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New Study on Improved Performance of Paving Asphalts by Crumb Rubber and Polyethylene Modification

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Abstract

Conversion of Crumb Rubber Tires (CRT) and waste plastics to functional materials has been shown in this research study as a feasible approach for the improvement of some physical properties of asphalt. The rheological study of the modified asphalt is made through softening point temperature, penetration point, and viscosity tests.

In the present study, CRT and Low Density Polyethylene (LDPE) (plastic wastes) were chosen to be the materials of choice to blend with the virgin asphalt. The reclaimed rubber in the form of powder having a particle size below 0.8 mm was used as an additive to liquid asphalt using the Hot Mix Asphalt Process (HMA) at 180.0 ± 2.0°C with a high-speed stirrer rotating at a speed of 3000 rpm for 60 min. For a consistent mix, the blending operations were performed with different CR and LDPE contents; they were 3.0%, 5.0%, 10.0% and 15.0% by weight. LDPE-CR composite was also added to the virgin asphalt at 1:1, 1:1.5, 1:2, and 1:3 ratios. The results of this research study have indicated that these modified asphalt patterns are characterized by having softening point temperatures and penetration points leading to suitable Penetration Indexes (PI) in comparison with virgin asphalt binder. The viscosity of virgin asphalt was also enhanced with the addition of additives. Best results were obtained when CR, LDPE, and CR-LDPE composite concentrations were attained below 10.0% with most at 5.0%. Determining the number and identities of components in the modified asphalt mixture by Thin Layer Chromatography (TLC) and phase distributions of micrographs from Scanning Electron Microscopy (SEM) was also studied.

Keywords: Low density polyethylene; Crumb rubber tires; Hot mix asphalt; Scanning electron microscopy

Introduction

The global problem with land disposal of automobile tires and plastic substances can only be solved by the feasible option left, and that is recycling and utilization of the recycled products. Besides, It is thought that the application of recycled automobile tires and plastics will not only solve the environmental of these industrial solid wastes problem, but also act as very promtising modifiers for the improvement of some materials` engineering characteristics such as asphalt pavement material [1,2]. Modifications of asphalt are attempts to extend the service life and improve the performance of asphalt pavements [3] thus will be definitely of a great environmental and economical advantage.

Asphalt is a thermoplastic material of hydrocarbons including parafinic, saturates, aromatics, resins, and graphitic asphaltenes [4-6]. It is widely used as a very effective binder for mineral aggregates to form asphalt mixes of pavement construction materials [7]. It is known as brittle and hard at a cold weather and soft at a hot weather.

Designers, when construct pavement roads, usually consider the major failure modes represented by fracture and permanent deformation of the asphalt. It is thought that the failure happens due to four different types of distresses [8]. Rutting is one type which occurs due to high temperature conditions, where strain accumulates in the pavement and permanent deformation takes place. Deformation results as a formation of ruts (tracks) on the surface of asphalt pavement (Photo 1). Heavy loads at low frequencies and/or high temperatures are the major cause of such failure. While, fatigue is observed due to the cyclic load of vehicles (especially heavy trucks) until it is cracked (Photo 2). This is often reduced by early repair planning. Moisture damage is another type which happens due to the lack of adhesion and cohesion between the asphalt cement and the aggregate and sand fractions. In presence of water, as asphalt is hydrophobic by nature and aggregate is not, the asphalt mastic can let go of the aggregate and sand fractions. Finally the thermal cracking that takes place mainly due to the exposure of the road to extremely low temperatures where thermal stresses exceed the strength of the materials. Frequent and long term low temperature exposure during winter can lead to physical hardening of the asphalt.

Photo 1: Severe ruts in an asphalt pavement, (by researcher camera, 10th sept. 2013).

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Thermal cracking also happens due to repeated thermal stresses below the design limit and this is called thermal fatigue cracking (Photo 3). Another reason for thermal distress is the repetitive loading by heavy traffic during the freeze-thaw cycle in early spring. They thought to represent a number of famous failure characteristics causing asphalt`s quality and performance in pavement of roads to decrease [9].

A high performance pavement requires asphalt cement that is less susceptible to high temperature rutting or low temperature cracking, and has excellent bonding to stone aggregates [10,11]. However, in pavement construction application, as aforementioned asphalt by itself often cannot meet optimum performance requirements. Therefore, approaches to circumvent the problems encountered have been developed. One common approach of modifying the properties of virgin asphalt in the past years is by blending with synthetic polymer binders [6,10]. The modification of asphalt concrete, with the incorporation of synthetic polymer binders can be considered as a solution to overcome the problems arising with the rapid increase in wheel loads and change in climatic conditions. Polymer modification can be considered as one solution to improve life fatigue, reduce the rutting and thermal cracking in asphalt road pavement [12,13]. However, asphalt, when blended or mixed with a polymer, forms a multiphase system, containing abundant asphaltenes which are not absorbed by the polymer. This increases the viscosity of the mix by the formation of a more internal complex structure [14]. Besides, the utilization of synthetic polymers usually increases the cost of asphalt [15]. The most common and globally used polymers include approximately 75% elastomeric modified binder, 15% plastomeric and the remaining 10% belongs to either rubber or other modifiers [16]. In this case, Plastic wastes present in many types of solid materials (i.e. water bottles, carry bags, wrappers of biscuits and detergents, etc.) combine the advantage of reducing cost as well as management problem for asphalt industries and producing better asphalt pavement [17,18]. Further, polyolefin's such as Polyethylene (PE) comprise 60% of these plastic wastes. Therefore, it is apparent that polyethylene would be more economical and effective in asphalt paving than other polymeric materials [15]. However, not all plastics wastes are compatible with the asphalt matrix [18]. PE has some difficulties as an asphalt modifier, e.g. intensive phase separation under quiescent condition, its disastrous effects on low-temperature properties of asphalt and its inertness with respect to fatigue properties of asphalt binder [19]. The major approach to solve this shortcomings PE should be accompanied with other materials like CR for asphalt modification [20,21].

In general, rubber as a polymer is a thermosetting material cross linked to processing and molding, however, it cannot be softened or remolding by re-heating unlike other types of thermoplastics polymer which can be softened and reshaped when heated. The major approach to solve this issue is the recycled and the reuse of waste tire rubber and the reclaim of rubber raw material [22]. In terms of performance of modified asphalt binders with rubbers, pavements consisted of such blends were found to achieve a number of advantages. The incorporation of CRT into the asphalt binder would cause the asphalt to possess ductility and crack resistant characteristics [23,24]. Improved asphalt characteristics also include resistance to rutting due to high viscosity, high softening point and better resilience, reduction of temperature susceptibility [25]. Some other studies also have shown that the blending of CRT with asphalt would improve also the resistance to permanent deformation, fatigue failure, and thermal cracking [26]. Finally, as to cost side, the service life of the roads is also extended due to reduction in road pavement maintenance costs, when rubbers-asphalt blends are used [25].

Although, the literature regarding the use of either recycled PE polymer (found in plastic wastes) or CRT separately as asphalt modifiers is very extensive, very few studies deal with the combined use of two different modifiers. In this research study, it is intended to investigate the effects of incorporating different amounts of an admixture of (CR/LDPE) on the asphalt as compared to single pure CR and LDPE blends to optimize the asphalt rheological properties. The rheological study of the final modified asphalt is made through softening point, penetration point, and viscosity tests.

Experimental Studies

Raw materials preparation

LDPE (18 - D003) was supplied by Brenntag company in Poland, asphalt of penetration grade (70/100) from a Russian crude oil company with specification shown in Table 1, CRT were obtained from Polish used car tires (CRT), Lotos (Poland) and free from steel, fibers and any

Photo 2: Fatigue cracking in road surface, (by researcher camera, 10th sept. 2013).

Photo 3: Longitudinal and transverse cracks due to thermal effects, (Taken by researcher camera, 10th sept. 2013).

Virgin asphalt	P.P. (25 °C/0.1mm)	S.P.T. (TR&B/°C)	Saturates (wt%)	Monoaromatics + naphthenic/ aliphatic-aromatic	Aromatics + polyaromatic (wt%)	Resin (wt%)	Asphaltene
70/100	65	47.7	8.2	16.7	33	21.8	20.4

Table 1: Physical properties and fraction content of asphalt.

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foreign contaminant in the rubber tire. Its size of particles was below 0.8 mm. Finally, Toluene as a solvent was purchases from Puch Company in Poland.

Experimental procedures

A weight of asphalt binder (600-700) g was poured into a metal container of one liter and placed on a hotplate fitted with a homogenizer (T50 model, IKA, Germany) at 3000 rpm. The sample was heated with vigorous speed until reaction temperature of asphalt reached 180 ± 2°C. This followed by the addition of various weight ratios of composite material produced by the use of an extruder machine. The composite material was made of a blend of CRT and LDPE to the melting asphalt binder.

Instrumentation involved in the analysis

The softening point (ring and bell test) was carried out to all samples according to ASTM D36-76. In this test, disks of asphalt were cast in shouldered rings. Then the disks were trimmed to remove excess of asphalt. Next, the disk was heated at a constant rate (5°C/min) in a water bath using a special apparatus.

A penetrometer, of PNR12 model (Germany made), was used to measure the penetration point according to ASTM D5-73. In this test, the sample (the virgin and the modified asphalt) was initially thermo-stated in a water bath, and then the penetration of a standard needle under a total-standard load (100 g) into each sample was measured and reported in 1.0 over 10.0 of mm.

The viscosity properties of asphalt samples were determined by a rotational viscometer (Model viscotester 2 Plus, HAAKE Inc, Germany) according to ASTMD 4402. The equipment was used to measure the viscosity characteristics of the virgin asphalt and modified asphalt (CR, LDPE, and an admixture of CR/LDPE). This test determined whether the additives decrease the viscosity of the modified asphalt used in the study, which consequently depends on the percentage quantity of the modifier (CR, LDPE, CR/LDPE) in a quantitative percentages of 3.0%, 5.0%, 10.0%, and 15.0%.

The Thin Layer Chromatography or TLC on rods chromarods S II (silica gel) coupled with flame ionization detector-TLC-FID (Analizator Latroscan, Latron Labs, Japan) used for the analysis of the modified asphalt with the additives by separating the compounds in the mixture. TLC was used to help determining the number and the identities of components in the modified asphalt mixture. TLC consisted of three main steps: (i) Spotting, where the asphalt mixture was dissolved in a 0.01 g/ml di-chloromethane solvent and the additive powder left over was filtered from the liquor, (ii) Development involved placing the bottom of the TLC plate into a shallow pool of a development solvent, which then let to travel up the plate for a certain time, where it reached the highest point. Thereafter, the procedure was stopped for the next step, (iii) Visualization of the compounds was carried out using the FID with a hydrogen volumetric flow rate of 150 ml/min, air volumetric flow rate of 1.8 L/min with an injected volume at 1 µl.

Microscopic Behavior of modified Asphalt Blend samples was observed using a scanning electron microscope (JSM-5610, model E-3) to examine sample of modified asphalt blends phase distribution. The structural formation of asphalt samples was recorded using a camera connected to the SEM. The SEM power was 0.5 keV and the magnification ranged up to 250 (Photo 4).

Results and Discussion

The results and effects of mixing PE, rubber (from CRT) as single additives and admixture of CR/PE with different ratios (3.0%, 5.0%, 10.0% and 15.0%) on some rheological properties of the asphalt such as Softening Point Temperature (SPT), Penetration Point (PP) and viscosity are measured respectively.

In this research study, the polymer was used in form of particles while it was added directly to the asphalt in order to substantially modify and improve the rheological properties of the virgin asphalt. When such modified asphalt binder is blended with gravel, it produces a very durable surface with more sustainability, less affect by temperature variations, lessening the vibrations and impacts as roads subjected to heavy traffic in terms of volume and loading [27].

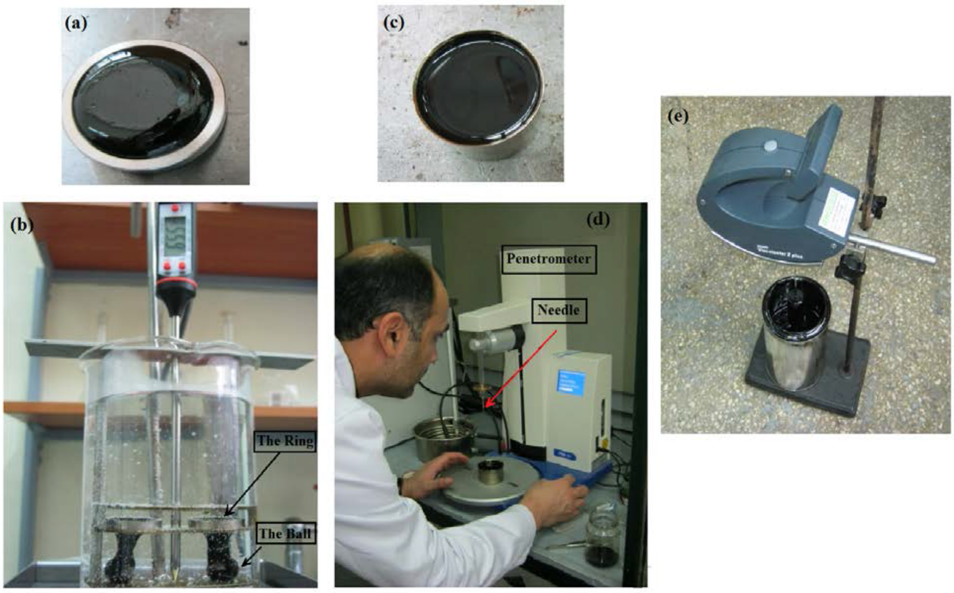

Photo 4: (a) preparation of a ring filled with the sample; (b) the procedure of the ring and bell test for measuring STP; (c) a canister filled with the sample for measuring the PP; (d) Penetrometer device used for measuring the samples; (e) a viscometer device.

Softening Point Temperature (SPT)

The softening point test is the measurement of temperature at which the substance attains a particular degree of softening under specified condition of the test [28]. Blending of CR, LDPE separately as single additives and an admixture of them of 3:1 and 2:1 ratios respectively in dose percentages of 3.0%, 5.0%, 10.0% and 15.0% has been carried out. A considerable variation was obviously attained at 10% of both CR and LDPE in their respective ratios, and therefore the investigation was further extended and carried out to include 1.5:1 and 1:1 ratios of same additives (Table 2). The results of the effects of these four additives on the SPT of the modified asphalt were represented in Figures 1 and 2.

Figures 1 and 2 show that there are no great differences in the SPT for modified asphalt up to 3.0% concentration of all additives (single pure CR, single pure LDPE, admixtures of CR:LDPE in ratios of 3:1 and 2:1) in asphalt as compared to the virgin asphalt (0.0% additives). It can be observed obviously that the SPT of the modified asphalt was increased considerably with the increase of percentages of the additives over 5.0%. For instance, it was increased from initial SPT of virgin asphalt equaled to 47.7°C to 56.5°C at 5.0%, then 70°C at 10.0% and finally reached 98°C at 15.0% of single pure LDPE additive. This large increase in SPT with increase in LDPE concentrations was as a result of the internal structure formed by LDPE which seemed to be thermodynamically unstable and thus has affected the S.P. of virgin asphalt, as pointed out in literature [28]. This can be an indicative the good performance to permanent deformation.

However, CR modified asphalt has shown as expected better results (Figure 1) in concern to S.P., which may be attributed to the close chemical similarities between CR and the asphalt that both of them are hydrocarbonous materials provide a high attraction and strong bonding among the molecules of both CR powder and asphalt binder. Besides, the small particle sizes of the rubber powder (< 0.8 mm) and their softness were also factors may contribute to the bonding between both CR and asphalt since provides a higher surface area. As a result, this will offer the final modified product with resistance in terms of permanent deformation (rutting and cracking), fatigue and temperature resistance [29].

Remarkably, a close relation in terms of their affect on SPT property of the modified asphalt can be observed when adding CR:LDPE in a ratio of 3:1 as an admixture additive to the virgin asphalt (Figure 2). However, the increase in the amount of LDPE in the admixture of CR/LDPE (from 3:1 to 2:1) seemed to be the responsible for increasing the SPT of the modified asphalt which was further confirmed when increasing the amount from 1.5:1 ratio to 1:1 ratio at 10% amount. Consequently, this may cause an adverse effect, e.g. less resistance to permanent deformation. The rate of STP increases by CR/LDPE in a ratio of 2:1 was in a higher mode reaching 70.0°C at 15.0% ratio than the admixture CR/LDPE of a lower amount of LDPE (3:1). The lowering in the amount of LDPE is more favorable when the least variation of SPT for CR/LDPE modified asphalt is needed to accomplish. Such fact is corroborated by [28] when they investigated the rheological properties of modified asphalt by the use of LDPE, HDPE and polypropylene.

Additive	Softening point Temperature °C			
(%)	LDPE	CRT	LDPE : CR 1:02	LDPE : CR 1:03
3	53	50.3	49.8	49.5
5	56.5	51	52	50
10*	70	57	62.3	53
15	98	59	70	60
Additive	LDPE : CR		LDPE : CR	
(%)	1:01		01:01.5	
10	65		63	

*The most noticeable additive percentage with a clear cut differentiations in SPT rate of increase

Table 2: Results of SPT of modified asphalt by different ratios additives.

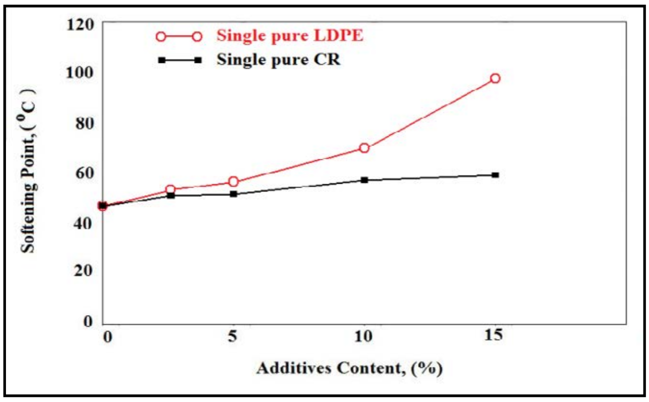

Figure 1: Relationships between SPT v.s contents of a pure LDPE, and a single pure CR.

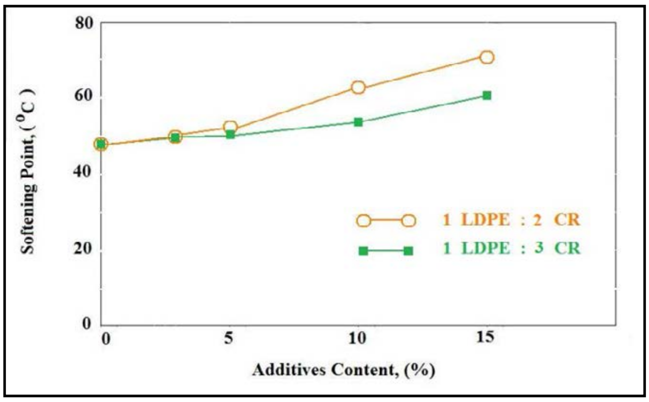

Figure 2: Relationships between SPT v.s CR: LDPE admixture content in two different ratios.

CR is believed to be more effective in a way that influences the blending process in two ways. The small particle size of the CR has probably achieved a good dispersion. In addition, as the particles size of CR are very small, this means they have a large surface area per unit mass of polymer which also means penetration of the asphalt and swelling of the CR is facilitated, and thus more rapid dissolution is completed. Semi powdered CR will therefore disperse and dissolve more rapidly than porous pellets [30]. The benefit of using CR with asphalt binders include improved temperature susceptibility, reduction in reflective cracking of the pavement, noise reduction and reduce propensity for failure at low pavement temperature [31].

Penetration Point (PP)

The PP test is considered as the most widely used method of measuring the consistency of the asphalt material at a given temperature. It is a means of classification rather than a measure of quality [28,32,33].

The effects of CR and LDPE shown in Figures 3, 4 and Table 3 as single pure additives and both CR and LDPE as admixture additives of 3:1 and 2:1 ratio respectively on the PP of the modified asphalt. From the Figures 3 and 4, it can be observed obviously that penetration was decreased continuously from 65 dmm as an initial value of virgin asphalt (0.0% additives) to 30 dmm, 40 dmm, 36 dmm, and 46 dmm at the final 15% dose of each aforementioned additive respectively.

In spite of the findings, considering the least percentages of additives which profoundly achieved an early differentiation in penetration was at less than 3.0% of both pure single additives of LDPE and CR (Figure 3) and at approximately 5.0% for an admixture of both CR:LDPE in a ratio of 3:1 and CR:LDPE in a ratio of 2:1 (Figure 4). This result was conforming with the results of another work dealing with the investigation of PP and SPT in regard to effect LDPE and HDPE and polypropylene additions to virgin asphalts [28]. The authors concluded that the addition of such additives usually accompanied with the decrease in PP while SPT is usually increased (an inverse relationship).

Next, penetration in all cases continued to decrease almost in equivalent rates until 10.0% additions. However, as the dose percentage of additives were further increased (> 10%), one can obviously observe a semi-sharp decline in a higher rate in penetration with the addition of CR:LDPE admixture in a ratio of 2:1. While a steady decrease in a slower rate of penetration was dominant at the addition of CR:LDPE admixture in a ratio of 3:1, making it more favorable. The lower values shown by penetration as CR content increases indicate that the asphalt binder becomes stiff and more viscous [34]. Likewise, it seemed over again that the increase in the amount of LDPE known with stiffness effects in the admixture of CR/LDPE (from 3:1 to 2:1) would be responsible for the high decrease in PP comparing to the flexibility effects of CR. This was conforming with the results of single pure addition of LDPE to the asphalt (Figure 3).

Additive	Penetration point, (0.1mm)			
(%)	LDPE	CRT	(PE : CR)	(PE : CR)
			1:02	1:03
3	41	49	58	61
5	38	48	43	51
10	35	43	41	48
15	30	40	36	46

Table 3: Results of PP of modified asphalt by different additives.

Penetration index

Table 4 demonstrates the well known fact that whenever the softening point temperature of particular asphalt type is increased, the values of penetrations points is however decreased [35], emphasizing the reduction in temperature susceptibility of the asphalt blends. The consistency of those types of modified asphalt material with increased SPT and decreased PP and so is the temperature susceptibility certainly would provide those types of modified asphalts with preference in road construction at countries of high temperature weathers such as some of the Arabic countries, and also in different industrial applications.

Penetration Index (PI) test is known as the distance in tenth of a millimeter (0.1 mm), which a standard needle would penetrate vertically, into a sample of a material (i.e., asphalt) under standard conditions of temperature, load and time. And it is another way of looking at the temperature susceptibility of the asphalt as described by Pfeiffer and Van Doormaal. Some authors stated that it is the measure of asphalt behavior deviation from Newtonian to non-Newtonian. Asphalt usually have values between +1 and -1 for road construction, while the asphalt with values less than -2 shows Newtonian behavior with brittleness at lower value and those greater than +2 are less brittle, exhibiting high elastic properties under higher strains [36].

Using the PI nomograph shown elsewhere [36], it was predicted that PI values for all the additives at an amount of 5.0% are laying between -1 and +1. These modified asphalts with such obtained values would proves that, the modified asphalt are less sensitive to temperature

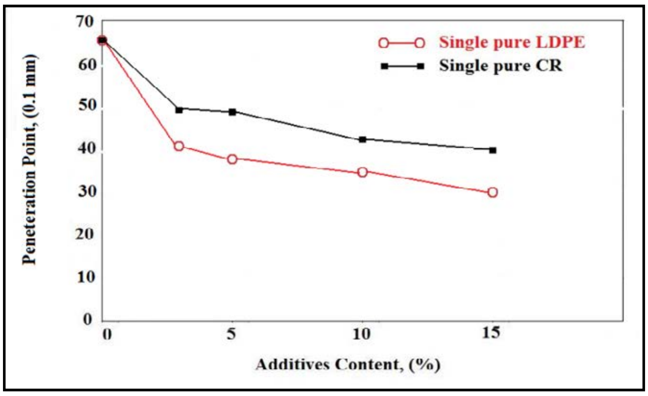

Figure 3: Relationships between PP v.s contents of a single pure LDPE, and single pure CRT.

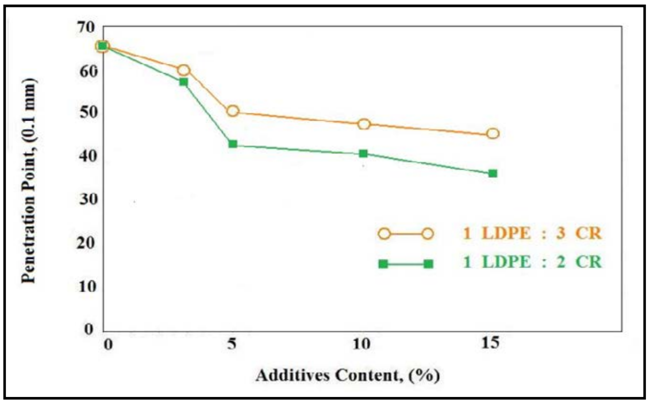

Figure 4: Relationships between PP v.s CR:LDPE admixture content in two different ratios.

Additive (%)	Single pure			Single pure			(PE : CR)			(PE : CR)		
	LDPE			CRT			1:02			1:03		
Test value	SPT	PP	PI	SPT	PP	PI	SPT	PP	PI	SPT	PP	PI
3	53	41	-0.9	50.3	49	-0.9	49.8	58	-1	49.5	61	-0.6
5	56.5	38	-0.5	51	48	-1	52	43	-1.2	50	51	1.1
10	70	35	2	57	43	0.9	62.3	41	0.8	53	48	-1.1
15	98	30	5.2	59	40	0.5	70	36	2.2	60	46	0.7

Table 4: The PI values in respect to the SPT and PP values.

Viscosity(dPas)			
LDPE	CRT	PE : CR 1:02	PE : CR 1:03
4	1	0.8	0.56
5	2	4	3
10	6	6	6
16	10	9	8

Table 5: Viscosity as a function of different quantities of CR, LDPE, and CR/LDPE.

than the virgin asphalt resulting in less cracking, at low temperature and less rutting during summer time [37]. However, it seemed that increasing the amount of LDPR in either case (as single pure or as an admixture with CR), caused the PI to exceed the desirable value for pavement construction applications.

Viscosity

Asphalt is identified as a thermo-visco-elastic material where temperature and rate of load application have a great influence on their behavior. At low temperature, asphalt exhibits elastic behavior while at high temperature, it exhibits a viscous behavior. Using the viscometer in testing the viscosity of the modified asphalt, results were obtained and represented in Table 5. The results illustrates that the viscosity of the modified asphalt blend with composite single pure CR, single pure LDPE and the admixtures of CR:LDPE additives in both ratios of 2:1 and 3:1 respectively, was increased as the content of those additives increased (Figures 5 and 6) in a higher manner than the virgin asphalt.

From the graph in Figure 5, it can be revealed that single pure LDPE and single pure CR modified asphalt have shown the most variation in viscosity, meeting the findings in other research data done by [34,38,39]. Moreover, from the graph in Figure 5, it can also be observed that the variation in regard to the effect of single pure LDPE and single pure CR additives on viscosity of the final modified asphalt is apparent at 3.0% of additives.

In contrast, the admixture of CR:LDPE in ratios of 3:1 and 2:1, when blended with the virgin asphalt under the experimental conditions (*ESCO1*), they both showed a less variation in viscosity, which was apparent at 5.0%. As the percentage of admixture additives (of both ratios) increased further to 10.0%, they both resulted in an equal viscosity value of (6.0 Pa s). The subsequent increase in percentage of both admixture additives to the virgin asphalt has led to make a clear variation with a lower rate particularly by the CR:LDPE in a ratio of 2:1. It appears that, the increase in CR quantity within the admixture additive is perhaps responsible for lowering the viscosity of the final modified asphalt product, implying that the CR is the dominant factor in having best acceptable viscosity results. This can be well evident and supported by results illustrated in Figure 5.

It was reported that, as melting temperature of LDPE is 122°C (which is lower than reaction temperature of asphalt (180 ± 2°C), it absorbs some oil from the melted asphalt and releases low molecular weight fraction into the bitumen which increases the viscosity of the polymer modified asphalt [40]. And by the time it cools harden mixture was formed, which can be beneficial as it increases the stiffness of the material, thus the load spreading capabilities of the structure, but also can lead to fretting or cracking [7].

Tine Layer Chromatography (TLC)

In general, it is believed that the asphalt-polymers interaction is of a physical type. When for instance, immersed in hot asphalt, CR particles absorb the component of similar solubility and swell quickly. Comparing the solubility parameters of asphalt components and rubber, it may be expected that, of the asphalt fractions, saturates are the most compatible with rubber. The extension of immersion time enhances the liquefied asphalt to penetrate into the matrix of polymer and swelling increases. The extent of rubber swelling in asphalt varies according to (i) temperature and time of rubber-asphalt contact, chemical composition of asphalt, rubber type, and particle size [31].

Table 6 shows the chemical components of the modified asphalt and their changes in percentages (%) as due to the physical interactions occurred by the additives within the final modified asphalt products. Referring to the above table, it can be observed that the percentage of saturates has been lower in (i) CR-modified asphalt at a percentage

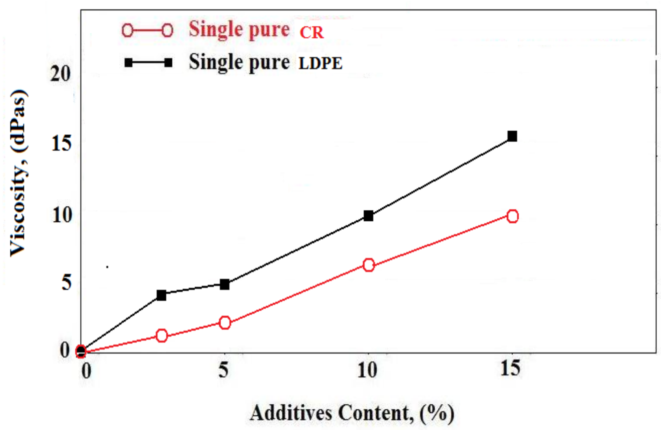

Figure 5: Relationships between viscosity and a pure LDPE, and a pure CR.

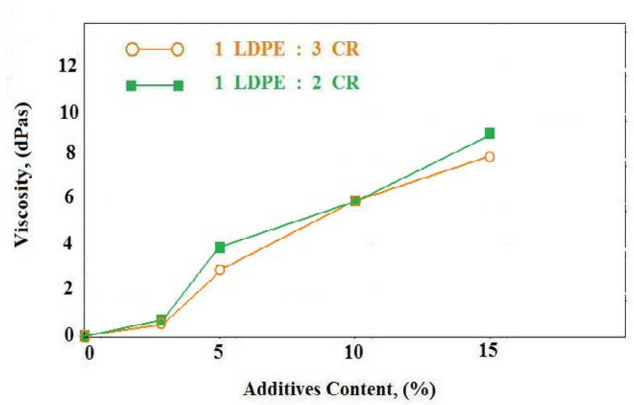

Figure 6: Relationship between viscosity and CR:LDPE admixture content in two different a ratios.

Virgin asphalt	Modified asphalt with							
	CR, (%)			LDPE, (%)		CR/LDPE, (%)		
	3	5	10	3	5	3	5	10
8.2	7.5	7.8	7.1	7.1	10.3	10.9	10.2	8.2
16.7	13.1	15.5	14.7	15.2	23.4	25.9	25.5	21.6
33	25.7	33.4	33.8	34.5	34.3	32.7	34.3	34.8
21.8	26.1	26.4	25.4	20.5	20.3	18.1	17.7	19.2
20.4	27.7	17.6	19.3	22.9	12	12.5	12.3	16.2

Table 6: virgin asphalt and modified asphalt components.

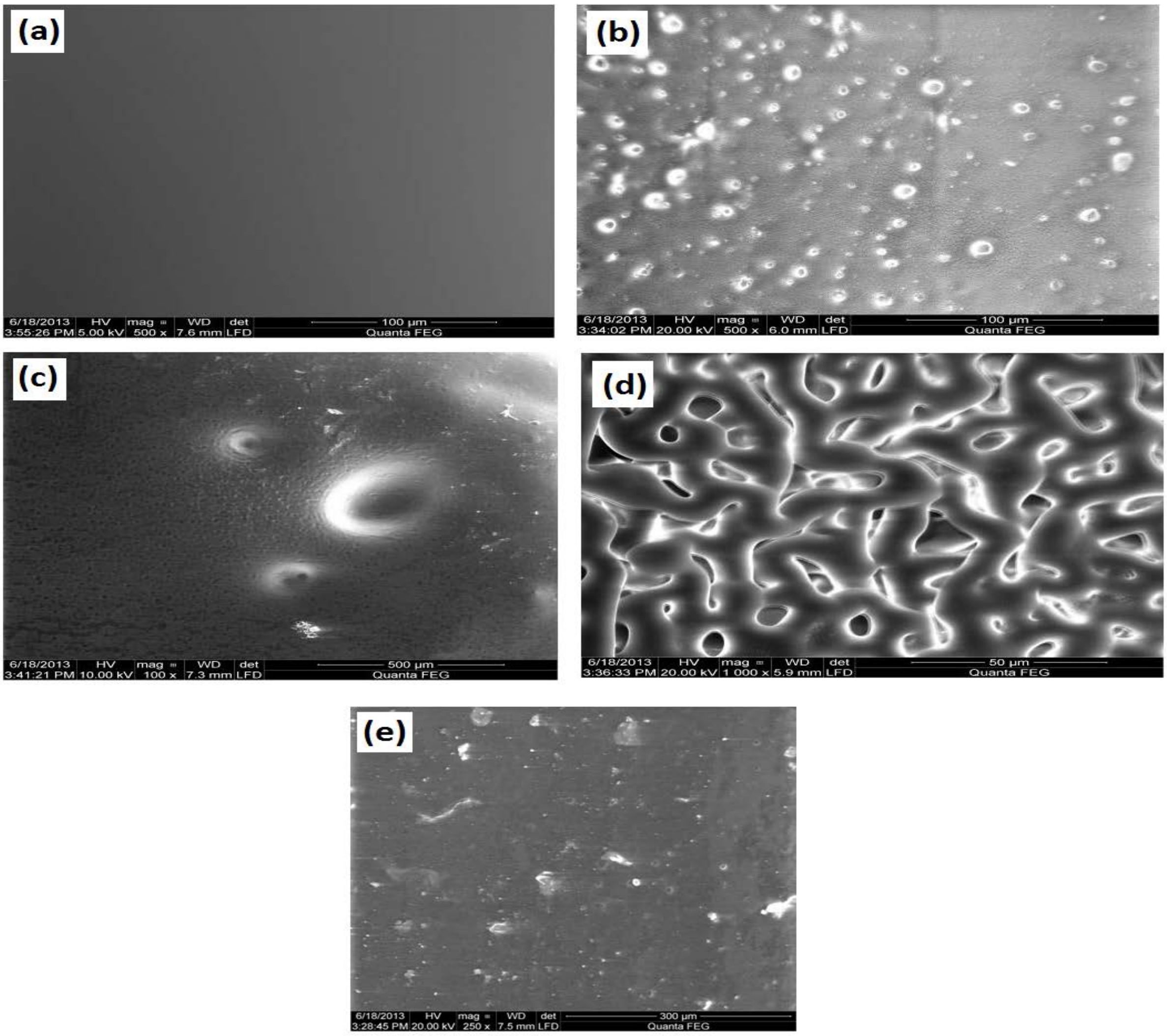

Photo 5: SEM photos of the final modified asphalt (b): 10.0% LDPE; (c): 10.0% CRT; (d) 10.0% CR/LDPE; (e) 5.0% LDPE blended with asphalt compared with the virgin asphalt (a).

dose of 10.0% than at 3.0% and 5.0%; (ii) LDPE-modified asphalt at percentage dose of 3.0% only. However, blending the admixture of CR/LDPE in asphalt has decreased the saturate percentage at 10.0% dose percentage comparing with the percentage dose of 3.0% and 5.0%. This corresponds also to the findings of Irena et al. [31] who have shown that when the CR content in asphalt is lower, the extent of swelling is greater, suggesting that it is not the whole asphalt material but only some of the small amounted components which contribute to the swelling of the CR. In contrast, the percentage amount of (i) resins and aromatics of the CR-modified asphalt at CR dose of (3.0%, 5.0% & 10.0%) have been increased, which can be attributed to the fact that CR powder had been degraded during interaction and part of the vulcanized rubber had gone desulfuration. These fractions produced components with smaller molecules and thus aromatics and resins had increased [41].

Controversy usually found in results and is observed in a number of articles in concern to the percentage amounts of the components when blending of asphalt with modifiers. This can only be explained by the number of experimental factors involved such as rubber content, rubber particle size, and chemical composition of the asphalt as well as the temperature and length of mixing time.

Morphological analysis (SEM)

An important part of the work is the microstructure study of the additives/asphalt blends; the additives are a single pure CR, a single pure LDPE and an admixture of CR:LDPE additive in a percentage weight of 10.0%. This step was done to observe the phase distribution of the additives in asphalt matrix at the same experimental conditions (Photo 5).

The SEM micrograph (Photo 5b) of the LDPE blended with asphalt in a percentage weight of 10.0% show that LDPE particles clearly separated from the asphalt matrix in the asphalt blends. A less phase separation or boundaries was attained when lower percentage weight of 5.0% was blended with the asphalt implies a better dispersion of the polymer into the asphalt. Similar results were obtained by [15] when they blended LDPE with asphalt in a percentage weight of 5.0%. This probably suggests the use of LDPE in a less than 5.0% as the best choice.

Likewise, the addition of CR to the asphalt in a percentage weight of 10.0% at the same experimental conditions (Photo 5c) seemed to display a satisfactory dispersion of CR into the asphalt matrix, in spite of the presence of a very little phase separation. This confirms and indicates that CR is a better asphalt modifier and more compatible with the asphalt as both include hydrocarboneous components, and physical interactions (and may be chemical reactions) strongly occur. It had been reported that more highly dispersed polymer rich phases are expected to improve the toughness of brittle asphalt at low temperatures and reinforce asphalt at high temperatures [42]. SEM Photo 5d displays the effect of the CR/LDPE (ratio, 3:1) addition to the asphalt in a dose percentage of 10.0%. The SEM photo shows a CR/LDPE additive suffering from severe phase separation as homogeneity in dispersion did not occur throughout the asphalt matrix and a gel-like formation was observed.

Conclusions

Environmental Hazardous solid industrial wastes such as scrap tires and waste plastics disposed on to landfills can be safely reused. This research study introduces a way to reuse the above wastes. The rheological properties of the final asphalt modified product were found to be improved through the influence on softening temperature point, the penetration point and the viscosity at the experimental conditions. The rheology of higher than or equal to 85.0% asphalt was strongly and best affected by the addition of single pure CR, LDPE, and CR:LDPE in a ratio of 3:1 as observed by the results of penetration, softening point and viscosity. From the test results, it was revealed that the amount of LDPE was the dominant factor showing unfavorable variation in penetration, softening point and viscosity in comparison to the single pure CR additive and admixture of CR/LDPE, when the concentration of LDPE exceeded 10.0% and its ratio in the admixture CR/LDPE above the (1/3). The PI index has confirmed the results when making a relation between softening point temperature and penetration point values obtained throughout the study.

The morphology of the final modified asphalt products of the different additive concentrations were studied by SEM to observe the phase distribution of the additives in asphalt matrix. The LDPE blended with asphalt in a percentage weight of 5.0% showed the least phase separations in the modified asphalt matrix among the other tested additives. Though, the addition of CR to the asphalt in a dose percentage of 10.0% displayed a better dispersion of CR into the asphalt matrix, in spite of the presence of a very little phase separation. SEM photo of a CR/LDPE additive surprisingly did not show a clear-cut homogeneity in dispersion throughout the asphalt matrix rather than an observable gel-like formation.

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