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Functional Properties Analysis of SMA Asphalt Mixtures Containing Rubber Powder and rPET

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ABSTRACT

SMA asphalt mixtures are one of the asphalt mixtures known so far. In these mixtures, the load transfer and degradation process takes place through the direct contact of stone on stone. In these mixtures, like other asphalt mixtures, various additives are used with the aim of improving the performance characteristics. Common additives in these mixtures include anti-stripping additives, polymers, nanomaterials, etc. On the other hand, during the past years, new technology in the production of additives has been developed. In this technology, with the chemical combination of two additives, a new substance is produced, which is referred to as a double additive and has the characteristics of both the main substances. In this research, this issue has been investigated in SMA asphalt mixtures, and the effect of dual additives produced from rubber powder and recycled polyethylene (rPET) has been investigated. The results of this research showed that the use of double additives of this research could meet the performance characteristics of SMA asphalt mixtures better than single additives, and the interaction of the two materials used can compensate for the weaknesses of single additives.

Keywords: dual base additive, recycled polyethylene, rubber powder, SMA asphalt mixture.

1. INTRODUCTION

One of the main goals of implementing asphalt procedures on roads is to ensure the performance of these procedures in different load and environmental conditions. Based on this, various types of asphalt surfaces have been developed, among which we can mention hot, semi-hot, SMA, porous, etc., asphalt mixtures. The use of various materials to improve and improve the properties of asphalt mixtures has been the focus of researchers in the field of asphalt pavements for the past years. These materials were either substitutes for stone materials or mixed with bitumen [1]. Considering that the main structure of asphalt pavements includes aggregate and bitumen, any change in these materials or the adhesion and connection system between these materials can change the general characteristics of the asphalt mixture and affect the useful life of the pavements. [2-3]. Although the research in the field of materials that can be used in the pavement is very wide, in a general classification, it can be stated that: polymers such as SBS, SBR, nanomaterials such as nano clay, isotherm, nano lime, recycled materials such as rubber powder, Recycled poly ethylenes constitute the main bitumen modifying materials [4,5]. On the other hand, recycled materials such as Reclaimed Asphalt Pavement (RAP) and synthetic aggregates such as light polyethylene aggregates as well as slag, constitute the major substitute materials for aggregate modification [6-9].On the other hand, during the past years, a new range of bitumen additives has been developed in which multiple additives are formed from the combination of two or more additives. In this way, by combining the properties of several used ingredients, the resulting additive can improve more properties in the mixture. By covering each other's weaknesses, these multiple additives create more advantages and technical justification for using additives in bitumen. In much of the research conducted regarding the manufacturing and development of dual or multiple bitumen additives, the use of rubber powder is more common, and materials such as polymers, nanomaterials, etc., have been used as a supplement to rubber powder [10].As mentioned at the beginning of the discussion, asphalt pavements are classified into different types depending on the type of materials used in it, one of which is SMA asphalt mixtures [11].In asphalt mixtures, SMA carries out the load transfer and reduction process through direct stone-to-stone contact. In SMA mixtures, the aggregate structure bears the main load, and the role of bituminous mastic is secondary. Of course, this issue does not mean that bituminous mastic is of little importance in SMA mixtures, but it is basically the second priority [12-14]. The most important advantage of SMA asphalt mixtures is the resistance of this mixture to high traffic and heavy axle load, and its main disadvantages include bitumen shedding. To improve the phenomenon of bitumen falling in these mixtures, the use of fibers has been recommended in many pieces of research [15].Various research has been conducted regarding SMA asphalt mixtures and the materials used to improve their properties, which are described below. Mashan et al. investigated the effect of rubber powder in modifying the properties of SMA asphalt mixtures and used 6%, 12%, 16%, and 20% percentages. In this research, taking into account the volumetric properties, Marshall strength, and resilient modulus, the value of 12% was determined as the optimal percentage of using rubber powder [16]. In a similar research, Katman et al. also introduced 12% value as a suitable value for rubber powder by examining the characteristics of permanent deformations [17]. Kalpa et al. also investigated the effect of the dry addition of rubber powder to SMA asphalt mixtures and observed that the addition of rubber powder provided a better index in terms of permanent deformations, fatigue, and moisture sensitivity. In the best case, compared to the control case, the investigated mixture has 64% improvement in permanent deformation, 6% improvement in fatigue, and 36% improvement in moisture sensitivity. The researchers of this study also investigated the economic impact of adding rubber powder and showed that adding rubber powder increased the cost by 3 to 4 percent per square meter, but it caused an average improvement of 20 percent during the useful life of the pavement [18]. Ameri et al. investigated the effect of HMA asphalt mixtures containing rubber powder and polyethylene terephthalate. The results of this research showed that the addition of polyethylene terephthalate increases the hardness of bitumen and thus increases the hardness of the mixture. Also, adding rubber powder compensates for part of the added hardness as a result of using polyethylene terephthalate. As a result, the use of the compound additive in asphalt mixtures can show a favorable result [19]. Li et al. investigated the effect of adding rubber powder and SBS polymer on the high-temperature performance characteristics of SMA asphalt mixtures. In this research, they investigated the effect of single and double addition of rubber powder-SBS and showed that with the increase in temperature from 50 to 70 degrees Celsius, the asphalt modified with the combination of rubber powder and SBS shows the smallest decrease in resistance. In this research, the use of a double additive of rubber powder and SBS instead of a modified mixture with rubber powder and SBS was suggested [20]. Accordingly, in this research, the effect of adding rubber powder and rPET in SMA asphalt mixtures has been investigated in order to determine the effect of this compound additive in asphalt mixtures with coarse grain size.

2. MATERIALS AND METHODS

In this research, a laboratory method has been used to investigate the changes caused by the desired additives. Accordingly, a control sample (control) without any additives was used. The results of different experiments have been compared and evaluated using this control sample. For this purpose, the introduction of bitumen and the materials used are discussed in the following, and the method of conducting tests and the standards used are also described. Finally, by presenting the results, the impact value of the used additives has been investigated.

2.1. MATERIALS

Stone materials were prepared from the Asb Cheran mine near Tehran in this research. The materials of this mine are of limestone type, and the size is 0 to 19 mm. The characteristics of the stone materials used in the research are mentioned in Table 1. The bitumen used in the research is PG64-22 bitumen, which was obtained from Tehran Refinery Company. The specifications of this bitumen are also stated in Table 2.

Table 1. Engineering properties of aggregate source

Aggregate Test	Aggregate	Test Method
Bulk specific gravity	2.484	ASTM C127
Absorption course aggregate (%)	2.1	ASTM 127
Absorption fine aggregate (%)	4.3	ASTM 128
Los Angeles abrasion Loss (%)	23	AASHTO T96
Tow Fracture faces (%)	93	ASTM D5821

Table 2. Properties of utilized bitumen based on related standard test methods

3	Method	criteria	Result
Penetration of 25 C	ASTM D5	60-70	68
Softening Point (C)	ASTM D36	45-54	48
Ductility of 25 (cm)	ASTM D113	100	100
Flash point (C)	ASTM D92	250	297
Fire Point (C)	ASTM D70	230	315
Specific gravity at 25 C	ASTM D70	1.05-1.06	1.048

As mentioned in the previous section, the additive used is a double additive made of tube-based rubber powder and recycled polyethylene terephthalate (rPET), brand name BG 1021, produced in Malaysia. The size of the primary particles of the two mentioned materials passing through the 50-sieve is considered. Figure 1 shows an example of the materials used in this research. Also, in order to prevent bitumen from falling and maintain the stability of the mixture, cellulose fibers have been used in the amount of 0.4% of the weight of stone materials.

Figure 1. Used recycled materials A: CR, B: rPET

A High Shear machine was used to make the addition. For this purpose, the bitumen temperature was first increased to 160 degrees Celsius. Then additives were added to the bitumen in the amount of 10% of the weight of the bitumen according to the compositions in Table 3. Additives were mixed for 45 minutes at 5000 rpm, and finally, bitumen-containing additives were obtained according to Table 3.

Table 3. Combination and naming of the mixtures

Sample name	rPET	CR
AC	0	0
100CR	0	100
75CR25rPET	25	75
50CR50rPET	50	50
25CR75rPET	75	25
100rPET	100	0

To make the SMA asphalt mixture, three different granulations were used according to the recommendation of NCHRP, with a maximum nominal size of 12.5 mm, and the optimal granulation was determined according to the method suggested by NCHRP. In the second step, for the control sample (bitumen without additives), the optimal amount of bitumen according to the NCHRP method was 6.1%. In the third stage, all the modified and control mixtures were made in the determined optimal granulation, as well as the optimal bitumen of 1.6%.

2.2. TESTS

In order to investigate the properties of SMA asphalt mixture containing rubber powder and rPET, in this research, the gyratory compaction method and tests of modulus of elasticity, indirect tension and moisture sensitivity, Marshall resistance, and dynamic creep were used, which are described below for each of the tests.

2.3. DYNAMIC CREEP TEST

One of the methods of measuring the permanent deformation characteristic of asphalt mixtures is applying several thousand repeated loads through a repetitive load test and recording the change of permanent locations as a function of the loading cycle. In order to achieve such a goal, in this research, a dynamic creep test was performed with the UTM25 device with a stress level of 450 kPa and a temperature of 50 degrees. The diameter of the samples used for this test is 100 mm, and the height is 50 mm. They were compacted and ready for testing with a gyratory compaction device with a 5% void space according to the AS 2891-12 standard.

2.4. RESILIENT MODULUS TEST

The resilient modulus is a dynamic test response defined as the ratio of repetitive axial deviatoric stress to reversible axial strain. The resilient modulus is used to evaluate the relative quality of the asphalt mixture as input data for pavement design, evaluation, or pavement analysis. In this research, this test was performed based on the ASTM D4123 standard and using a UTM25 device at 25°C and half sinusoidal load, and finally, the average of 5 final resilient modulus that the device provides as output is reported as the resilient modulus of mixtures.

2.5. INDIRECT TENSILE TEST

The value of indirect tensile strength in asphalt mixtures is one of the important tests in asphalt mixtures because it can simulate the loading mechanism in real pavement conditions. This test is performed on the door in two states. In the first state, which is known as the dry state, the samples made at a temperature of 25 degrees Celsius are tested, and their resistance value is measured. The second stage is known as the wet state. First, the samples are saturated with more than 85% by vacuuming and covered with plastic. In the following, the samples are first kept for 16 hours at a temperature of minus 17 degrees Celsius, then they are kept for 24 hours at a temperature of 60 degrees Celsius, and finally, they are kept at a temperature of 25 degrees for 2 hours and evaluated for indirect tensile strength. To evaluate the humidity sensitivity, the value of indirect tensile strength obtained in the wet state is divided by the value of indirect tensile strength obtained in the dry state and finally reported as a percentage in the form of a TSR parameter. In this research, the AASHTO T283 standard was used to conduct a more indirect and dry tensile test.

2.6. MARSHALL RESISTANCE TEST

The amount of Marshall Resistance depends a lot on the angle of internal friction of the materials used and the bitumen viscosity at the test temperature. In this research, the Marshall Resistance value was obtained using the Marshall Resistance test and according to the ASTM D 1559 standard.

3. RESULTS AND DISCUSSION

In this section, the results and comparison between the results of each experiment for different research additives have been discussed.

3.1. DYNAMIC CREEP

In this research, Slump is used to evaluate the rutting resistance of asphalt mixture based on the proposal of NCHRP Project 09-33. Slump for the examples of this research is presented in Figure 2. As can be seen from the results, the addition of rubber powder and rPET in different percentages has provided different results. In the beginning, when the share of rubber powder in the additive is more, we see an increase in the amount of Slump and, as a result, the increase in rutting resistance. Further, with the increase of rPET in the additive, the amount of Slump in control is significantly reduced, and finally, the amount of Slump for the sample containing 100% rPET is lower than the value of the control sample. The trend observed for rubber powder has been observed in many pieces of research, but in the case of rPET and the increase of Slump, for example, 25% of this material and then the decrease of the amount of Slump, the reason for this can be attributed to the increase in the hardness of the bitumen and consequently the increase in the hardness of the mixture.

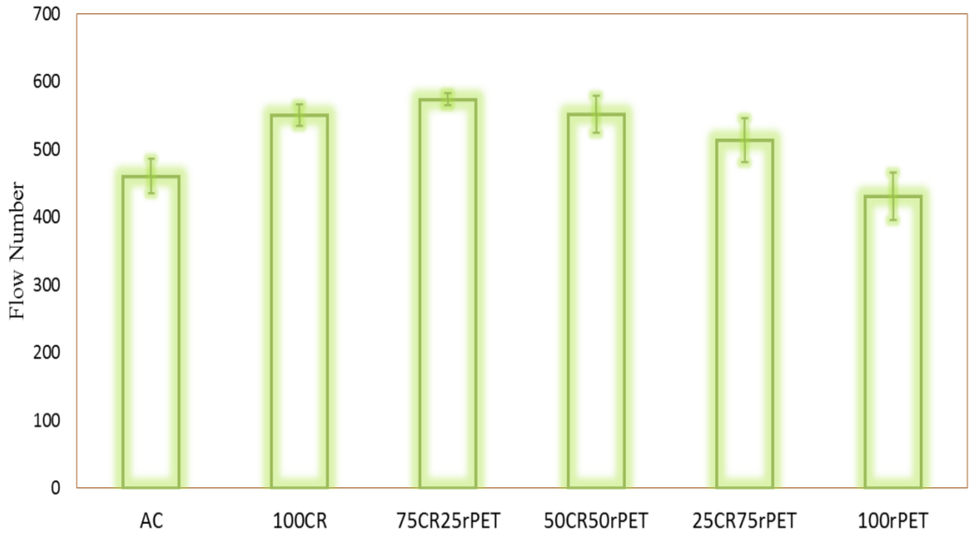

Figure 2. Results of the dynamic creep test

3.2. MARSHALL RESISTANCE

The results of the Marshall Resistance test are shown in Figure 3. As can be seen from the graph, all additions of all percentages of rubber powder and rPET had a positive effect on Marshall's endurance. The addition of 100% rubber powder had a very small effect on increasing the Marshall resistance, but with the addition of rPET, the hardness of the mixture increased, and the Marshall resistance increased. Finally, when the share of rPET reaches 100% in the additive, this value becomes significant.

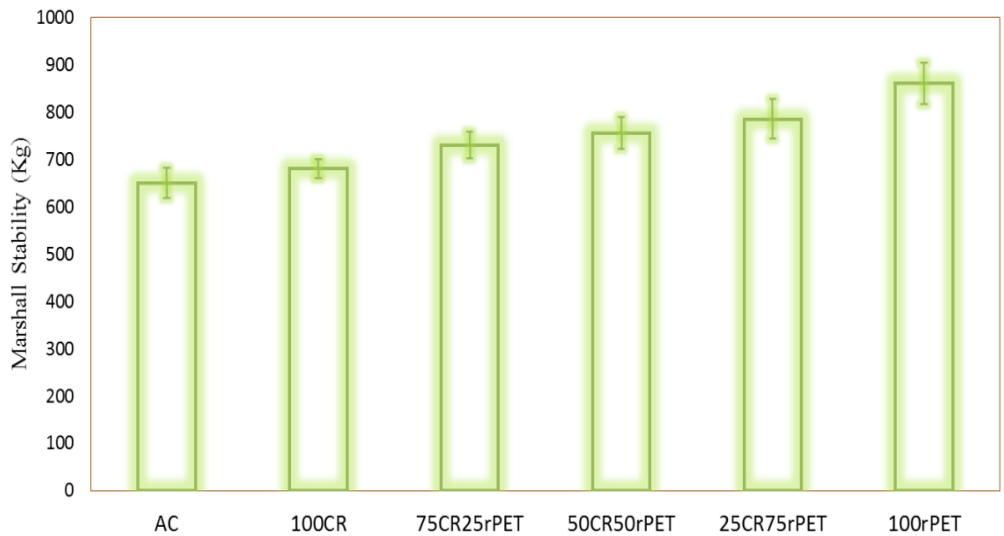

Figure 3. Results of the Marshall stability test of the modified and non-modified specimens

3.3. INDIRECT TENSILE STRENGTH

Figure 4 shows the results of the indirect tensile strength test in wet and dry conditions. The observed trends are different for wet and dry conditions. In dry samples, with the addition of different percentages of rubber powder and rPET, a decreasing trend in indirect tensile strength is observed. This amount of decrease is insignificant at first, and then with the addition of more rPET in the additive, the decrease becomes faster. In wet samples (moisturedamaged samples), the indirect tensile strength increases with the addition of rubber powder, but then the indirect tensile strength decreases with the addition of rPET in the mixture. Finally, the value of indirect tensile strength of the sample containing 100% rPET additive is significantly different from the control sample. This process can be considered due to drying and increasing the hardness of bitumen as a result of adding rPET and increasing the softness of bitumen as a result of adding rubber powder so that the addition of rubber powder increases the resistance of the samples against moisture damage and the addition of rPET increases the resistance of the sample in Reduces moisture damage.

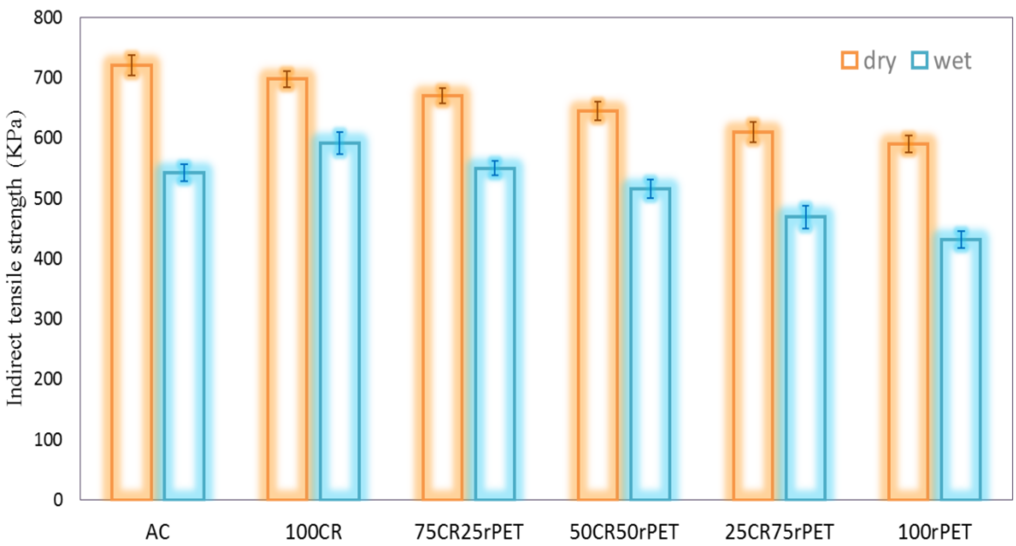

Figure 4. Indirect tensile strength

3.4. *MOISTURE SENSITIVITY*

The TSR parameter is used as a parameter to define humidity sensitivity. This parameter refers to dividing indirect tensile strength by dry indirect tensile strength. The results related to this parameter for the modifiers used in this research are shown in Figure 5. As can be seen from the results, the addition of rubber powder, which increases the softness of the bitumen, increases the amount of resistance to moisture, but with the addition of rPET, the hardness of the mixture increases, and as a result, the amount of resistance to moisture decreases. Finally, as can be clearly seen from the graph, the best resistance to moisture is for the sample containing 100% rubber powder, and the lowest resistance to moisture is for the sample containing 100% rPET.

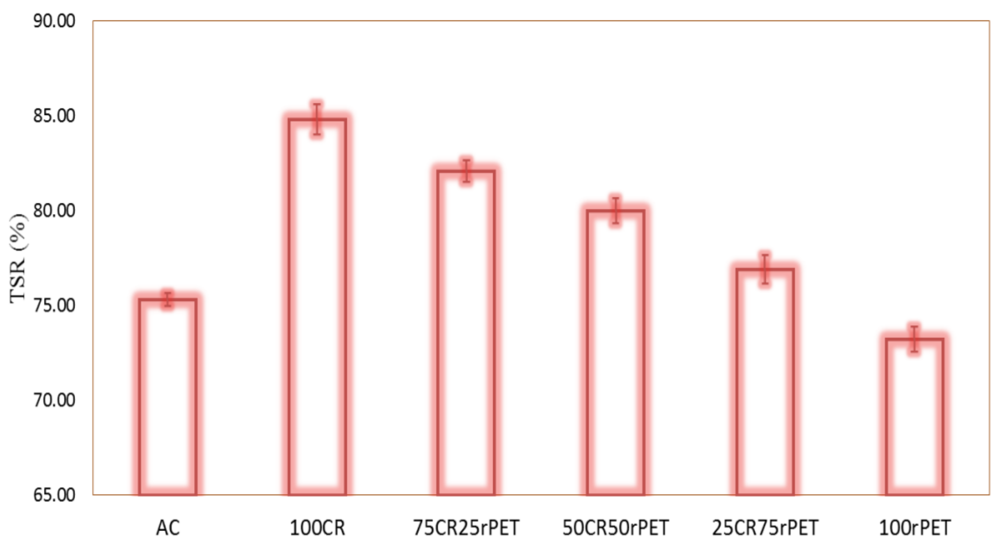

Figure 5. TSR results of the specimens

3.5. RESILIENT MODULUS

The test results of the yield modulus of the samples used in this research are shown in Figure 6. The resilient modulus test is investigated because it examines the hardening of the mixture and provides an important parameter for determining the thickness. As it is clear from the results, the addition of additives in all different combinations has improved the resilient modulus. But this improvement is different for the samples in such a way that this value is slightly higher for the sample containing 100% rubber powder than the control sample, and it is more significant for the sample containing 100% rPET.

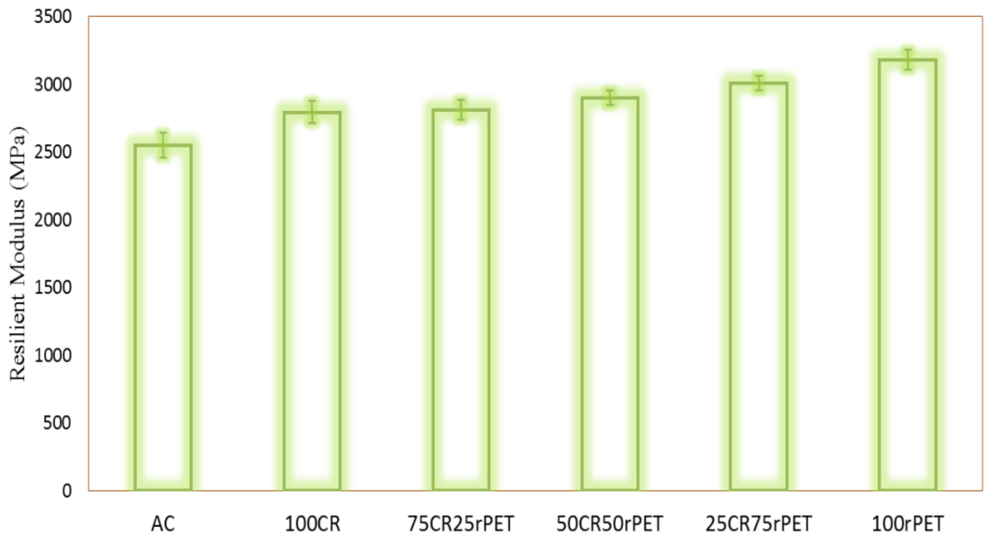

Figure 6. Results of the resilient modulus test

4. CONCLUSION

This research investigates the functional characteristics of SMA asphalt mixtures in different states, including unmodified SMA and 5 combinations of rubber powder and rPET additives. For this purpose, an additive with percentages of (0.100), (75.25), (50.50), (25.75), and (0.100) was made from rubber powder and rPET and was replaced with 10 percent by weight of bitumen. In this study, functional characteristics such as Marshall Resistance, modulus of elasticity, indirect tensile strength, moisture sensitivity, and dynamic creep were investigated. The main results of this research are:

- The results of the Marshall Resistance test showed that the SMA asphalt mixture shows more resistance when modified with different compounds of this research, and this increase is greater for samples containing rPET than other samples.
- The results of the resilient modulus test showed that the addition of additives increases the resilient modulus of the asphalt mixture; meanwhile, adding more rPET causes more hardness and, as a result, increases the resilient modulus.
- The results of the dynamic creep test showed that the use of an additive with a combination of 25% rPET and 75% rubber powder shows the highest amount of slump value.
- The results of the indirect tensile test indicated that the use of additives reduces the indirect tensile strength in the dry state. This reduction is the highest in the sample containing rPET. For wet samples, the highest indirect tensile strength was obtained for the sample containing 100% rubber powder.
- The results of the moisture sensitivity test showed that the SMA asphalt mixture without the use of various additives also has the resistance of the bare minimum of Iran's regulations. Meanwhile, the addition of an additive with 100% rubber powder has shown the greatest improvement in moisture sensitivity. Also, the addition of 100% rPET reduces the value of the TSR parameter to less than the value of the control sample.

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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