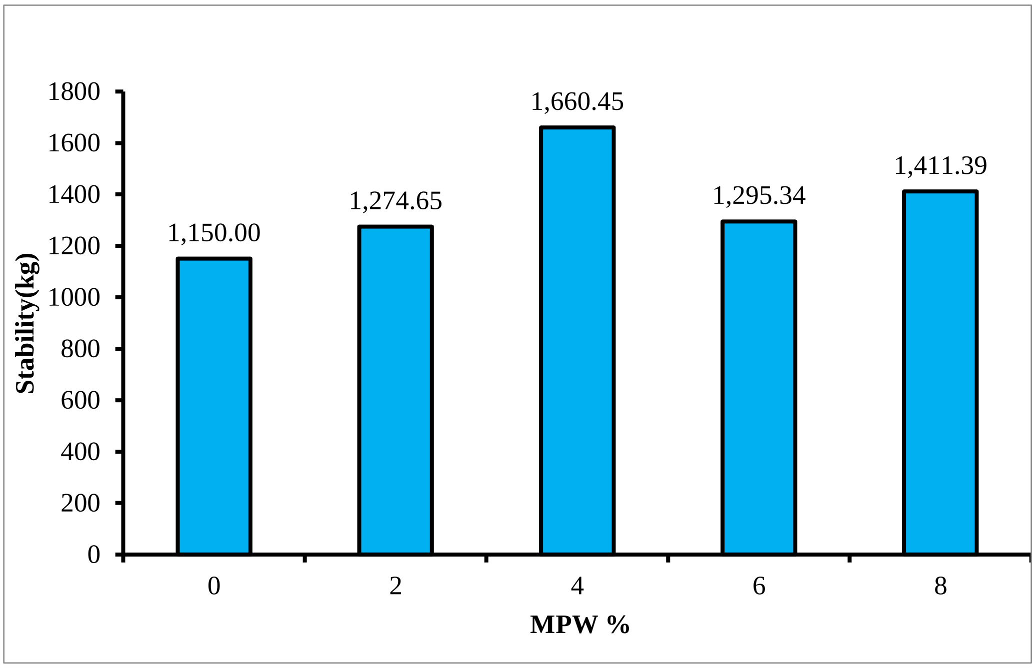

Fig .3 Stability of MPW- modified mixtures

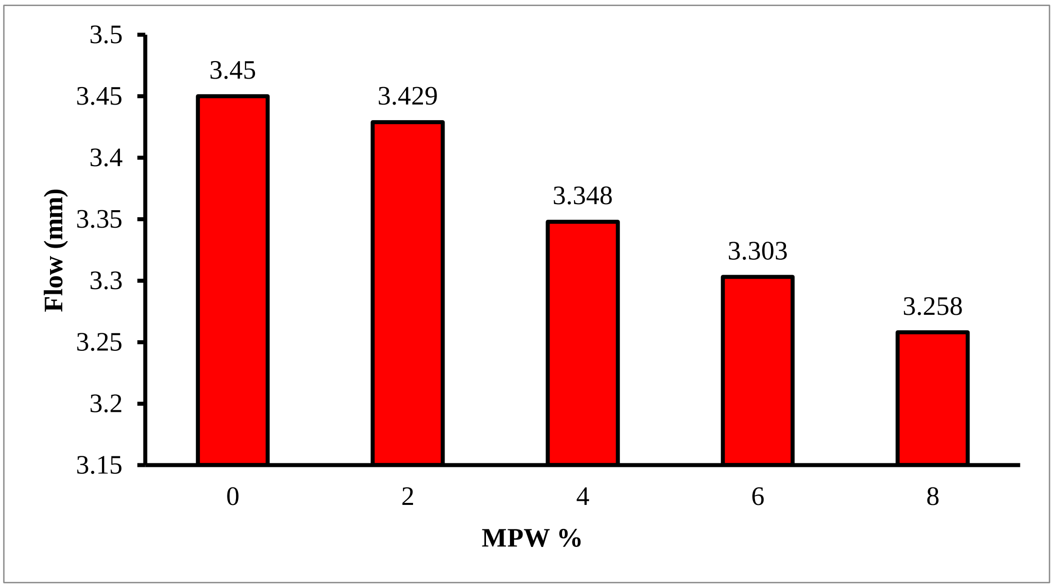

Fig .4 Flow of MPW- modified mixtures

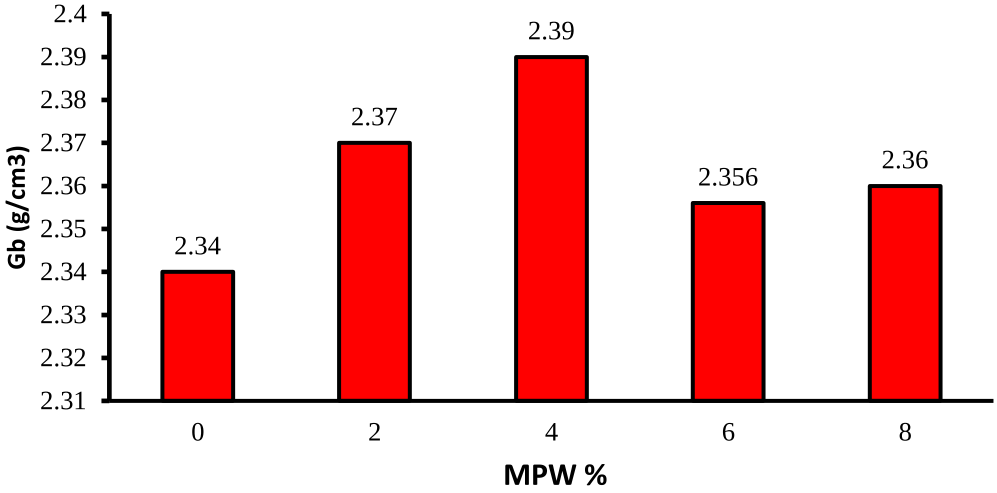

Fig .5 Bulk density of control and MPW-modified mixtures

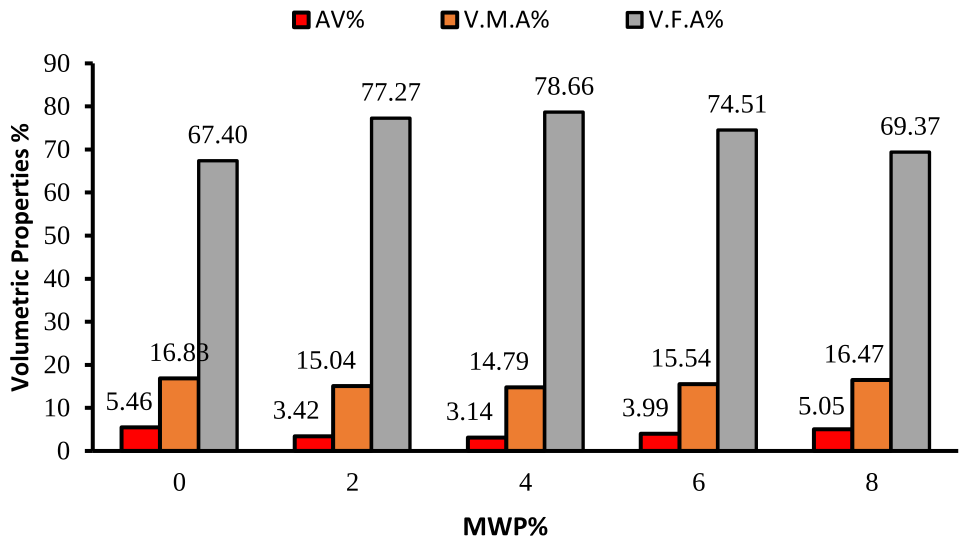

Fig .6 Volumetric properties of control and MPW-modified mixtures

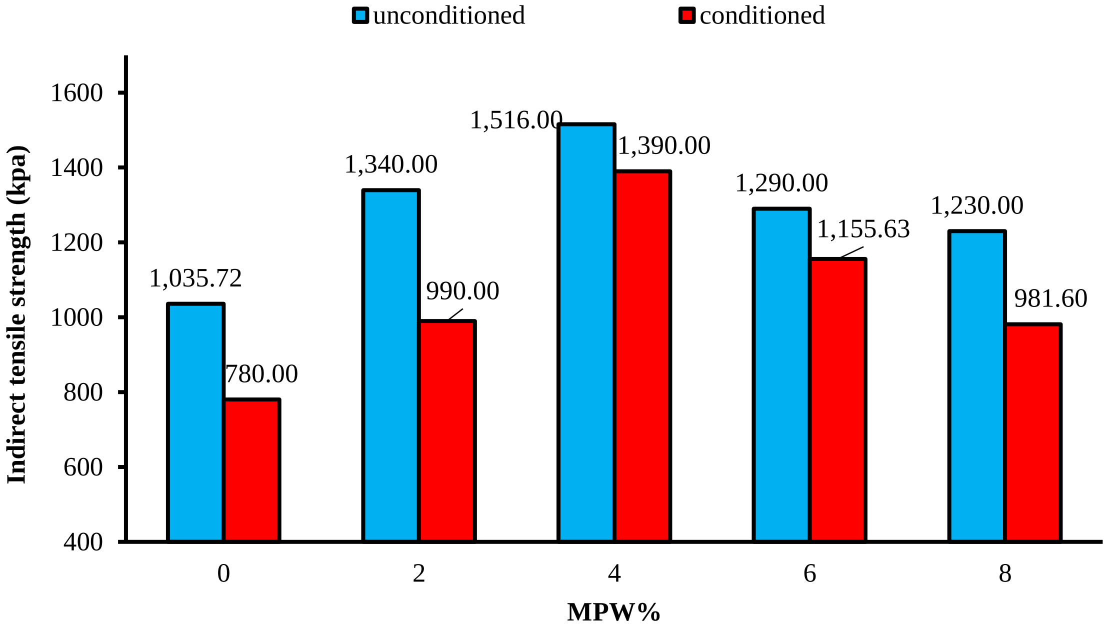

Fig .7 Indirect tensile strength for the control and MPW-modified mixtures

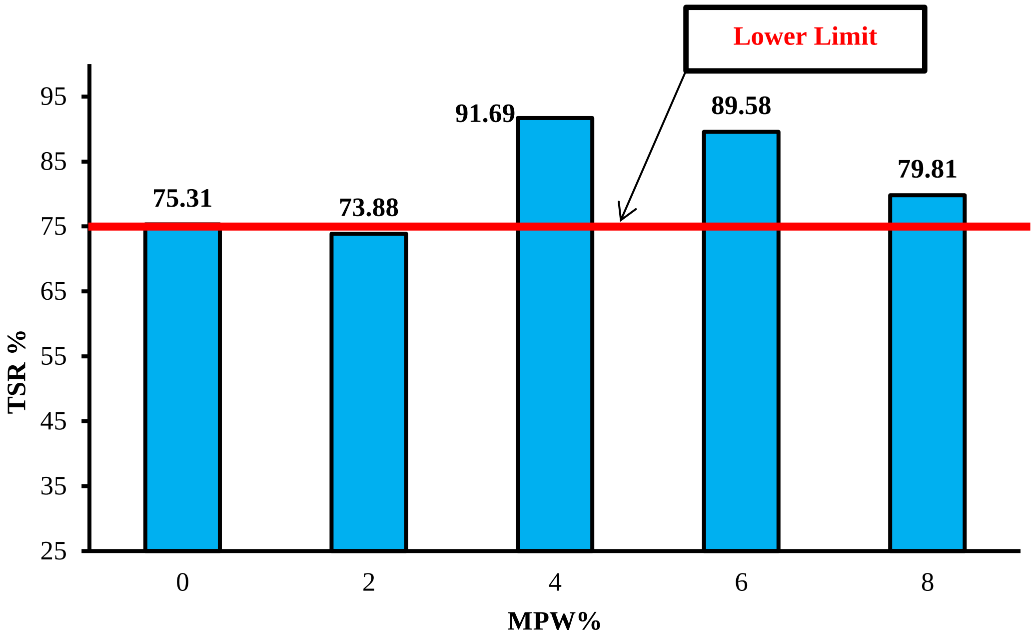

Fig .8: Tensile strength ratio for the control and MPW-modified mixtures

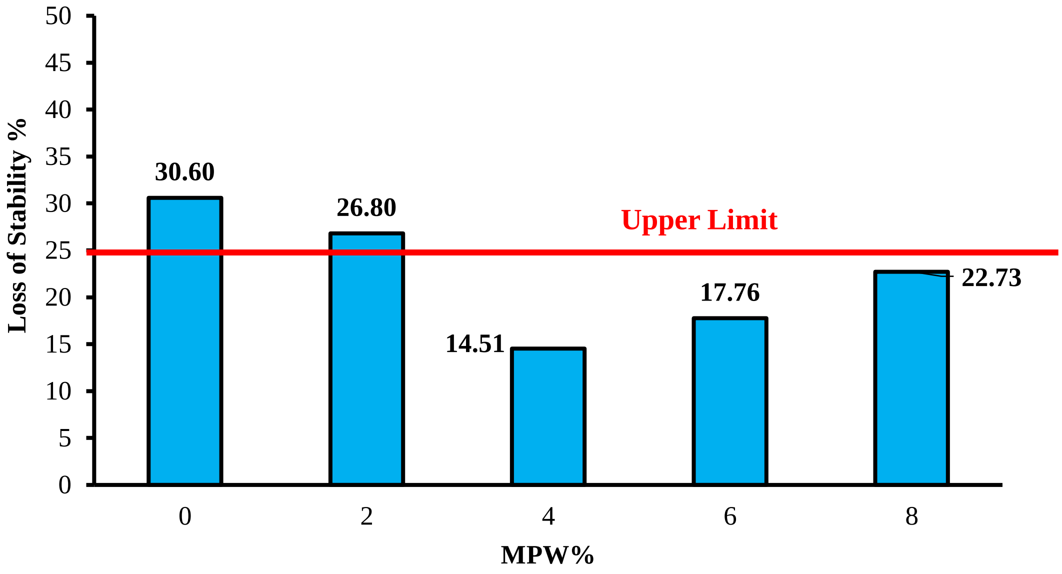

Fig. 9 Loss of Stability ratio for the control and MPW-modified mixtures.

6. CONCLUSIONS

In this investigation, medical plastic waste (MPW) was incorporated as an additive into bitumen (penetration grade 60/70) to evaluate its potential application in asphalt modification. The MPW content was systematically varied, ranging from 2% to 8% by weight of the bitumen. In conclusion, the following key findings can be drawn from the study:

1. The Marshall tests demonstrated that the addition of 4% MPW resulted in a substantial increase of 44.4% in the Marshall stability and 39.14% in the MQ value of the unmodified asphalt mixture.
2. The use of MPW in hot mix asphalt (HMA) mixtures exhibited enhanced resistance to deformation, attributed to the higher MQ values and improved Marshall strength (stability).
3. The modified asphalt mixtures incorporating MPW displayed TSR (Tensile Strength Ratio) values exceeding 91%, indicating excellent resistance to moisture damage. Moreover, the inclusion of MPW significantly enhanced the moisture resistance of the asphalt mixtures.

4. All MPW mixes displayed better moisture resistance than the control, with the 4% MPW mix having the lowest LSR%. Importantly, all mixtures adhered to the Egyptian code's LSR limit (<25%).

These conclusions highlight the positive effects of incorporating MPW in asphalt mixtures, including improved stability, enhanced resistance to deformation, and increased moisture resistance.

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