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Study the Effect of Adding Plastic and Rubber Waste Mixture on the Physical and Chemical Properties of the Asphalt

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دراسة تأثير إضافة مخلوط من المخلفات البلاستيكية ومسحوق المطاط على الخصائص الفيزيائية والكيميائية للمصفوفة الإسفلتية

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Abstract

The use of industrial waste such as scrap rubber tires and plastics in the production of asphalt binders has become widespread due to economic and environmental benefits. In particular, the use of recycled waste plastic in asphalt binders and mixtures is gaining more attention. This presents work analyses and evaluation of rubber granules extracted from used tires, and plastic waste in asphalt modification. It focuses on the physical properties of modified asphalt compared to the conventional asphalt binder. The evaluated properties of asphalt binders were penetration value, storage stability and ductility test. Overall, the incorporation of combined polymer wastes into asphalt matrix can significantly improve physical properties of asphalt and has potential economic and environmental benefits. The performance of modified asphalt is highly dependent on multiple parameters, such as waste sources, mass of materials, and the blending conditions such as reaction temperature and mixing speed.

Keywords: Plastic, Rubber, Polymer, Asphalt, Exhausts.

الملخص

أصبح استخدام النفايات الصناعية مثل إطارات المطاط الخردة و البلاستيك في إنتاج مواد ربط الأسفلت واسع الإنتشار نظرا للفوائد الاقتصادية و البيئية على وجه الخصوص، يكتسب استخدام نفايات البلاستيك المعاد تدويرها في مواد ربط الأسفلت و مخاليطها مزيدا من الاهتمام . يقدم هذا العمل تحليلات و تقييما لحبيبات المطاط المستخرجة من الإطارات المستعملة ،و نفايات البلاستيك في تعديل الأسفلت . و يركز على الخصائص الفيزيائية للأسفلت المعدل مقارنة بمادة ربط الأسفلت التقليدية .كانت الخصائص التي تم تقييمها لمواد ربط الأسفلت هي قيمة الإختراق ، و ثبات التخزين ، واختبار الليونة . بشكل عام ، يمكن أن يؤدي دمج نفايات البوليمر المركبة في مصفوفة الأسفلت إلى تحسين الخصائص الفيزيائية للأسفلت بشكل كبير ، وله فوائد اقتصادية و بيئية محتملة . يعتمد أداء الأسفلت بشكل كبير على معايير متعددة ، مثل مصادر النفايات ، و كتلة المواد ، و ظروف الخلط مثل درجة التفاعل و سرعة الخلط .

الكلمات المفتاحية: بلاستك، مطاط، أسفلت، بوليمر، نفايات.

Introduction

In some countries, cities' main streets and roadways are characterized with old deformed asphalt pavements due to a number of reasons, i.e. natural weather factor, uncontrolled traffic factor or a lack of frequent maintenance[1]. Known solution to this problem is using of modified asphalt binders, which are unfortunately more expensive as ordinary asphalts and thus not available for some communities in developing countries. From a different angle, the problem of the study can be described also on the basis of environmental concerns of a worldwide landfill disposal of polymer waste materials. The disposal of expired automobile tires and plastic substances randomly is considered one of the major causes of damage to our ecosystem and problem source to the health of all types of life alarmingly. Annually, a large amount of tires become exhausted and disposed of as wastes frequently seen on the sides of roads and highways, especially outside Europe and USA, where appropriate recycling technologies are not available. The best ways of recycling these waste materials is to use in asphalt road construction This research work is intended to investigate the utilization plastic wastes and crumb rubber obtained from scrap tires as asphalt binder modifiers to improve the physical properties of asphalt binders.

Background of Asphalt Mixtures

Roadways in all countries are believed to be one of the most important elements of infrastructure that. Asphalt binder is the commonly used by the paving industry.

Asphalt matrix is the black-colored product obtained at refining crude oil. At this process the crude oil is pumped from storage tanks, where it is kept at about 60°C, through a heat exchanger system where its temperature is increased to typically 200°C by exchanging heat gained from the cooling of newly produced products in the refining process. The crude oil is then further heated in a furnace to typically 300°C where it is partly vaporized into an Atmospheric Distillation Column. Here the physical separation of the components occurs. The lighter components rise to the top and the heavier components fall to the bottom of the column and pass through a second heat exchanger prior to treatment in a vacuum distillation column. Finally, asphalt is obtained by vacuum distillation or vacuum flashing of atmospheric residue from the vacuum distillation column. This is "straight run asphalt”. This process is called asphalt production by straight run vacuum distillation which is using for asphalt pavement applications [1-2-3]. Asphalt production scheme is presented in Figure 1 [3]. Due to interesting potential characteristics of asphalt such as impermeability, adhesivity, elasticity, resistance to the influence of weathering, chemicals, which make it the most suitable engineering material as a binder of mineral aggregates in paving and roofing applications [1-4]. Yet, conventional asphalt in roads are usually sensitive to the increased traffic volume and vehicle loads due to its visco-elastic nature [4]. Modified asphalt with virgin polymers for the improvement of performance properties of the pavement asphalt has been taken place over the last decades. Later, the scientists and the engineers of roads have focused on the use of alternative modifiers coming from recycling and processing of polymer waste materials, particularly crumb rubber (CR) derived from scrap tires since, similarity in performance was found between recycled polymer and virgin polymers modified asphalt [5, 6].. Yet, the management and recycling approach of crump rubbers (CR) are still challenge for industry, engineers and scientists, due to the vulcanization process during the initial stages for the production of rubber tires. In addition, scrap tires constitute about 80% of the total waste rubbers generated annually [7]. However, from an environmental point of view, the utilization of waste tire rubber as a asphalt additive may contribute to solve a waste disposal problem, since the development of the automotive industries may produce lage numbers of tires worldwide every year [8, 9].

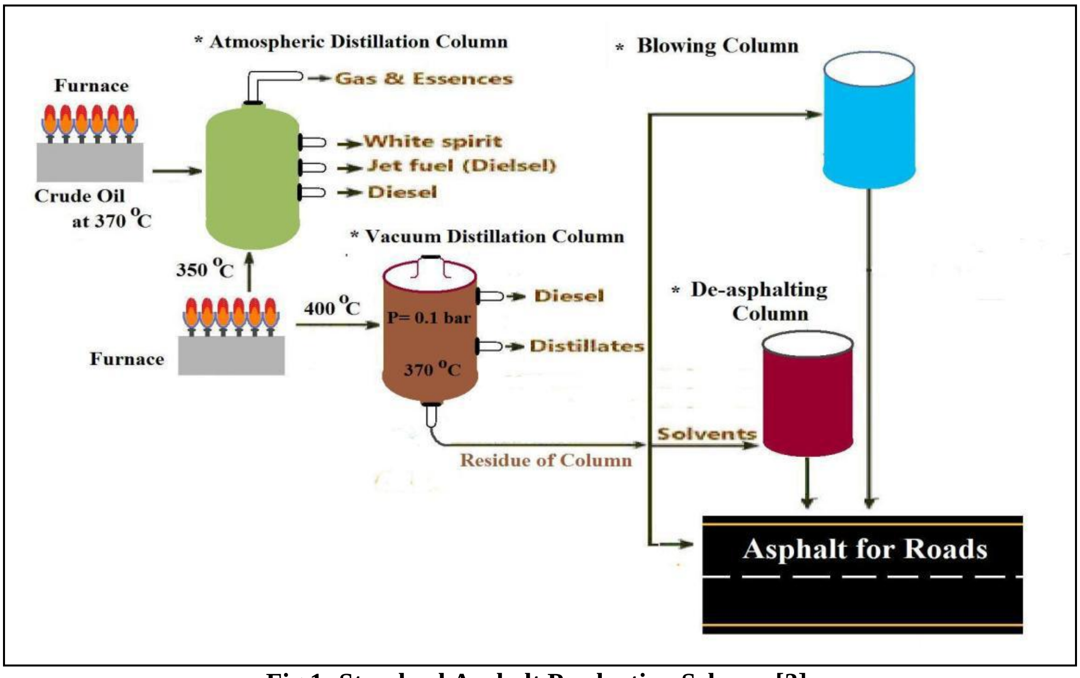

Fig.1: Standard Asphalt Production Scheme [3].

Main Chemical Components in Asphalt

Asphaltenes and maltenes are two main chemical of constituents into which asphalts are often separated due to its complex composition. Maltenes can further be divided into three groups: saturates, aromatics, and resins [3, 9]. Figure.2 shows the representative structures of four chemical groups in asphalt. The complexity of the chemical structure, content of heteroatom, aromatic, and increase the molecular weight are in the order of saturates < aromatics < resins < asphaltenes [10]. Resins, which have polar character, are responsible for the adhesion and ductility of asphalt and also the dispersion action of the asphaltenes [3, 11, 12]. While asphaltenes are responsible for the bulk of asphalt and oils, the asphalt components with the smallest molecular weight and the non-polar fraction has an influence on flow and viscosity properties [3].

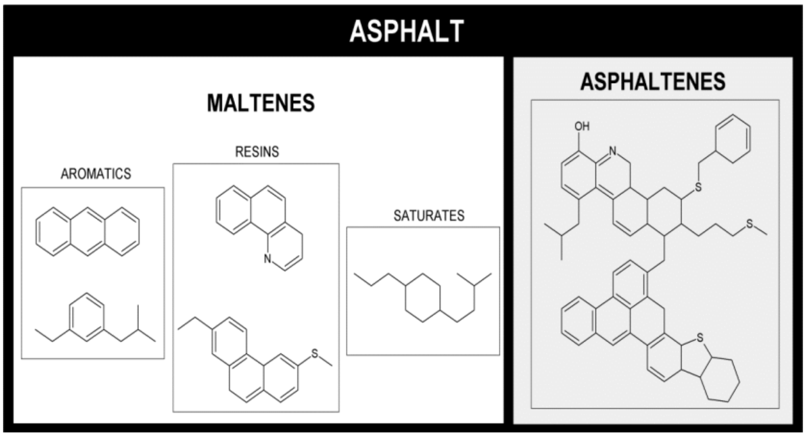

Fig.2: Representative structures of asphalt main fractions [3]

Main Failure Modes of Pavement Asphalt

Rutting failure is one type which can be noticed in road constructed at regions of high-temperature conditions, such as in North African countries, where strain accumulates in the pavement and permanent deformation takes place in the form of ruts (tracks) on the surface of asphalt pavement [3]. Permanent deformation is the most critical load-related distress that develops on asphalt pavements and greatly affects its performance [13]. There are two main forms of rutting as follow: lateral flow of or, shear occurs when there is not enough in the hot mix asphalt. This type of rutting is common in slow-moving lanes and intersections due to slow moving and steady traffic [14].. Plastic flow normally leads to longitudinal depressions along wheel paths with humps (upheavals) of materials on either side of the rut (Figure.3-a). The humps are created as the material is squeezed out from under the heavy loads [14]. Researches indicates that plastic/shear flow contributes to about 90% of rutting in asphalt concrete and consolidation/densification to about 10%. Mechanical deformation results from insufficient structural capacity of the paving system. In this type of rutting, the strength and thickness of the pavement layers and/or subgrade provide insufficient support to the existing traffic (Figure.3-b). The mechanical deformation is usually accompanied by longitudinal and/or alligator cracking, which usually begins at the bottom of the asphalt layer where tensile stresses are excessive [13, 14]. This is often reduced by early repair planning.

The second type of failure is called moisture damage. It is usually caused when the AC does not bond well with the aggregate and sand fractions. This lack of adhesion and cohesion between the main road pavement components becomes obvious in the presence of water (i.e. rain). In this case, and since the asphalt is hydrophobic and aggregate is hydrophilic, the asphalt mastic can be repelled from aggregates and sand fractions, resulting in random cracks in the surface of the pavement. Finally, the thermal cracking failure occurs mainly due to the frequent and long-term exposures of the road to extremely low temperatures in the winter seasons, leading to road hardening and where thermal stresses exceed the strength of the materials, and the road pavement becomes cracked. The repeated thermal stresses below the design limit can also be a cause of thermal fatigue cracking failure. Another reason for thermal distress is the repetitive loading by heavy traffic during the freeze-thaw cycle, which is considered another cause of this failure. This mode of failure is observed usually due to the cyclic load of heavy trucks until road pavement is fractured and many random cracks show up. According to Figure.4, it is shown that only about 10% of asphalt is used as roofing material for buildings, for humidity and leakage protection. Five percent is used in other applications such as thermal and acoustic insulation as well as corrosion protection components of paints and varnishes, while the remaining 85% of the asphalt binder is commonly used by the paving industry [3].

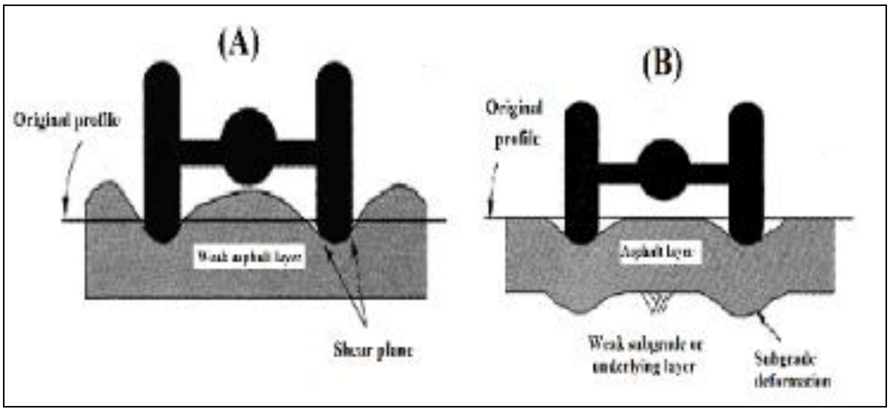

Fig. 3: Severe ruts in an asphalt pavement(a), Fatigue cracking(b) [13]

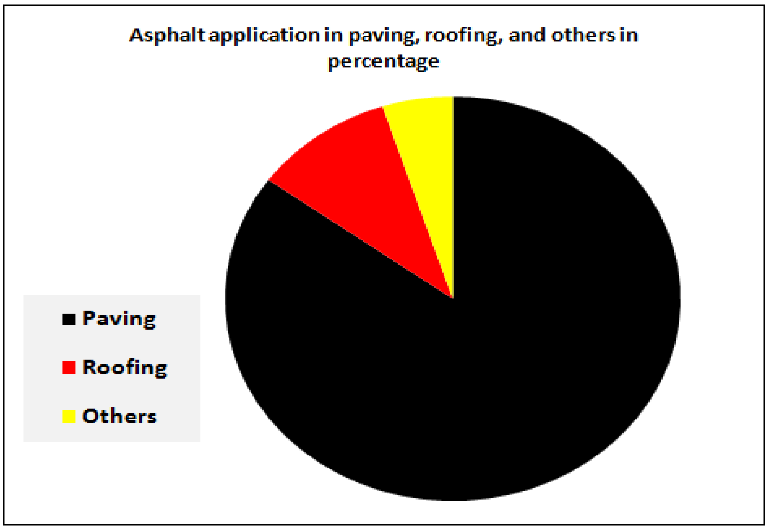

Fig.4: Asphalt application in paving, roofing, and others in percentage [3].

Environmental Impacts of Polymers Waste and Their Recycling

. In regard to waste tires, it was reported that the world's annual generation of this waste is about 1.5 billion waste tires [3, 15]. Another research study reported that, about 97 million motor vehicles were manufactured, and the amount of waste tires generated was around 25.6 million tons, in 2016 alone [16], and the estimated total number of used tires will be at 1.2 billion by 2030 [17].

Also, It is expected that, by the end of 2030, the number of scrap tires will reach about 5 billion worldwide. Conversely, the current global annual accumulation waste plastics is around 150 million tons. Their non-biodegradable nature and toxic ingredients pose major environmental concerns [18]. Plastics have been widely used in various fields for their significant benefits in terms of cost-effectiveness, light weight, durability, and ease of processing compared to many other materials [19]. Another review paper has reported that "the production of plastics presented a growth from 2 million metric tons in 1950 to 322 million metric tons in 2015. The cumulative amount of plastic production reached 8.3 billion metric tons in 2017" [20]. Ahmadinia et al., (2012) reported that the annual consumption of plastics has increased from about 5 million tons in the 1950s to about 100 million tons in 2001 [21]. Figure.6-a shows the scrap tires [17]. While, burning scrap tires at the open land which is one of the potential hazards of uncontrolled tire landfills is presented in Figure.6-b) [3, 22], while These, in turn, pose pollution problems first to atmospheric air by the release of volatile toxic gasses such as dioxins and polycyclic aromatic hydrocarbons and second to the water when the intense heat allows pyrolysis of oil and other toxic material to leach onto the soil profile reaching the underground water runoff [23, 24].. At this point in time, there is also the availability of plastic wastes, which is enormous, as the plastic materials have become part and parcel of our daily life. Either they get mixed with the MSW or they are disposed over land areas. If they are not recycled, their present disposal approach may be by land-filling or incineration. However, both of those processes have significant impacts on the environment [3, 25].

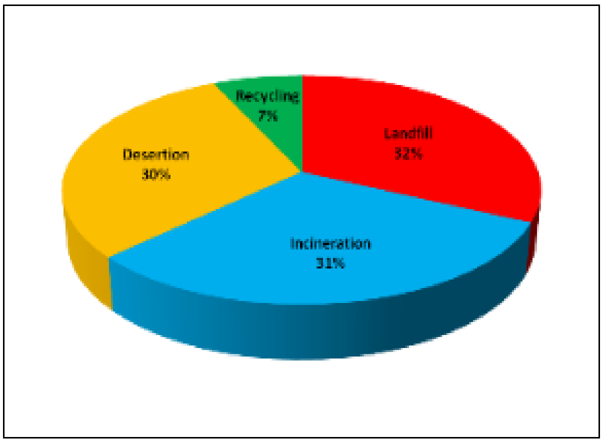

Figure.5: Disposal of plastic waste in China in 2019 [19].

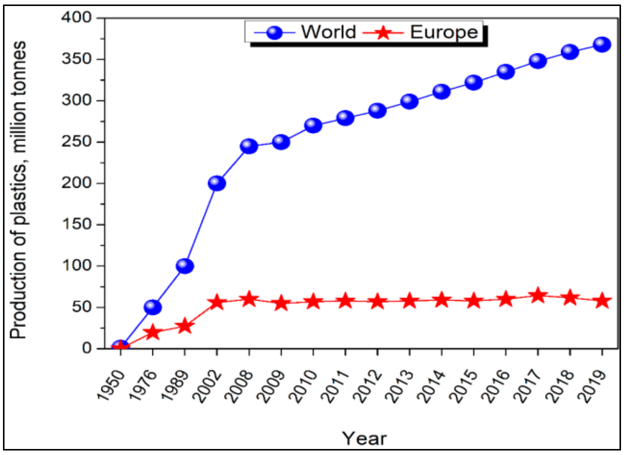

Figure .6: Tons of plastics for generation and different treatments; adapted from [20].

Figure. 7: Scrap Tires (a) [17], Burning scrap tires at the open land(b) [3, 22].

A research study was conducted to investigate the utilization of waste plastics and rubber tires as asphalt binder modifiers in the pavement of flexible highways. One conclusion from the study was that the project is not only to improve the physical and rheological properties of asphalt mixture but also to prevent the landfill disposal of such materials, collect them at low cost, and provide a solution to the global environmental issues imposed by the increased disposal of such wastes [26].. In addition to its utilization as a recyclable material, the applications of CR in the pavement field has also received great attention from environmentally conscious people due to the environmental benefits of recycling scrap tires [27], which offered low-cost recycled resources and finally encouraged economics.

Technologies of Asphalt Modifications with Rubber Granules

Crumb rubber obtained from used tires can be incorporated into an hot mix asphalt (HMA) by mainly one of two common approaches. These process are called the dry process and the wet process. In the dry process, rubber granule is used in an HMA mix, replacing a small amount of aggregates in the asphalt mix before the addition of the asphalt, as presented by Figure 8 [16] . On the other hand, the wet process refers to the modification of the asphalt binder with rubber granules, which is used to replace a certain quantity of asphalt by weight. In this process, the rubber granules are mixed with the hot asphalt binder, before being mixed with the aggregates to produce an HMA, as presented in Figure 9 [16]. The dry method is much simpler than the wet method, due to the procedure for replacing some amounts of the aggregates with crumb rubber is easier than replacing some of the asphalt mixture. Moreover, the dry method can be implemented in most cases at a much lower cost, without the need of a major refurbishment of the mixing procedure. However, the application of the dry method is limited compared to the wet technique. This is because the modified asphalt mixture with rubber produced via the dry technique suffer from volume instability, and techniques relatively low strength, as some of some of the aggregates are replace by rubber [16]. On the other hand, the modified asphalt mixture with crumb rubber produced using the wet method shows higher rutting resistance and performs better against fatigue cracking [16], indicating a greater durability of the modified asphalt mixture. When polymers such as rubber and plastic are added to asphalt mixture, the properties of the modified asphalt blend depend on various factors including, polymer characteristics, asphalt characteristics, mixing condition, and compatibility of polymer with asphalt [28].

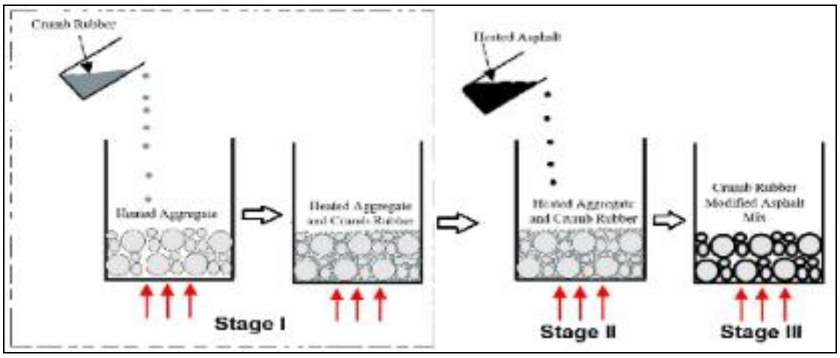

Figure. 8 :The dry process of mixing crumb rubber to produce an HMA mix [16].

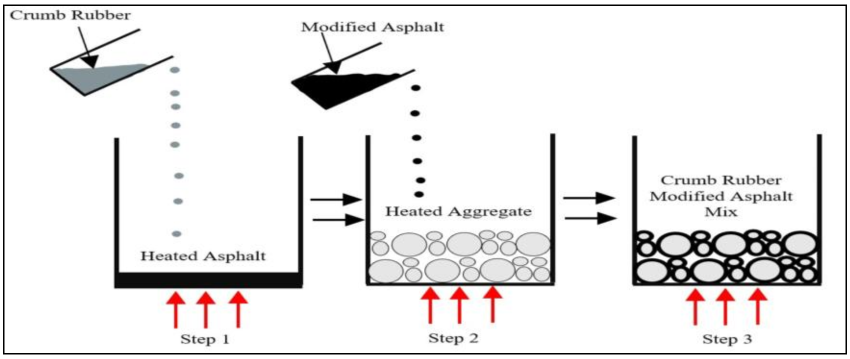

Figure .9 :The wet process of mixing crumb rubber to produce an HMA mix [16].

The Benefits of Using Rubber and Plastics Waste in Asphalt [29, 28]:

1. reduce structural thickness of pavements
2. increase the stability and the strength of mixtures
3. improve the abrasion resistance of blends
4. reach stiffer blends at high temperatures and reduce rutting
5. improved durability,
6. increased elasticity and resilience at high temperatures,
7. improved resistance to surface initiated,
8. improved fatigue properties,
9. reduced temperature susceptibility,
10. improved permanent deformation and aging and oxidation resistance,
11. reduce life costs of pavements,
12. rubber-asphalt blends better pavement durability and performance,
13. rubber-asphalt also show reduced construction time due to thinner lifts,
14. reduced traffic noise,
15. improved safety due to better long-term color contrast for pavement markings because carbon black in the rubber acts as a pigment that keeps the pavement blacker longer,
16. reduction of road pavement thickness,

17. the use of polymer waste as modifier in asphalt production provides asphalt with a similar property to virgin polymers, substantially reducing the construction cost, and protecting the environment from additional contamination.
18. savings in energy and natural resources by using waste products and not contributing to the stockpiles.

Finally, it has been reported that "in a study conducted in EU concerning life cycle analysis of ELTs, the results showed that by recycling an amount of approximately 400,000 t of ELTs, which can be used as artificial turf, a reduction of approximately 280,000 t CO_2/year can be achieved" [30].

Cost Analysis of Asphalt Modifications Process

From an economic point of view, the cost of the final product is of great importance for production companies. according to asphalt mixture productions, studies indicate that the initial cost of complete blending of modified asphalt with polymer materials is higher than conventional asphalt. For this reason, the initial cost modified asphalt with ground tire rubber mixture can be 30% to 80% higher than conventional asphalt. however, These companies, which continued their business of modified asphalt productions, have definitely an amazing vision; they considered the life cycle cost. Pavement maintenance and rehabilitation strategies are very important parameter and will influence the life cycle cost. Pavement maintenance and rehabilitation strategies are very crucial parameter and will affect the life cycle cost. This is easily proven by experience in states such as California and Arizona. They have extensive experience in asphalt rubber admixture technology which has been shown to be cost effective for binders when properly produced and installed [31]. It makes sense considering the total cost which means a rubber asphalt project is lower than the unmodified asphalt project.
pavement thickness using modified-asphalt mixture has been reported to be reduced by up to 50% using the vehicle simulator. In addition to reducing thickness, pavement maintenance rates and rehabilitation strategies is also commonly reported to be reduced [32].

Literatures Review

Khiong et al., (2021) have published paper presents the results of a laboratory-based experimental studies on the properties of modified asphalt mixture with crumb rubber, using the hot-mix asphalt (HMA) process. Crumb rubber contents of 5 wt%, 10 wt%, 15 wt%, and 19 wt% were added to the unmodified asphalt in order to prepare the modified asphalt binder samples, while the unmodified asphalt binder was used as the control sample. The crumb rubber modified binders were examined for measuring physical property using the penetration test, and temperature resistance using the softening point test. All of the asphalt mixes were examined in order to determine their volumetric properties, like bulk density, voids in total mix (VTM), voids in mineral aggregate (VMA), and voids filled with asphalt (VFA). In addition, the Marshall stability, Marshall flow, and stiffness of all of the samples were evaluated. Obtained results showed that the modified asphalt samples possessed higher viscosity and temperature resistance than the unmodified asphalt mixture. The viscosity and temperature resistance of the asphalt binders increased with the increase in crumb rubber content. The overall research findings suggest that crumb rubber can be used to produce durable and sustainable HMA mixes, with manifold environmental benefits, for use in flexible pavements [33]. Zhu et al., (2022) investigated the performances of rubber asphalt (RA) with 15–35 wt% of crumb rubber content. The effect of preparation conditions including 170–230 °C of reaction temperature, 8–225 min of reaction time and 0-10% of aromatic oil (AO) content were studied. The reaction mechanism between crumb rubber and asphalt was performed by micro and macro tests, and the fundamental properties, construction workability, storage stability, high and low temperature performances of RA were explored. The results showed that the crumb rubber in 15–35% RA only swells at 170 ◦C, while the crumb rubber swells first and then degrades at 190–230 ◦C. The swelling and degradation rates of crumb rubber increase with the increase of reaction temperature, the decrease of rubber content and the increase of AO content. The higher rubber content means higher softening point, ductility, elastic recovery and lower penetration of RA. Higher reaction temperature means higher penetration, ductility and lower softening point of RA. With the increase of AO content of RA, the penetration and ductility increase while the softening point and the elastic recovery decrease. The construction workability of RA promotes with higher rubber content and lower AO content. The storage stability of RA decreases with the increase of rubber content and the decrease of reaction time as well as the AO content. The complex modulus increases while the phase angle decreases when swelling is dominant, and the complex modulus decreases while the phase angle increases when degradation is dominant. The high temperature rutting resistance of RA increases with the increase of rubber content and the decrease of AO content. The low temperature crack resistance of RA increases with the increase of rubber content and AO content. The results could provide reference for the preparation of RA with middle/high content of waste tire crumb rubber [34]. Mjthab and her coworkers (2011), studied asphalt modified by ethylene-vinyl acetate (EVA). They reported in their conclusion that EVA modifier has essentially stiffened the asphalt mixture and thereby made the asphalt more resistant to traffic loading and rutting, particularly at higher road temperatures during the hot summer seasons when asphalt surfaces were at higher risk of softening and rutting under traffic. The modified asphalt with EVA became much like a hard plastic and, therefore, the product was considered a plastomer [35]. Another study conducted by García-Morales and his coworkers, used Recycled ethylene-vinyl acetate (EVA) for asphalt modifications process. The content levels of the modifier ranged from 0 to 9 wt%. The results have proved that the recycled EVA can increase the mixture viscosity at higher service temperatures, with consequent benefits on road performance, such as resistance to rutting. However, the asphalt viscosity at the production and application temperatures proved to be sufficiently low for its adequate use in pavements even at concentrations as high as 9 wt% [36]. Paulo and Pais, . Sulyman et al., (2013) investigated the use of crumb rubber extracted from used tires and polyethylene composite for the modification of asphalt binder. The polymer waste composite was prepared using extrusion process at 180ºC and shear rate of 100 rpm. Different content levels of composite were added to the virgin asphalt matrix at 180ºC, for 60 min. Obtained results showed that the modified asphalt had better properties than unmodified asphalt binders [37]. the effect of rubber content derived from used tires on the physical and rheological properties of asphalt binders. The content of rubber used for modification of asphalt mixture were 3%, 9%, and 15 wt%. The rubber-asphalt was produced at temperature reaction and blending speed of 150ºC and 250 rpm, respectively, for reaction time of 120 min. Results of the work pointed that all properties of modified-asphalt binders were improved by the addition of finer crumb rubber. Softening point, viscosity, and the complex shear modulus were increased as the amount of CR increased in the mixture, while penetration and phase angle (δ) values were decreased as compared to the virgin asphalt. The softening point was increased from 46ºC for unmodified asphalt to 54ºC, 55ºC, and 58ºC with 3%, 9%, and 15 wt% of CR, respectively [38]. Onyango M.A., 2009 have extensive project focused on the permanent deformation of asphalt pavement. The research project aims to evaluate existing mechanistic models that predict permanent deformation in asphalt binders by comparing computed permanent deformation to that measured in a full-scale accelerated pavement test. Main keys of the project were abstracted as follow: Six pavement sections were constructed in the Civil Infrastructure Systems Laboratory (CISL) of Kansas State University with six different asphalt mixes. The sections were loaded with up to 700,000 load repetitions of a 22,000lb single axle. The transverse profiles at the pavement surface were measured periodically. For material characterization, asphalt mix samples fabricated in the laboratory, were subjected to dynamic modulus, static creep - flow time, dynamic creep - flow number, triaxial and uniaxial strength tests, repetitive shear at constant height (RSCH) and frequency sweep at constant height (FSCH). The finite element software, Abaqus, was used to simulate and evaluate four permanent deformation prediction models, which are: creep model, elasto-visco-plastic model, viscoelastic model and Drucker-Prager model. The predicted permanent deformation was then compared to permanent deformation measured in CISL for the six of asphalt pavement sections. It was found that, with some improvements, creep and elasto-visco-plastic models could be used to predict permanent deformation in asphalt mixes. The viscoelastic model greatly under-predict permanent deformation, and the Drucker-Prager model with hardening criteria over predicts permanent deformation as compared to values measured in CISL [39]. Malomo et al., (2023) investigated the production and characterization of asphalt modified with waste rubber. Asphalt matrix and rubber granulates were blended in different ratiosas follows; asphalt/ rubber (100/0), asphalt/ rubber (70/30), asphalt/ rubber (60/40), asphalt/ rubber (50/50) and asphalt/ rubber (40/60). All the samples were subjected to physico-mechanical test and FTIR characterization. The results showed good improvement in the properties of asphalt after addition of rubber [40].

Materials and Methods

Materials

To evaluate the influence of adding rubber (CR) and plastic waste (PE) on the properties of the asphalt matrix, different contents of crumb rubber with PE waste mixture were added to the asphalt grade 60-70 at (5, 10, and 15 wt%). The physical properties of asphalt such as softening point and penetration tests were evaluated. Furthermore, the mechanical properties of pure and modified samples, including Marshall Stability was also studied. The materials used were aggregate, asphalt matrix, filler, and additives.

Aggregates The aggregate used in this study contains coarse aggregate, fine aggregate, and filler. The physical properties of crushed aggregates have been presented in the appendixes.

Asphalt An asphalt matrix of 60/70 penetration grades was used in the study. It is used in road works in Libya. Refinery providing asphalt used in this study is Wesal company for asphalt and waterproof in Libya. The physical properties of the used asphalt were identical to the AASHTO standard specifications for roads.

Table.1: Properties of asphalt used in this study.

Properties	Method	Result	Range
Penetration (0.1mm)	AASHTO(T49)	64	60-70
Ductility (cm)	AASHTO(T51)	>100	>100
Softening point (ºC)	AASHTO(T53)	52	35-70
Flash point (ºC)	AASHTO(T48)	180	180-200

Rubber granulates: The rubber granulate (RG) was obtained from the grinding process of scrap car tires with a particle size ranging (0.20– 0.80 mm) as shown in Figure . 10 it was supplied by Orzeł company in Poland. While, SEM of RG, as well as raw rubber granulates are shown in Figure .11 and .12, respectively.

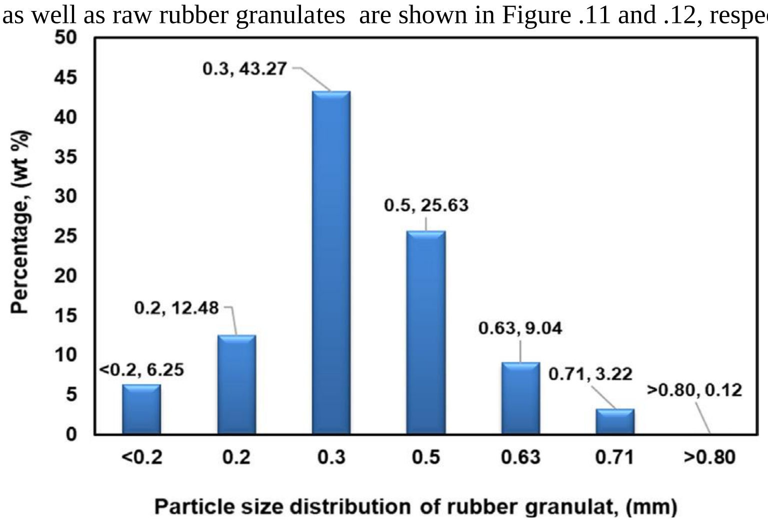

Figure .10: The particle size distribution of rubber granulate used in this study [41].

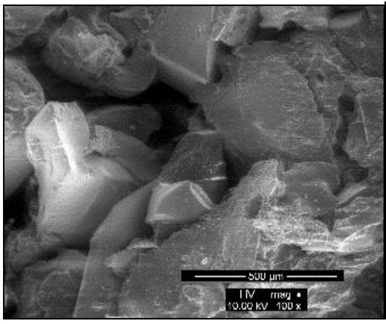

Figure .11: The SEM image of rubber granulate , Figure .12: Raw rubber granulates extracted from used tires.

Plastic waste

In this study, plastic bages waste of low denstity polyethylene (LDPE) was collected from the environment, then cleaned, cutting and used as addtives with rubber. The percentage of LDPE waste was kept constant at 5% during the whole process of asphalt modification

Methods

Modification Process of Asphalt Mixture

Samples preparation

In this study, modified asphalt with rubber granulates and Polyethylene was prepared as follows: the preparation steps started with keeping the neat asphalt in an oven at about 165±5°C for 60 min. Next, 400 g of the asphalt was added to the asphalt open batch reactor using a mechanical stirrer with an initial mixing speed of about 2000 rpm, followed by the addition of modifiers contained rubber granulates and a small pieces of plastic waste at percentage ratios of 5, 10, and 15 wt%. After addition of all amount of the modifier, the mixing speed of 2000 rpm was take place for 1 hr. Weight fractions of combined modifiers was kept at 95 wt% of rubber to 5 wt% of PE. Finally, all modified samples of the asphalt binders as well as neat asphalt tested according to the Libyan standard. The blending process of asphalt mixture with rubber and PE is presented in Figure 13.

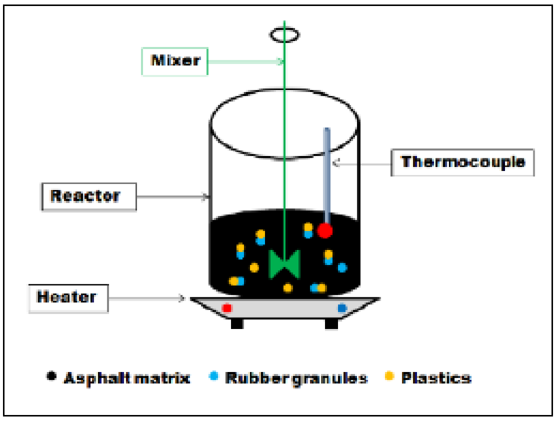

Figure 13: Asphalt modification process.

Physical Properties of Asphalt

Softening Point Test

Ring and ball softening point test was carried out on all samples according to the AASHTO (T53). In this test, disks of the samples were cast in shouldered rings, and then the sample were trimmed to remove excess asphalt. Next, samples were placed in a rings holder and immersed in water bath, Then the special rings were placed on the samples (placed in rings) and bath was heated at a constant rate of 5°C min^{-1}. When the samples surrounding the balls touched the bottom plate of rings holders, the softening temperature of asphalt was recorded as shown in Figure .14 [3].

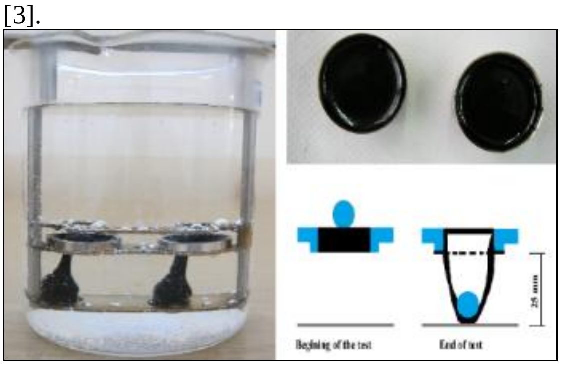

Figure .14: Softening point test.

Penetration Test

The penetration test was conducted according to the Libyan Standard. In this test, the asphalt samples were initially thermo-stated in a water bath at 25°C for one hour, after that the penetration of a standard needle is allowed to penetrate vertically into each sample was measured, under a specified load of 100 g and loading time, and the measured value is reported in units of 0.1mm. [42]. Figure .15 simply shows the asphalt penetration test


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Figure 15: Asphalt penetration test.

Storage Stability Test

Storage stability of the binders was tested according to Libyan standard test. The test was carried out as follows: each sample of the studied product was separately poured into an aluminum tube of 37 mm in diameter, 173 mm in height, and sealed. Next, it was stored vertically at 180 ± 5°C for 72 hours. Then, the tube was subjected to freezing at 5ºC for a day to completely solidify. Finally, the tube was cut horizontally into three equal parts. The top and bottom ends of the tubes were then melted into separate small beakers and analyzed for its penetration method. The good storage stability of the sample implies that the difference between penetration value of the top and the bottom parts of the tube could be less than or equal to 5 (0.1mm). Storage stability is considered a very important parameter for initial properties on modified asphalt, especially for transportation.

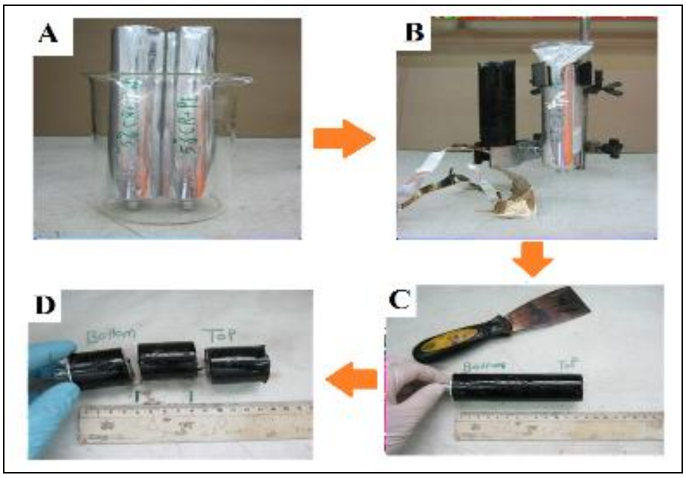

Figure 16: Steps for storage stability test adopted from the work [3].

Ductility Test

The ductility test was conducted according to (AASHTO:M20) [42]. It provides a measure of tensile properties of asphalt materials. Simply, it measures asphalt binder's ductility by stretching a standard-sized briquette of asphalt binder to its breaking point at 25ºC. The stretched distance in centimeters at breaking is then called as ductility. The main characteristics of the test are known with a number of facts including:

1. modified asphalt's indirect resistance to tension,
2. change of length in modified asphalt at a rate of 5cm/min,
3. it is conducted with constant temperature of 25ºC.

Mechanical Test (Marshall)

Stability represents the maximum load required to produce specimen's failure when load is applied at a constant rate [43]. Figure 17 show the main stages of Marshall stability test.

Figure 17: Show the main stages of Marshall stability test.Thermo-gravimetric Analysis (TGA)

Thermo-gravimetric analysis (TGA). Thermo-gravimetric analysis is used to study the general behavior of thermal degradation of materials [3]. Thermo-gravimetric analysis were performed on a TA instrument (SDT Q500) operating under nitrogen gas with a flow rate of 50 cm^3/ min through a furnace. Samples were about 10 mg in weight, varying the heating rate of 20ºC/min and temperature range of 20 - 600ºC.

Experiment 1, the modification process of asphalt by rubber-plastic waste was conducted as follows: 1000 g of pure asphalt was kept in the oven at 180ºc for about 120 min. Then, 400 gram of the hot asphalt added to the reactor at 165ºC, with an initial mixing speed of 2000 rpm, followed by the addition of 5 wt% of modifier for 60 min, a final product with the softening point and penetration values were found to be 54.2ºC, and 54 (0.1mm), respectively.

Results and Discussions

Experiment 1, the modification process of asphalt by rubber-plastic waste was conducted as follows: 1000 g of pure asphalt was kept in the oven at 180ºc for about 120 min. Then, 400 gram of the hot asphalt added to the reactor at 165ºC, with an initial mixing speed of 2000 rpm, followed by the addition of 5 wt% of modifier for 60 min, a final product with the softening point and penetration values were found to be 54.2ºC, and 54 (0.1mm), respectively .

Experiment 2 If, use content level of 10 wt% of rubber-asphalt, and everything else being equal, in experiment 1, a final product with the softening point and penetration values were obtained to be 57.7ºC, and 51 (0.1mm), respectively.

Experiment 3 If, use content level of 15 wt% of rubber-plastic waste, and everything else being equal, in experiment 1, a final product with the softening point and penetration values were obtained to be 64.8ºC, and 47 (0.1mm), respectively. Pure and modified asphalt samples are presented in Figure 18. The results of the effects of these three contents of modifier on the softening point (SPT) and penetration test, respectively of the modified asphalt were represented in Table .2.

Figure 18: Represent pure and modified asphalt binders.

Characteristics of Asphalt Binders

Physical Properties

Based on the results obtained, it was noted that modifier significantly affects the asphalt stiffness and elastic properties. Penetration of studied specimens was reduced by increasing modifier content. It is decreased to 63, 57, and 50 (0.1mm) for adding modifier of (5, 10, and 15 wt%), respectively. The reason is due to the interaction between rubber-plastic additive and asphalt binder. In addition, the adsorption of the maltene phase by crumb rubber particles increases the asphaltene part of the asphalt and causes swelling through the blending process. Furthermore, the crumb rubber particles stiffness is more than bitumen. Hence, increasing the crumb rubber content leads to increased stiffness [42, 3, 44]. Also, an increase in the softening point, which represents the temperature at which asphalt reaches softening, was observed. It is increased to (54.2, 57.3, and 63.8ºC) when adding (5, 10 and 15 wt%) crumb rubber-plastic waste, respectively. This increase in SPT with increase in the content of additives was as a result of the internal structure formed by rubber-plastic waste which seemed to be thermodynamically unstable and thus has affected the softening point of pure asphalt, as pointed out in literature [27]. This can be an indicative the good performance to permanent deformation. Similar results were obtained in the study [27,41, 3, 44,45].

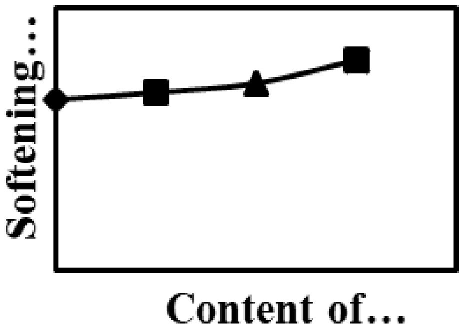

Figure 19: The effect of rubber-PE waste content on the softening point.

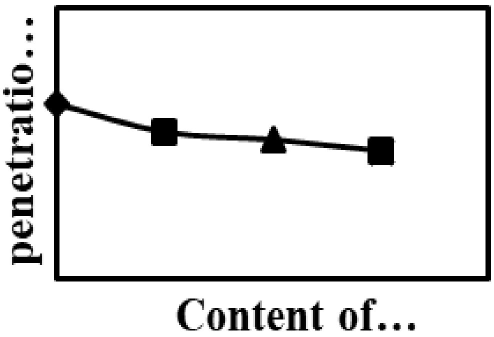

Figure 20: The effect of rubber-PE waste content on the penetration.

Ductility

The ductility of the modified asphalt with only 10wt% rubber-plastic and pure asphalt samples as shown in Table 2 indicated that pure asphalt has the highest ductility value followed by sample with 10 wt% waste-rubber-plastic waste composition with values of 117cm and 100cm, respectively. From the ductility test, the result established that the asphalt will harden as the waste rubber-plastic mature is added. Thus, the waste additive will be highly important in achieving stiffer asphalt when the hardness and viscosity increases, that is, as it becomes more harden and viscous in nature. This result agreed with the ductility test carried out on asphalt-rubber reported in the previous studies [43, 3,44, 41]. Increase in substitution of rubber with bitumen causes increase in viscosity, it becomes harder and stiffer. The reason may be the reduction of oily materials in bitumen because of their absorption by the small rubber particles leading to a toughness increase resulting in less ductility with an increase of rubber content, in addition to an increase in the mass of the rubber particles. Accordingly, increasing the asphalt binder mass can increase the binder flexibility, toughness, and resistance to cracking. It is worth noting that the modified asphalt becomes thicker than the original asphalt sample [44].

Marshall Test

Stability represents the maximum load required to produce specimen's failure when load is applied at a constant rate. Marshall stability value of modified asphalt with 10 wt% rubber-PE waste was measured higher than 600 kg which is lower limit value according to Libyan highway construction specifications. It is noted that it is increased by about (5%) when modifier is added by (10 wt%). However, the value of Marshall's stability at this ratio of modifier satisfy the specifications for the maximum stability value [43]. The increase is due to the increase in the viscosity of modified asphalt, which consequently increases the bonding force between the aggregates and asphalt at high temperatures. Since the stability is primarily affected by the internal friction of aggregates and the viscosity of asphalt, the addition of modifier will improve the mechanical properties of the asphalt mixture [44]. Table 2 shows physical and mechanical properties including softening point test and penetration values of asphalt mixture.

Table 2: Physical and mechanical properties of asphalt binders.

Amount of modifier	Physical and mechanical properties of the samples				
	Softening point, (oC)	Penetration, (0.1mm)	Ductility (cm)	Flash point (oC)	Marshall stability, (kg)
(0.0 wt%)	52	64	117	180	700
5 wt%	54.2	54	----	---	----
10 wt%	57.1	51	100	296	767
15 wt%	63.8	47	----	---	----

Thermal Analysis (TGA)

TGA for Rubber Granulates

Thermal stability of the rubber is evaluated based on percentage weight loss at increase temperature. Figur20 presented the TGA-DTG curve of rubber granulate. From the figure, it can be seen that there was no weight loss percentages until a temperature has reached 370ºC. Beyond this point, increasing temperature there was a two sharp weight loss around 400ºC and 437ºC, respectively. Therefore, at the hot mix asphalt process; that was 165-170ºC, there would be neither chemical nor structural modifications to occur by heating. However, the main goal of using TGA analysis of rubber granulate is to identify the thermal stability of rubber (maximum temperature could be used in the modification process of asphalt).

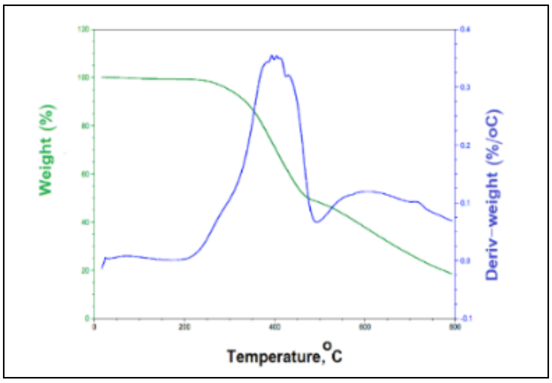

Figure 20: TGA of rubber granulates

TGA for Asphalt Binders

Thermal stability of the modified asphalt mixture is evaluated on the basis of percentage weight loss at different temperatures from TGA thermo-gram and compared to that of pure asphalt. The thermo-gravimetric curves of the pure asphalt and modified asphalt with only 10 wt% are shown in Figure 4.5. From the figures, it can be seen that the decomposition of samples has similar trends. There were no weight loss percentages for the samples until a temperature of 340°C. However, there was a sharp weight loss percentage only around 380°C, which then reached completion at a temperature of approximately 400°C. The residue weight of about 7% of the total weight of the pure asphalt sample is recorded at 475°C. Whereas, the residue weight, which remained at the temperature of 500°C for the modified asphalt, was little higher; it was recorded at of about 20%.

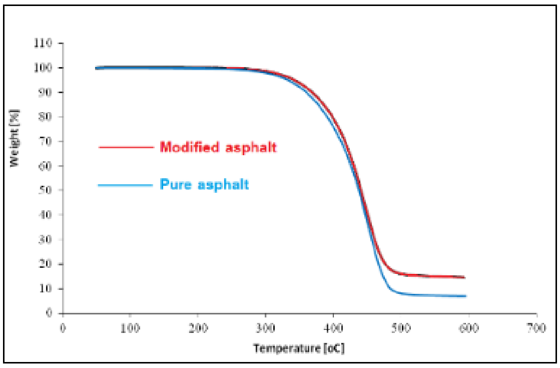

Figure 21: TGA of pure and modified asphalt binders.

Conclusion

Based upon the experimental results of this research work, the following main conclusions were drawn:

1. **The results** of the study show that rubber granulates extracted from scrap tires without any previous use of chemical treatment can be successfully applied as asphalt additive.
2. Content levels of additives were playing the major factor on the asphalt modification process.
3. Ductility of modified asphalt decreased from 117cm for pure asphalt to 100cm, for modified asphalt with 10 wt% (95% rubber and 5 wt% PE).
4. Physical properties of modified asphalt including softening point and penetration test were improved by addition of rubber-PE additives.
5. Marshall stability value of modified asphalt with 10 wt% rubber-plastic waste was measured higher than 600 kg which is lower limit value according to Libyan highway construction specifications.
6. Thermal stability by using TGA technique showed a good result stability of modified asphalt with 10 wt% of rubber-PE mixture (95% rubber and 5% PE) compared to the pure asphalt mixture.

Recommendations

The main recommendations were listed as following:

1. To investigate the effect of more content levels of rubber – plastic additives on the physical properties of asphalt binders.
2. To investigate the effect of different types of plastic wastes such as polypropylene (PP), polyvinylchloride (PVC) on the physical and mechanical properties of asphalt mixture.
3. To investigate the rheological properties of modified asphalt binders.
4. To investigate the life cycle cost of modified asphalt and unmodified aspalt binders.

5. To evaluate the effect of different condition of modification process on the properties of asphalt mixture, including modification temperature and time.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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