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Analysis and Comparison of Moisture Sensitivity and Mechanical Strength of Asphalt Mixtures Containing Additives and Carbon Reinforcement

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ABSTRACT

Structural weakness in asphalt stems from the weakness of two components of asphalt, namely bitumen and stone materials. For many decades, various additives have been used to modify bitumen as well as various fibers to create a proper bond between bitumen and aggregates. The use of additives that have structural similarities or components with bitumen has also received more attention in recent years by various researchers. Carbon is one of the materials that can be described as very similar to bitumen. This material has recently been used in both pure and fiber forms for research on concrete. In this research, the addition of this material in fibers and powder combined with bitumen has been studied and compared. Experiments such as modulus of resistance, indirect tensile strength, and Marshall Strength have been used to evaluate asphalt mixtures' properties. This study showed that the use of carbon in both fibers and powder would bring positive results for asphalt mixtures.

Keywords: **Carbon powder, Carbon fiber, Asphalt mix, Functional properties**

1. INTRODUCTION

Road surface design is based on the projected traffic for the design period and operation period [1-3]. Traffic parameters based on demand, safety, type of road operation, etc., predict the amount of traffic and the number of heavy and light vehicles in the coming years. Based on this forecast, determine the load on the pavement structure [4-8]. Vehicle safety is one of the most fundamental principles in traffic engineering and transportation planning in the world. Lack of safety principles in road engineering design, maintenance, and transportation planning of the country, has caused heavy damage to society in recent years, so that every year part of the country's construction budget is spent on drawing, improving, and maintaining roads [9-11]. Road pavement is considered as the national capital of the country, and every year they allocate a part of the construction budget to be spent on their repair, improvement, and maintenance [12, 13]. As a result, by implementing the proposed model, millions of dollars in annual costs can be reduced, and the roads can be maintained in optimal conditions. Advances in the automotive industry and the manufacture of vehicles with heavier axles, including buses and trucks with multiple axles, and the failure to consider these loads in the design of procedures, especially asphalt procedures, cause various breakdowns in The paved surface and the attention of pavement researchers has been diverted to strengthen and improve the pavement performance of roads [14, 15]. The use of various materials and materials is one of the methods to improve and enhance the properties of asphalt, on which various researches have been done. Materials and materials used to improve the properties of asphalt mixtures can be divided into three general types: bitumen modifiers, asphalt mixers, and stone material substitutes [16].

The properties of the constituent materials play an important role in the structural properties of the pavement. Although the amount of bitumen is much less in weight than stone materials, bitumen has a very important role in the performance of asphalt pavements and the durability and stability of asphalt mixtures. Any change in the performance of bitumen causes many changes in the performance of asphalt mixtures [17]. Therefore, to improve the properties of asphalt mixtures, the use of various additives such as polymer additives, SBS, rubber powder, EVA, etc., is used to improve the properties of asphalt mixtures [18]. On the other hand, usually, the use of suitable aggregates or improving the consistency between aggregate and bitumen in asphalt mixtures can prevent stripping [19]. Various aggregates such as slag, recycled asphalt RAP, etc., are used to replace stone materials [20]. To increase the cohesion between aggregate and bitumen, the use of a wide range of fibers to reinforce asphalt mixtures has been suggested [21]. The properties of asphalt mixtures are affected by the change and modification of bitumen, stone materials, as well as the relationship between stone materials and bitumen. Various materials have been considered for this modification or change so far. In this study, first bitumen modifiers and stone material modifiers, and finally asphalt mixers are investigated. Modified bitumens in asphalt pavements generally have four main roles: increasing the resistance of the asphalt mixture to permanent deformation, improving the fatigue life of the mixture, increasing the hardness modulus, and improving the adhesion between bitumen particles and stone materials. All of this can be done to some extent without affecting the performance of the mixture [22]. The choice of modifier for a particular project can depend on many factors, including build capacity, availability, cost, and expected performance [21]. A wide range of additives can be used to modify bitumen. The additives used can have a structure similar to bitumen or recycled materials. The use of Nano-materials is more prominent in past research. Materials with a similar structure or composition to bitumen can improve some of the properties of bitumen, such as strength and adhesion properties [22]. In this regard, some elastomers such as SBS, SBR have increased the adhesion strength of bitumen, fatigue resistance, and reduced the sensitivity of thermal cracking [23]. Liu et al. High degree of softness and better robustness, improvement of bitumen resistance against emerging surface cracks, reduction of fatigue cracks, and improvement of pavement durability are some of the issues seen in bitumen modification with carbon-based materials and similar to bitumen structure [24]. Researchers have consistently attempted to evaluate the effect of using elastomers in improving the properties of bitumen by conventional laboratory methods. Therefore, performing laboratory tests such as creep, indirect tensile test (ITS) and modulus of resistance, etc., on hot asphalt concrete containing bitumen modifiers has been one of the methods that have been seen repeatedly in research, and the results have shown that the use of this modifier Which can lead to improved bitumen properties; For example, KOK et al. Examined asphalt mixtures containing rubber powder. In this study, rubber powder was combined with bitumen, and experiments such as dynamic creep, indirect tension, and bitumen properties evaluation tests were performed. The results of this study showed that the use of rubber powder improved the behavioral properties of the asphalt mixture. In this research, an additive of 5% rubber powder was introduced as a desirable sample [25]. Ameri et al. Also investigated the simultaneous effect of rubber powder and recycled polyethylene. The results of their research showed that the use of modifiers with 25% recycled polyethylene and 75% rubber powder used in combination with bitumen, good results in tests of modulus of resistance, dynamic creep, indirect tension, and Shows moisture sensitivity [26]. The use of various materials such as steel slag, recycled asphalt RAP, etc., is also one of the ways to improve the properties of asphalt mixtures. Accordingly, Ziaee et al. Performed substitution of steel slag at the rates of 25, 50, and 75% instead of calcareous aggregates, tests of aggregates, and mechanical performance of asphalt mixtures. The results of this study showed that in parameters such as fracture percentage, Los Angeles wear, total index, surface texture, and percentage of uncompressed empty space, the use of slag has better results than calcareous aggregates. On the other hand, the results of functional tests such as modulus of resistance also showed better performance of asphalt mixtures containing slag [27]. A limited amount of materials, an increase of bitumen percentage, a decrease of load under special conditions are among the factors that limit the use of slag and RAP materials in asphalt mixtures [20]. However, the use of balanced percentages of these materials can improve many properties of asphalt mixtures due to use of these materials [28]. Asphalt reinforcement using a variety of fibers is another way to improve the performance of asphalt mixtures. In a study, Fu investigated the effect of glass fibers on the performance properties of asphalt mixtures. The results of this study showed that the use of 0.3% glass fibers significantly improves the cohesion between materials and has a positive effect on the performance properties of mixtures [29]. Ameri et al. Also studied fibers such as basalt and glass fibers and concluded that the above fibers could increase the Marshall strength, modulus of resistance, dynamic creep as well as indirect tension [30]. Asphalt mixtures are discussed using various methods and experiments. Tests that have been used more in previous researches have included performance tests of asphalt mixtures such as modulus of resistance, dynamic wear, indirect tension, and the like [31]. In some cases, other experiments, such as the use of SEM photographs, boiling tests, etc., were used to evaluate improved asphalt mixtures [32].

2. MATERIALS AND METHODS

2.1. MATERIALS

To evaluating the modified and unmodified asphalt mixtures in this research, bitumen with a performance grade of 58-22 PG has been used. Preliminary results on bitumen consumption that describe the basic properties of the bitumen used are presented in Table 1. The stone materials used in the research are also calcareous materials. These materials are of better quality than siliceous materials. The results of the initial tests on stone materials are presented in Table 2. These materials are sieved according to the granulation presented in Figure 1 and used in asphalt mixtures.

Table 1. Technical specifications of bitumen used

Characteristics	Test Method	Standard limits		Consumption bitumen
		Lower limit	upper line	
Specific gravity at 25° C	ASTM D-70	1.01	1.06	1.03
Penetration degree at 25 ° C	ASTM D-5	60	70	64
Softening point (degrees Celsius)	ASTM D-36	49	56	54
Angmi 25 degrees Celsius	ASTM D-113	100	--	102
Melting point	ASTM D-92	250	--	305

Table 2. Specifications of stone materials

Description	Standard Test	Test Result
Maximum wear by the Los Angeles method (percentage)	AASHTO T96	22.3
Maximum penetration coefficient (percentage)	BS 812	16
Minimum fracture on two fronts on sieve number 4 (percent)	ASTM D5821	93
Maximum water absorption percentage (coarse aggregates)	AASHTO T85	2.2
Maximum water absorption percentage (fine-grained materials)	AASHTO T84	2.4
The real specific gravity of coarse-grained stone materials	ASTM C127	2.59
The real specific gravity of fine-grained stone materials	ASTM C128	2.32

Carbon powder is mixed with bitumen using a High Shear device. The conditions for mixing carbon powder with bitumen in the mentioned device were performed at 4200 rpm for 45 minutes at a mixture temperature of 175 degrees. Mixing of carbon fibers with stone materials has been done manually, when bitumen is mixed with aggregates. Necessary controls in this section include manual control of fiber concentration in one part of the mixture and the need for fiber dispersion in all parts of the mixture in the same way. The characteristics of carbon fiber are shown in Table 3.

Table 3. Specifications of carbon fibers

Fiber name	Length (m)	Tensile strength (MPa)	Melting point (Celsius)	Specific weight (gr / cm3)
Carbon fiber	25	600	230	0.91

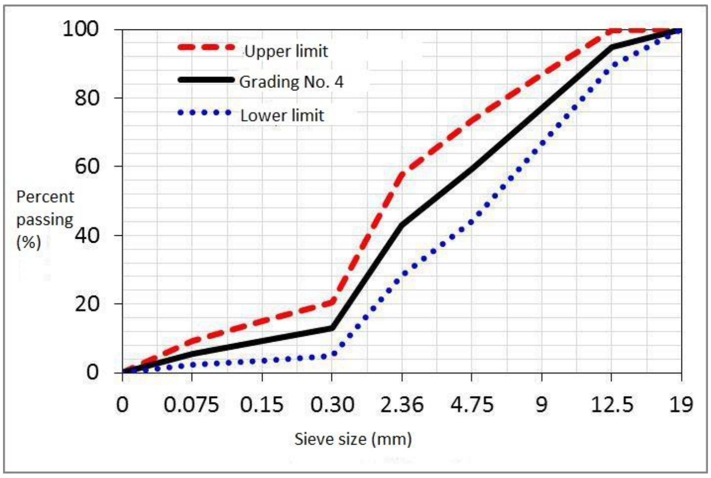

Figure 1. Granulation of functional materials

The samples used in this research are divided into 5 general categories. First, the control sample (sample without additives and without reinforcement), samples containing carbon powder (in 2% and 10%), and finally samples containing carbon fiber (in two categories of 0.5 and 1%). The naming of the samples is given in Table 4.

Table 4. Composition and naming of mixtures

Number	Modifier	Sample name	Percentage used
1	Witness	AC	0
2	Carbon powder	CP1	10
3	Carbon powder	CP2	20
4	Carbon fiber	CF1	0.5
5	Carbon fiber	CF2	1

The optimal bitumen of the control sample was obtained by using the Marshall optimal bitumen determination method equal to 5.1. This optimal bitumen is used for all mixtures. Compacted specimens were compacted with ASTM D 3387 [33].

2.2. EXPERIMENTS

2.2.1. Marshal Resistance

Marshall Resistance test was performed at 60 ° C in accordance with ASTM D 1559 [34]. To compact the samples required for Marshall Resistance, a 75-stroke Marshall Compaction device was used.

2.2.2. Resistance Modulus

A resistance modulus test was performed at 25 ° C using ASTM D4123 [35]. The samples required for this experiment were fabricated using a gyratory compaction device.

2.2.3. Indirect Traction and Moisture Sensitivity

An indirect tensile test is performed according to the AASHTO T283 standard [36]. The samples required for this experiment were made with a free space of 7% using a gyratory compaction device. The samples were tested in both wet and dry forms. Wet samples were first reached 85% with a vacuum device and exposed to -18 ° C for 16 hours, then exposed to 60 ° C for 24 hours, and finally tested at 25 ° C.

3. RESULTS AND DISCUSSIONS

In this study, as mentioned, tests of modulus of resistance, Marshall Resistance, indirect traction, And moisture sensitivity have been used.

3.1. MARSHALL RESISTANCE TEST

Marshall Strength is significantly affected by the internal friction angle of the material and the viscosity of the bitumen at 60 ° C. In general, it can be said that the amount of Marshall Endurance indicates the ability of the asphalt mixture to withstand rutting and protrusion under heavy traffic loads. The results related to Marshall Endurance of research examples are presented in Figure 2. As can be seen from the diagram, all the additives have a positive effect on the Marshall strength, and this positive effect is different for different samples. The reason for this difference can be considered in the type of material used because a substance such as Carbon powder, when mixed with bitumen, increases the hardness of the bitumen, and this hardness enters the mixture and increases the Marshall strength. But the fibers are added to the aggregate and bitumen mixture, and no specific chemical reaction occurs between it and the material. In fact, the role of fibers is to withstand tensile strength, and precisely for this reason, one cannot expect much change in compressive strength from this material.

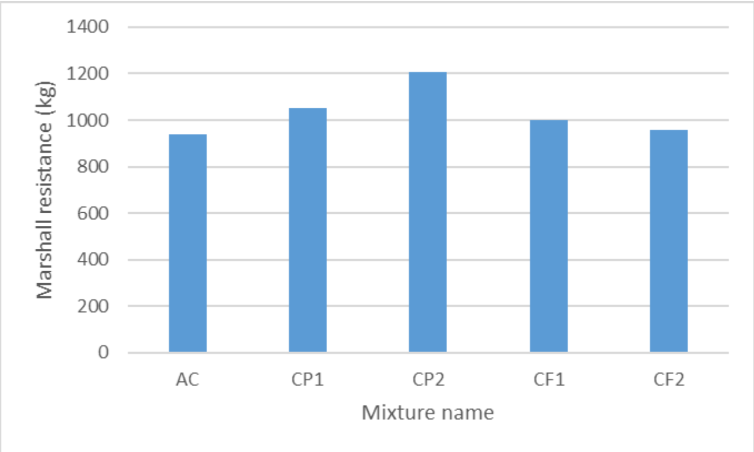

Figure 2. Marshall Resistance Results of Modified and Unmodified Samples

3.2. RESISTANCE MODULUS

The earth modulus test is a non-destructive test in which the loads applied to the sample are small. This test was performed by a UTM device. The modulus of resistance is indicated by the symbol (MR), and the value indicated by MR is the maximum energy that the unit volume of asphalt mixture can withstand without any permanent deformation and by loading the mixture to its original state come back. The value of MR is obtained by integrating the enclosed area of the stress-strain diagram. The results of this experiment are shown in Figure 3. The bulk modulus test is examined in that it examines the hardness of the mixture and provides the designer with an important parameter for determining the thickness. As can be seen from the diagram, all additives and reinforces have had a positive effect on the modulus of resistance. Among these positive effects, the effect of using carbon powder is more than carbon fiber. Carbon powder, affecting the bitumen of the mixture, causes the bitumen to harden and naturally mix. Carbon fibers and fibers, in general, are reinforcing. These materials increase the hardness of the mixture by increasing the tensile strength, and these two issues can be cited in justifying the cases observed in this study.

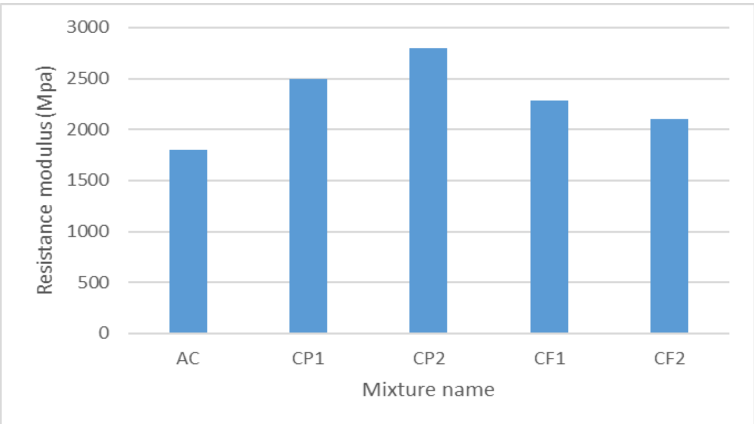

Figure 3. Resistance modulus test results

3.3. INDIRECT TENSILE

The results of the indirect tensile strength of the samples in both wet and dry conditions are presented in Figure 4. As can be seen from the diagram, the addition of modifiers has caused many changes in the samples and has changed both the wet and dry strengths, and these changes are very similar for the wet and dry samples. But the reason for these changes is the difference between fibers and powder. Because fibers increase the strength by increasing the tensile strength and bearing part of the tensile force, but carbon powder increases the tensile strength by increasing the hardness of bitumen and the hardness of the mixture. As it is known, it varies between the different percentages used as the percentage change changes. The reason for this is in a term called the bare percentage of the use of different substances. For example, according to the diagram of this experiment, along with the two experimental diagrams discussed, it is clear that the optimal percentage of carbon fibers is 0.5%. The same situation is true for carbon powder.

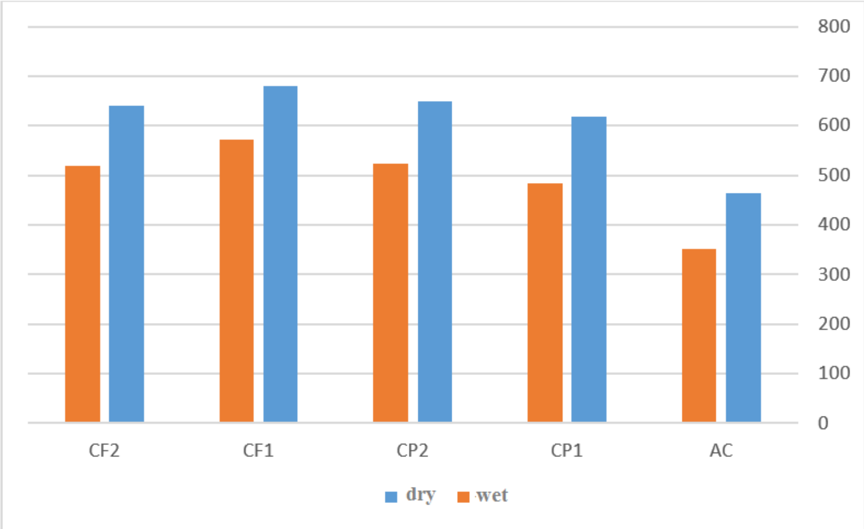

Figure 4. Indirect tensile strength in both wet and dry states

3.4. MOISTURE SENSITIVITY

Another characteristic of the indirect tensile test is the TSR coefficient. This coefficient is one of the coefficients for determining the moisture sensitivity of the mixture, the results of which are presented in Figure 5. The TSR parameter is expressed as a percentage from the division of more indirect tension to dry indirect tension. Acceptable standard limits for this coefficient in various standards are between 75 to100. As can be seen from the diagram, the addition of all materials has a positive effect on moisture sensitivity, and these materials, as described in the results of the indirect tensile test, improve the moisture sensitivity through various indirect tensile solutions.

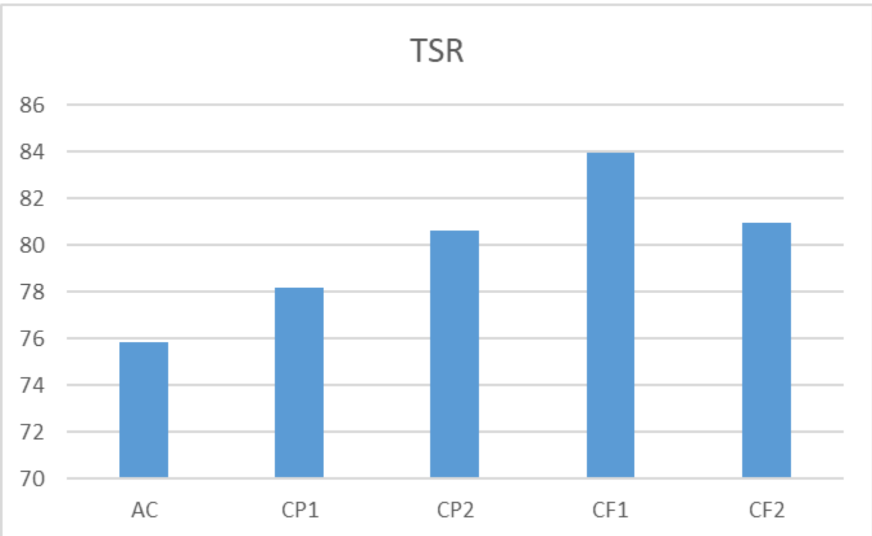

Figure 5. TSR results of samples

4. CONCLUSION

In this research, the properties of asphalt mixtures containing carbon additives and carbon fibers have been investigated and compared. For this study, tests of modulus of resistance, Marshall Resistance, as well as indirect tension and moisture sensitivity have been used. Carbon powder in 2% and 20% and carbon fiber in 0.5% and 1% respectively. The main results of this research are:

1. The use of the proposed materials of this research has had a positive effect on the modulus of the conductivity test. This effect is greater for 20% carbon powder and 0.5% carbon fiber than two similar samples.

2. The use of two substances has also had a positive effect on Marshall Resistance. However, the effect of carbon fiber was less than that of carbon powder. The greatest effect in this experiment belongs to 20% carbon powder.

3. The results of the indirect tensile test are also positive, and as mentioned, both materials, both in fiber and in powder form, have a positive effect on indirect tensile strength. This positive effect can be clearly seen in the TSR parameter, which also indicates the moisture sensitivity of the mixture.

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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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