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Usage of Waste Plastics in Road Pavements

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Roadway pavement

Abstract: Storage of various products obtained from wastes or leaving these to the nature lead to many difficulties and huge problems such as environmental pollution. Today, some studies are carried out on the recycling of wastes and by-products gained during the manufactory of various products. Wastes can be used to obtain new products or as an additional substance on the existing products. Both recycle of wastes and by-products prevents damage to the environment and reduces the occurrence of related problems to a minimum level by mitigating the usage of very scarcely found natural substances. Thus, it is important that industrial wastes be gained to state economy through being recycled for various uses. In recent years, studies on removal of wastes by recycling on highway layers have been extended. The aim of this study is to introduce the technical advantages of plastic materials known only as a simple waste material and to convert the environmental, economic and technical disadvantages of these materials as waste as an asphalt coating material. In the study, the samples were prepared by mixing bitumen with bituminous waste plastic heat treatment method and prepared samples were subjected to Marshall Strength and Indirect Tensile Strength tests and the results were interpreted.

Atık Plastiklerin Karayolunda Kullanımı

Anahtar Kelimeler
Çevre,
Atık plastik,
Modifiye bitüm,
Sıcak asfalt karışım,
Marshall Stabilite Testi,
Yol kaplaması

Özet: Atıklardan elde edilen çeşitli ürünlerin depolanması veya doğaya bırakılması birçok zorluğa ve çevre kirliliği gibi büyük sorunlara yol açar. Günümüzde, çeşitli ürünlerin imalatı sırasında kazanılan atıkların ve yan ürünlerin geri dönüşümü üzerine bazı çalışmalar yapılmaktadır. Atıklar yeni ürünler elde etmek için veya mevcut ürünler üzerinde ek bir madde olarak kullanılabilir. Hem atıkların hem de yan ürünlerin geri dönüşümü, çevreye verilen zararı önler ve çok az bulunan doğal maddelerin kullanımını hafifleterek ilgili sorunların ortaya çıkmasını asgariye indirir. Bu nedenle, endüstriyel atıkların çeşitli kullanımlar için geri dönüştürülerek devlet ekonomisine kazandırılması önemlidir. Son yıllarda, karayolu katmanlarında geri dönüşüm yoluyla atıkların giderilmesine ilişkin çalışmalar genişletilmiştir. Bu çalışmanın amacı, sadece basit bir atık malzeme olarak bilinen plastik malzemelerin performansları açısından teknik avantajlarını tanıtmak ve bu malzemelerin atık olarak çevresel, ekonomik ve teknik dezavantajlarını asfalt kaplama malzemesi olarak kullanarak avantaja dönüştürmektir. Çalışmada sınıflandırılmış granül haldeki atık plastik ısıl işlem yöntemiyle bitümle karıştırılarak numuneler hazırlanmış ve hazırlanan numuneler Marshall Dayanım ve İndirekt Çekme Dayanım deneylerine tabi tutularak sonuçları yorumlanmıştır.

1. Introduction

Due to population growth and rapid industrialization, the world's natural resources are decreasing each year and their needs are increasing [1]. Instead of using natural materials, the by-products and waste materials produced during the production or processing of these natural materials should be reused [2]. This will lead to energy savings through efficient use of natural resources, and the environmental impact of waste materials will make a major contribution to the country's economy in the long run and minimize storage for disposal [3].

As the quality of life increases as a result of the progress achieved by industrialization, the inevitable growth in the population causes the depletion of natural resources and pollution of the environment

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more and more and this necessitates waste management [4].

Changing living standards make it difficult to control and manage waste by increasing waste quantity and waste diversity [5]. The pollution caused by the wastes increases the size of the existing and potential risks day by day and causes the decrease of natural resources [6]. For these reasons, waste management is becoming increasingly important and complex in our age [7]. As a matter of fact, the theme of World Environment Day in 2018 has been determined as 'Combating Plastic Pollution' [8]. With this theme, it is aimed to reduce the production and use of plastic products used in the world [9].

As a result of the researches, it is observed that 50% of the environmental pollution occurred in the last 35 years [10]. Plastics are used in the construction of many household and industrial materials [11]. Worldwide, the production of waste plastics is 460.000 t/day, which accounts for approximately 8% (24% by volume) of municipal solid waste. Plastic based solid wastes constitute 8% and 12% by volume of solid wastes collected in the world [12].

Plastics Manufacturers Association (PAGDER) According to the data, which is 80.8 kilograms per person in 2015 in Turkey plastic consumption increased by 11.5 percent over 3 years 2018 well reached 90.1 kilograms [13].

Within the scope of sustainable development, waste management strategies aiming to ensure that wastes do not threaten the environment and human health and turn them into an input for the economy are adopted throughout the world [14]. Integrated solid waste management is a process which begins with waste reduction at source, reuse, recycling and recovery practices and ends with collection and disposal of waste. The Ministry of Environment and Urban Planning's Packaging Waste Regulation aims to recycle 20% of the year 2020 and is 60% in line with the EU [15].

Indeed, according to the report prepared by the Chamber of Certified Public Accountants of İstanbul (ISMMMO) titled "Treasure in The Trash", 2 Million Turkish Liras worth of waste is regained to the economy on a daily basis thanks to street collectors, wholesalers and recyclers. When the same calculation is made for the whole year, it is seen that the amount that we throw away and cannot recycle is 1.1 Billion TL. As a result of the comparison between 800 Million TL regained to the economy with brand new products, it was calculated that Turkey saved 405 million TL worth of additional waste [16].

In the Workshop Report of the Association of Plastic Industrialists (PAGDER) Strategic Expansions for Plastic Recycling Enterprises; the global market size of plastic recycling sector with current prices will exceed $ 900 billion in 2050 and Turkey in 2025 if current growth continues to 3,25 billion dollars; In 2050, it is estimated that it will reach a sector of 63 billion dollars [17]. It is stated that the plastic recycling sector, which is expected to process 4.3 million tons in 2030, is expected to reduce the current account deficit of raw materials by 35.1% [18].

The use of industrial wastes in road construction has become widespread in recent years % [19]. It is possible to remove industrial wastes by using them in road construction % [20]. They can be used in wearing and binder courses, base and sub-base layers and base-floor (as filler material) % [21]. In addition, they can be used as aggregate or supplemental cement material in rigid pavement or cement-concrete [22].

In this study, it is investigated whether waste plastics can be used together with bitumen in asphalt concrete. In addition, the effect of waste plastic used on asphalt concrete on plastic deformation was investigated. In this study, two kinds of plastics were investigated. Shredded polyethylene terephthalate (PET) and granular low density polyethylene (LDPE) obtained from black nylon bags were added directly to the hot mix asphalt (HMA) for a certain period of time to the prepared samples. The waste plastics were mixed into the bitumen in the heat treatment. In addition, hot plastic asphalt (HMA) samples were prepared by reducing the bitumen rate by a certain amount.

2. Material and Method

2.1. Material

2.1.1. Waste Plastic

The word plastic is derived from the Greek word plastikos meaning "capable of being shaped or molded" [23]. Plastic is a general name used for materials obtained by breaking the bond in simple-structured molecular groups called monomer formed by carbon (C) with hydrogen (H), oxygen (O), nitrogen (N) and other organic or inorganic elements and turning them into polymers, which are long and chained structures. For example, Ethylene is a monomer. It is one of the most widely used plastics [24]. As can be understood from the definition above, plastics are not available in nature, but derived from humans by using catalysts on elements in nature at a certain temperature and pressure and allowing monomers to react [25]. Plastics are obtained from residual materials generated after processing crude petroleum in refineries. According to studies, only 4% of the petroleum in the world is used for producing plastics [26]. Although rubber and other similar natural products are defined as plastics, these are excluded from plastics in the modern definition. It is difficult to make the distinction between resins and

plastics. Most artificial materials can be referred to as both resin and plastic. Plastic materials have become the most important commercial materials in the world since they are lightweight, cheap, and easy-to-process and have numerous different areas of use. Huge amounts of plastic materials are used in everyday life. Most of these materials are used only once and thrown away and take up a lot of space in terms of volume, which has caused environmental pollution [27].

Waste plastics fall into two categories as production waste and consumption waste. Production wastes are clean wastes, which were generated in the production phase and their type and color are known. Since these wastes do not contain any foreign substances, they are directly crushed in plastic crushers, melted and granulated. This is referred to as dry crushing. Consumption wastes are derived from collection of plastics within the scope of recyclable waste. Collected waste plastics are kept in water tanks in order to eliminate foreign substances. Then, waste plastics are dried in ovens at a temperature which will not impair their chemical structure. Dried plastics are crushed in plastic crushers, melted and granulated. This is referred to as wet crushing. The reason why plastics are granulated is to obtain equal density.

Two types of plastics were used in the research. These are granular low density polyethylene (LDPE) obtained from black nylon bags and shredded polyethylene terephthalate (PET / PETE) from Sefalı Scrap Recycling Company located in Isparta Province Waste Collector Zone. These plastics are also available in the market.

Table 1. One kg of PET bottle flake

Sieve Size (mm)	Amount (g)
12.5	-
9.5	-
4.75	0.72
2.00	33.35
0.425	613.29
0.180	129.98
0.075	203.92
Dust	19.20

2.1.2. Aggregate and bitumen

Aggregate and bitumen used to prepare test samples were obtained from the Municipality of Isparta. Weights and characteristics of aggregates used in tests are indicated in Table 2. The gradation graph of aggregate selected within the specification limits is given in Figure 1.

Standard aggregate tests have been performed on bitumen which was used in the mix [28]. The bitumen characteristics obtained as a result of tests can be seen in Table 3.

Table 2. Gradation Limits [29]

Sieve Diameter (mm)	Limit values % exceeding	Gradation of the mix % exceeding	Weight (g)
19 (3/4")	100	100	0
12.5 (1/2")	83 – 100	90	124.5
9.5 (3/8")	70 – 90	80	124.5
4.75 (No. 4)	40 – 55	45	435.75
2.00 (No. 10)	25 – 38	30	186.75
0.425 (No. 40)	10 – 20	15	186.75
0.180 (No. 80)	6 – 15	10	62.25
0.075 (No. 200)	4 – 10	6	49.8
Dust	0	0	74.7
Total	100%	100%	1245

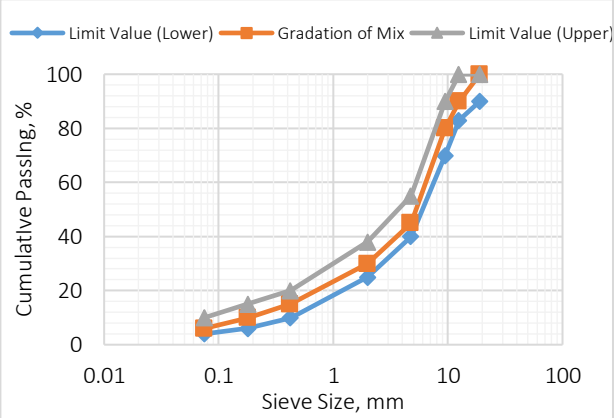

Figure 1. Gradation graph of aggregate selected

Table 3. Characteristics of Bitumen Used

Test	Mean Values	Standard
Penetration (25 °C)	60-70	ASTM D5
Flash Point	180ºC	ASTM D92
Combustion Point	230ºC	ASTM D92
Softening Point	45.5°C	ASTM D36
Ductility (5 cm/minute)	>100 cm	ASTM D113
Specific Gravity	1.030	ASTM D70

2.2. Method

Several methods have been tried to add waste materials to HMA. The pyrolysis method is one of the most common methods. The pyrolysis method – an important method used to recover waste materials – involves heating organic substances in an oxygen-free environment and turning them into gas, solid or liquid products and it is based on deformation of wastes with or without catalysts with the effect of temperature in inert, vacuum or reducer (hydrogen) environments. Thus, it is aimed to acquire a kind of waste material which causes environmental pollution and appears as an input to the economy. The reason for the use of plastics in the study is that the deformations of plastics under high tension are similar to those of metals. When the process is completed in pyrolysis method; it is observed that the chemical structure of plastics has changed and the resistance of tensile plastics to gas has decreased. In addition, in addition to plastics, the pyrolysis process is not suitable for all products whose crude material is obtained as petroleum, as it changes their chemical

structure. Another method is to mix the waste material with aggregate as aggregate. The plastics adhered to the pan due to high temperature and their chemical structure was deformed as a result of this method. Therefore, we concluded that this method was not appropriate and decided to add the waste material into the bitumen. The waste material was added to the HMA as an additional substance.

With time study, samples were prepared by adding waste materials to bitumen in preheated furnaces to 160 °C. Since the melting temperature of the plastics is 270/380 °C, the oven is fixed to 160 °C in order not to disturb the structure of the bitumen. The main reason for the preparation of the samples by this method is to ensure full adherence between the waste material and the bitumen, which begin to soften at a certain temperature. Optimum ratio and time were determined by time research.

In addition, by reducing the bitumen rate used in HMA, the amount of waste material was reduced and prepared in the samples.
Samples prepared with waste plastics were applied Marshall Stability and Indirect tensile strength tests.

3. Research Findings

3.1. Marshall Stability Test Results

Marshall Samples 5% - 4.73% bitumen and bitumen with 60-70 penetration for wear layer Type-1 aggregate gradation.

Two types of plastic wastes were utilized during the tests. Firstly, PET shredded bottle were used in hot mix asphalt instead of bitumen. 15 g (1,21%), 20 g (1.61%), 30 g (2.41%), 35 g (2.81%) of waste plastic were added to bitumen and the same amount of bitumen was reduced to prepare Marshall samples. Figure 2 shows Marshall Test results of samples prepared by keeping in oven for 20 min and adding 5% bitumen.

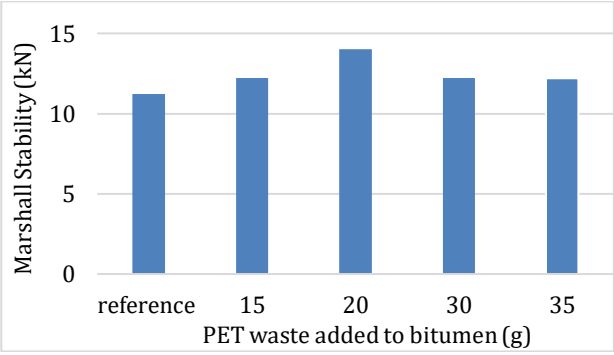

Figure 2. Comparison of Marshall Results of samples prepared with PET

As can be seen in the figure, Marshall Stabilities of samples prepared with PET have increased. The sample prepared with 20 g gave the highest Marshall stability value and yielding remained within the specification limits. Also, a time study was performed and the best Marshall and yielding values at optimum temperature were investigated. Samples prepared with 10 g, 20 g, 30 g, 35 g and 5% bitumen can be seen in Figure 3.

In addition, bitumen and waste plastic were kept in an oven to preheat at 160 °C in order to ensure bitumen and waste plastic combine better. Samples were kept in the oven for 20 min, 1 hour 20 min and 2 hours 20 min and results were examined. Keeping samples in the oven for 1 hour 20 min produced the best result. Thus, the optimum value at the optimum temperature was investigated.

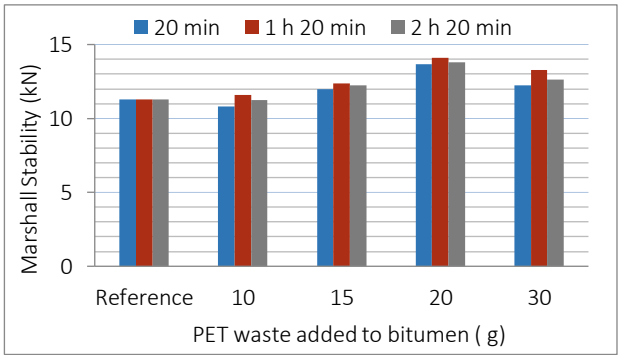

Figure 3. Time study of samples prepared with PET

Time values were studied for samples prepared by adding 15%, 20%, 25%, 30%, 35% PET shredded bottle by weight. The graph shows that all samples prepared with PET shredded bottle were above the Marshall lower limit value. Sample prepared with 20% kept in the oven for 1 hour 20 min produced the best result.

Also, Marshall Samples containing bitumen equal to 4.73% of total weight at Type-1 aggregate gradation and PET waste were prepared for 15 g, 20 g, 25 g, 30 g, 35 g and 20 g produced the best result.

The second type of waste used in the study was granulated LDPE. Among samples prepared with 5% bitumen, 20 g kept in an oven for 1 hour 20 minutes produced the best result. Marshall Stability significantly increased for samples prepared with granulated LDPE. However, yielding values increased beyond the technical specification values.

Marshall Stability increased for all samples prepared by adding PET shredded bottle into bitumen. Also, yielding remained within technical specification values with bitumen reduced by the amount of waste added. This result shows that we can produce environment-friendly solutions by using waste plastics in pavement construction and increase the Marshall stability by reducing the amount of bitumen. Test results show that we can both increase the stability and prevent experimental pollution by reducing bitumen in HMA.

3.2. Indirect Tensile Strength Test Results

Indirect tensile strength test is performed to determine the moisture susceptibility of bituminous mixtures.

After determining Marshall Stability of samples prepared with optimum bitumen ratios, samples prepared with the same ratios were applied conditioned indirect tensile strength test. As can be seen in the Figure 4, the values are close to the right values. PET shredded bottle was used as waste material in samples subjected to indirect tensile strength test. As this graph shows, PET shredded bottle wastes may increase load distribution capacity of bituminous pavements and crate a stronger tensile strength against loads.

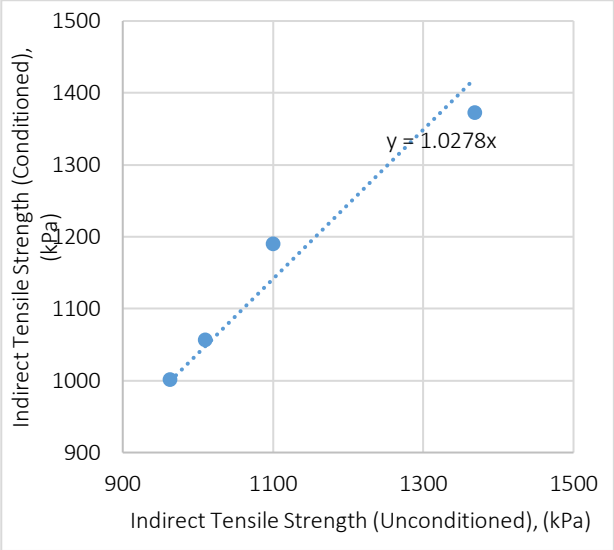

Figure 4. Indirect tensile test results of samples prepared with waste plastics

4. Discussion and Conclusion

The amount of waste plastics, which are industrial solid wastes, increase with each passing by and they have reached a level threatening the environment. Wastes must be used in various areas and disposed of in order to solve this problem.

In the world, most of these industrial wastes may be used in roadways from the base layer to the pavement layer. Using waste materials instead of traditional materials in road construction allows for production with lower costs, disposal of waste materials causing environmental pollution and preservation of natural materials. Sufficient research should be conducted on waste materials, these materials should be known better and the material providing an advantage should be chosen based on its properties and used in the suitable road layer (provided that it meets specification values).

Two values obtained from the results stood out among the results of the tests performed. The first is that Marshall stability values increased for samples prepared with PET shredded bottle, whereas yielding values remained within specification limits. The second result was that these stability values were achieved with less bitumen. Therefore, it is safe to say that waste materials may be used as binding material in bituminous mixes. However, the need for a preliminary treatment (granulation of wastes) and the addition of a heating unit to asphalt plants to achieve optimum results by adding waste plastics to the mix are factors that increase costs.

The worth of bitumen used for a 1 km road is TL 64743.52. However, if waste plastic is used instead of bitumen, the bitumen cost will be reduced by 32% and 23.13253 tons of waste plastic will be regained to the economy without polluting the environment. Also, processing costs will be eliminated as well since waste materials will not be stored and cause environmental pollution.

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