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Evaluation the performance of flexible pavement modified with high density polyethylene and crumb rubber powder: A review

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Abstract

Background: Bitumen is always used as binder road construction material, and it is extracted from petroleum purification processes. The increase in traffic density on roads, overloading of commercial vehicles and temperature variance in pavements drove to formulation of different distresses similar to rutting, the cracks of bituminous surfacing and bleeding. Thus, the researchers applied various techniques to reinforce the total asphalt performance by utilizing different types of additives. This study aims to discuss the application of high-density polyethylene and crumb rubber powder (CRP) in asphalt concrete mixtures. **Results:** The use of polymers offers improved drainage control and presents a better cost because it avoids fibrous materials using in bituminous mixtures. Previous results demonstrated that the asphalt mixture modified with polymer (HDPE) enhanced rutting resistance while also improving rigidity and tensile strength. Moreover, the best concentration of HDPE in the concrete asphalt mixture was from 2% to 6% by weight of bitumen. Crumb rubber powder positively influences rutting resistance, tensile strength, and fatigue resistance in asphalt pavement. The recommended concentration for adding Crumb rubber powder is 5-15% by weight of bitumen. **Conclusions:** Finally, adding single additives to asphalt pavement is not enough to enhance the bituminous pavement performance. Previously, some researches have been performed for improving PE flexibility using normal rubber, recovered rubber and Styrene-butadiene rubber. Therefore, it is recommended to use the admixture of HDPE and CRP in flexible pavement.

Keywords: Flexible pavement, HDPE, CRP, Rutting resistance, Tensile strength

1. Introduction

Heavy and increased traffic loading negatively affect the rheological performance of bituminous pavements. The surface portion of the asphalt pavements is essentially consisted of asphalt, aggregates, and mineral filler. Bitumen as a bonding substance is produced from hydrocarbons and has an intense effect on the bitumen paving surface efficiency [1]. In bituminous pavements, three essential forms of distress cause the structure damage such as rutting, thermal cracking and fatigue cracking [2]. Researchers have been actively working on modifying bitumen by utilizing the incorporation of polymers enhances its physical properties and flow behaviour characteristics [3]. Bituminous modifiers can enhance the characteristics of bitumen and bituminous mixtures. Asphalt including these modifiers was known as modified bitumen. Rubber-modified bitumen (RMB) and polymer-modified bitumen (PMB) are often utilized under conditions including ultimate climatic variance. Some of the characteristics of modified bitumen include the following: minimize sensitivity to temperature difference, considerable the deformation resistance at maximum temperatures, preferable long-term durability characteristics, and maximum fatigue life, best adhesion among bitumen and aggregates and banning of occur rutting. The properties of mixtures of bitumen and polymer relate on the kind of polymer and its concentricity. Generally, the polymer is used in concentrations of (4–6) % of the bituminous weight [4]. Polyethylene (PE) is a very common plastic used vastly all over the world. When applied for modifying bitumen, PE can enhance the asphalt pavements toughness, thus minimizing their deformation when subjected to heavy traffic loads at elevated temperatures [5]. Feng and Al [6] discussed the shear resistance for asphalt modifying with HDPE. They outlined that HDPE concentration aided the asphalt perform better in elevated temperatures. Furthermore, they deduced that softening point of mixtures raised with the appending of HDPE. This addition aids bitumen resists the rutting and deformations. The results illustrated that stiffness rate raised with HDPE modulation. High density polyethylene (HDPE) modified binder mainly examined and estimated. The results support the high density - PE addition cause developing in stability [7, 8]. A.K. Sarka et al. evaluated the efficacy of high-density polyethylene (HDPE) and low-density polyethylene (LDPE) as bitumen modifiers, employing polymer concentrations ranging from 1% to 4% by weight of the bitumen. Their findings demonstrated that HDPE exhibited superior performance compared to LDPE in enhancing both the rheological properties of the bitumen and the mechanical characteristics of the resulting asphalt mixtures. [9]. Lu et al. (Zhou et al.) demonstrated that incorporating high-density polyethylene (HDPE) at concentrations ranging from 2% to 8% by weight significantly improved the self-healing properties of asphalt binder [10]. Rubber has as well been utilized as a bituminous modifier in bituminous pavements ever after the last middle century. McDonald utilized crumb rubber-modified bitumen (CRMA) to improve the asphalt mixtures performance [11–12]. In recent years, crumb rubber has been extensively employed as an additive in asphalt mixtures for constructing road surfaces. [13]. Al-Khateeb and Ramadan investigated the influence of rubber additives on key rheological properties of asphalt binders, including the Superpave rutting parameter (G/sinδ), fatigue parameter (G·sinδ), and storage modulus (G') at varying concentrations. Their results indicated that the inclusion of rubber significantly improved both rutting resistance and fatigue performance in the modified binders, [14]. In a microscopic investigation, Moro et al. examined the incorporation of crumb rubber (CR) as a modifier in asphalt concrete (AC) mixtures using the dry process. Their analysis demonstrated that CR modification resulted in enhanced mechanical strength and improved resistance to rutting deformation [15].The main objective of this research was to collect data about the influence of HDPE and CRP as modifiers on the characteristics of bituminous mixture. Each additive demonstrates significant effectiveness in enhancing the properties of bituminous concrete mixes. Consequently, combining HDPE and CRP is anticipated to further improve the mechanical properties, rutting resistance and indirect tensile strength of asphalt concrete pavement.

2-The distresses of Asphalt pavement

Asphalt pavement distresses are described by three fundamental types of cracking, the deformation of asphalt surface and surface defects. Asphalt concrete damage as a result of many reasons like mixtures decay and viscoelastic flow. The distresses of bituminous pavement sorting according to (Ballinger and Miller) [16] were offered in Table (1).

Class	Type of distress
Cracking	Longitudinal, Transverse, Block , Edge, Fatigue, Reflective
Surface disfigurement	Rutting ,Depression, Shoving, Corrugation , Bumps of overlay
Defects of Surface	Potholes, Stripping , Raveling, Patching

Table (1) Prevalent flexible pavement deterioration issues [16]

The study of pavement distresses and failure are described as complicated because of many factors connected to the pavement decadence and defect. The asphalt is not capable of maintaining at original state of the pavement under the effect of traffic loading at high temperatures, which leads to perpetual deformation, recognized as rutting. At minimum temperatures the bitumen becomes friable and leads to crack as a result of rigid structure is incapable of relaxing the interior stresses resulting from traffic load (AASHTO, 2002) [17].The essential reasons that lead to damage to the pavement surface.Use of materials not to corresponds to the standard specifications limits, Errors occur in the method of construction and quality control process, Increasing the wheel loads magnitude and the load repetition number as a result of the traffic volume increase and Different environmental factors such as snow, frost action, loss of much rain and water content. The structural damage which appears in asphalt pavements can be divided in two major structures: deformation of pavement and cracking, both of which are due to inverse environmental conditions and effect of load repetitions. The pavement service life can be decreased as a result of fatigue cracking and cause structure collapse of pavement. Various factors because pavement performance efficiency and drove to pavement defect such frequency and the loads intensity value, duration of load cycles and variance in temperatures [18].

In order to determine the bituminous pavement failures, the main factors should be limited: localized reduction, ruts, potholes, settlements, cracks, etc. Each of them has multiple causes such as localized reduction which spread progressively in its neighbourhood; its gradation creates waves on the road surface. [19]. the pavement manufacture has been aimed to enhance pavement implementation; expand the life of asphalt pavements, in addition to minimize pavement rehabilitation efforts. The cracking and rutting fatigue are two main distresses that appear in asphalt pavement [20].Vertical stresses which occur on upper of soil sub grade shows the rutting failure however Horizontal tensile strain under the bituminous layer provides an idea about the fatigue failure for bituminous pavement. Table (2) discusses the main distresses that determined and its causes with their treatment according to (Sharad and Gupta, David) (2006) [21].

Table (2). The major distresses that determined and its causes with their treatment

Distress	Potential factors	Remediation
Longitudinal and incidental Cracking	Intense traffic and construction issues, contraction from low temperatures, and the reflection of cracks.	Crack treating or spraying Patching
Edge cracking of the pavement (PEC).	Inadequate edge drainage, axle loads passing over the outer edges of the roadway, and substandard paving layers along the road sides.	Crack repair and/or widening the shoulder. As the severity escalates, patches and modifications to the damaged areas are necessary.
Alligator Cracking (AC)	As a result of low-quality materials, inadequate structure, decreased base strength, or compromised drainage.	Rehabilitation of drainage if necessary, probably replacement of the base materials followed by a full-depth patch.
Rutting	Excessively soft asphalt due to poor mix design or improper compaction during construction	The grinding of pavement level. intense rutting a full depth patch
Distortion	the basic materials sediment	Levelling should be replaced with a full-depth patch whenever feasible.
Pothole	The occurrence of various types of cracks at an advanced stage, indicating central problems with the asphalt mix or drainage.	Using cold mix for padding; otherwise, applying a pothole patch
Raveling	Padding with cold mix; if not, a pothole patch is needed. Weak adhesion of aggregates can occur due to moisture in the aggregates, reduced asphalt content, or dust on the aggregates. Additionally, aggregate breakage from heavy loads, inadequate compaction allowing water to wash away aggregates, poor construction leading to separation of asphalt and aggregates, and aged pavement that has deteriorated over time can all contribute to the issue	A surface cure is required, along with sealcoating or micro surfacing if ravelling is present. For localized areas, splash patching should be applied.
Block cracking (BC)	Daily temperature fluctuations and the age of the asphalt in the mixture can contribute to these issues. Additionally, reduced compaction during construction may also play a role.	Recycling may be necessary. If base problems are found, rehabilitation or rebuilding
Rippling	The instability of the asphalt concrete surface layer may result from an excessive amount of asphalt cement, an abundance of fine aggregates, or the use of rounded or smooth-textured coarse aggregates.	Small waving can be fixed with an overlay or surface-milling. Severe corrugations require more extensive milling prior to resurfacing.
Depression	Decline in the base layer creates surface reflections due to missing sub layers and poor asphalt coverage	Apply a sand-asphalt mixture, perform cold milling, and then apply a protective coating

3-Improving Asphalt Pavement Using Additives

Modified asphalt mixtures incorporating additives represent the most effective solution for enhancing pavement performance, when the asphalt mixture fails to align with climatic conditions, traffic load requirements, or structural pavement specifications [22]. Various form of additives which can be used as a monocular additive or as part of a composite reinforcement system. Research indicates that a single additive typically cannot enhance all performance properties of asphalt pavements simultaneously. For example, modifiers such as polymers, natural rubber (NR) and crumb rubber (CR) have been used to resist the rutting at maximum temperatures and ravelling in asphalt mixes. Improve resistance to rutting at high temperatures and reduce ravelling in asphalt mixes. Nevertheless, these additives often fail to mitigate low-temperature [23]. Consequently, while binary additive systems show potential for enhancing comprehensive asphalt mixture performance, current research remains predominantly focused on single-modifier applications. The development of composite reinforcement approaches remains at an early experimental phase, requiring further investigation to realize their full potential [24]. for modifying bituminous materials with supplementary additives can be systematically categorized as follows [25]: The primary objectives of modifying bituminous blends are to enhance elasticity at low service temperatures to prevent cracking, increase rigidity at high temperatures to resist rutting, improve mixture stability, strength, and fatigue resistance, and reduce required pavement thickness. Based on experimental studies, asphalt modifiers can be classified by composition into several key categories, including polymers (elastomers and plastomers), fillers, fibers, hydrocarbons, anti-stripping agents, and crumb rubber. These additives exhibit significant variations in their physicochemical properties, leading to diverse impacts on asphalt concrete performance. As noted by Giavarini, such modifiers generally increase high-temperature stiffness, decrease low-temperature stiffness, and improve elastic recovery [26]. Asphalt additives or modifiers were classified into ten common groups [27]. Asphalt modifiers are categorized into ten primary classifications [27], as detailed in Table (3), with Terrell and Epps defining the properties of each group. This study focuses on three modifier types: rubbers, plastics, and fibers (Groups 3, 4, and 6). Rubbers and plastics belong to the polymer family, consisting of long-chain molecules formed from repeating monomer units. Fibers may be polymeric, natural organic, or mineral-based, characterized by their filamentous structure. These Group 3, 4, and 6 modifiers effectively mitigate both rutting and cracking. Other modifier groups serve distinct purposes, including environmental protection (against moisture damage or aging), void filling, or partial asphalt cement replacement

Table (3). General classification of asphalt modifier [TE] [28]

Modifier Type	Models
1. Filler	• Mineral Filler, fly ash, lime and Portland cement • Sulfur •Carbon Black (CB)
2. Extender	• Sulfur • lignin
3. Rubber a. (RR) b. (BC) c. (SL) d. (NL)	• Recycled Tires (RT) • Styrene-B- Styrene • Styrene-B- Rubber • Natural Rubber (NR)
4. Plastic	• (PE) • Poly -V- Chloride • Ethyl- V- Acetate • (PP)
5. Combination	• Polymeric combinations from Groups 3 and 4 were utilized in composite formulations
6. Fiber	• Natural: Asbestos and rock wool • Synthetic: Polypropylene, fiber-glass and polyester
7. Oxidant	• Manganese Salts (MS)
8. Antioxidant	• Lead compounds • Carbon • Calcium- salts
9. Hydrocarbon	• Recycling and regenerating oils • Stiffen and natural bitumen
10. Antistrip	• Lime •Amines

4-Enhancing Asphalt Mix Properties Using Crumb Rubber

Several years ago crumb rubber was used in asphalt mix in the shape of wet state or dry state. In the wet process, CRMB is produced through the high-temperature blending of finely graded rubber particles (0.075-1.2 mm) with base bitumen prior to aggregate incorporation. This modification process induces both physical and chemical transformations through rubber-bitumen interaction, resulting in particle swelling as the rubber absorbs lighter bitumen fractions. The consequent formation of a viscous gel matrix significantly enhances the binder's rheological properties, particularly increasing overall viscosity. [29]. Dry state, Granulated, ground, or crumb rubber (CR) is incorporated as a partial replacement material, typically constituting a minor proportion of the total composition of the fine aggregate (3 to 4% by weight of the total aggregate in the mix). The particles of rubber (0.40 to 9.50 mm) are incorporated with the aggregate before the bitumen supplement. Comparison the wet process, the dry process has remained a relatively obscure approach in CRM asphalt manufacturing, especially when contrasted with the wet method. Several factors contribute to this, including higher expenses associated with requiring specially graded aggregates to accommodate the recycled tire rubber, challenges in construction implementation, and most critically inconsistent performance outcomes. and Although premature failures have been observed in dry-process CRM-modified asphalt pavements, this method offers significant advantages. It enables the incorporation of higher quantities of recycled crumb rubber than the wet process, yielding greater environmental benefits. Additionally, dry-process CRM asphalt production is more logistically straightforward, making it accessible to a broader market. Research has examined the effects of crumb rubber on bituminous mixtures, revealing that rubber modification enhances penetration resistance by increasing binder viscosity at 60°C. The benefits were particularly pronounced under low-frequency loading conditions, with higher rubber content improving high-temperature deformation resistance and low-temperature flexibility. [30]. It was inferred that raising the content of rubber improved the binder aging resistance and extended the admixtures fatigue life, while it caused reducing in both the resilient modulus (Mr) and the indirect tensile strength (ITS). Thus, the incorporation of CR served to increase the elastic properties of hot mix asphalt (HMA), thereby enhancing its resistance to crack propagation, [31]. It was advanced a modern method for providing activated Crumb Rubber, through comparative analysis between activated crumb rubber (CR) asphalt mixtures and conventional CR mixtures, researchers concluded that the activated versions demonstrated superior performance characteristics, [32]. It was illustrated two gap-graded asphalt mixtures incorporating crumb rubber were evaluated for their mechanical performance characteristics. The study evaluated the performance of dry-process rubber-modified mixtures against a conventional rubber-free asphalt blend. Results demonstrated that the rubberized mixtures exhibited superior performance characteristics, outperforming their non-rubber counterparts, [33]. It was examined this investigation analysed how incorporating rubber modifiers influences the rheological behaviour of asphalt binders, specifically examining three key Super pave performance indicators: rutting factor, fatigue factor, and storage modulus across different incorporation rates. The research team documented consistent improvements in both rutting and fatigue performance parameters with increasing rubber content, demonstrating enhanced binder performance characteristics, [34]. It was illustrated utilize of Crumb rubber (CR) serves as an effective performance-enhancing additive in asphalt concrete (AC) mixtures by means of the dry process in a microscopically study and deduced that the addition of CR drove to improved strength and decreased rutting, [35]. It was fixed the fracture resistance properties of crumb rubber-modified asphalt were enhanced through wax additive incorporation, and the data proven that elevating the proportion of CR significantly reduces the binder stiffness at lesser temp-erature, [36]. It was inspected that CR influence on (BC) and the internal bonding strength of AC mixes and noted that CR led to an increase in the rigidity and stability of mixtures, producing in a small reducing in IDT, [37].

4-1 Ground Tire Rubber Blending Processes

CR is generally utilized to alter asphalt mixes usually through two distinct techniques. Initial state is "wet -state", involves blending fine rubber particles with heated bitumen to produce a modified- rubberized binder .Alternatively, the dry process substitutes a portion of mineral aggregate with coarse rubber granules, effectively allowing the rubber to act as a flexible aggregate component within the composite [38-39].

4.1.1 The Wet Process:

McDonald innovate the wet process technology for CR-modified bituminous mixture before mixing the CR-modified asphalt binder with the aggregate. The technology was performed in the United States in various locations, including California, Florida, Texas and Arizona. recently, the wet-operation has since expanded to S-Carolina, New Mexico and Nevada. The widespread adoption of CR-modified asphalt stems from its environmental benefits and performance advantages, including improved skid resistance, greater flexibility, enhanced crack resistance, and reduced traffic noise. In the wet process–high viscosity method, the modified asphalt must meet or exceed a minimum rotational viscosity threshold of 1500 centipoise (cP) at 177–190°C during the reaction phase. While a CR content of at least 15% is typically required to achieve this viscosity standard, certain mix specifications can attain the necessary performance with lower CR percentages [40].

4.1.2 The Dry Process:

Dry state, nearly 1.0 to 3.0% coarse rubber from the mix weight is inserted to the graduation of aggregate their volumes (2.0 - 6.30 mm) [41]. Existing research indicates that the rubber-to-aggregate ratio significantly affects the mechanical performance of dry-process rubberized asphalt mixtures [42]. Furthermore, mixtures incorporating surface-treated crumb rubber demonstrate superior engineering properties compared to those containing untreated rubber particles [43]. R-M asphalt mixtures exhibit lesser MR, necessitating greater layer thicknesses when binder content increases within the 10.0-20.0% compared to control asphalt mix [44]. Dry state, the physical properties and stiffness characteristics of rubberized asphalt mixtures require precise regulation, given the time- and temperature-sensitive nature of the rubber-bitumen interaction. A Turkish case study established optimal production parameters through Marshall mix design methodology, specifying:, the optimum parameters are 0.95 mm CR graduation, 10.0% tire rubber percentage, 5.50% binder ratio, 155°C mixing temperature, 15min mixing-time, and 135°C temp of compaction when the mix design demand consideration of Marshall procedure [45].

4.1.3 Previous Studies of Using C.R.P with Different Ratios.

Table (4), (5) and (6) illustrate previous studies that discuss the influence of crumb rubber modified bituminous mixtures.

Table (4). Previous studies that discuss the influence of various ratios for crumb rubber-m-asphalt mixtures.

Author & year	Additive %	Material	Test	Results & summary
Ghaly 2008 [46]	2.0,3.0,4.0 and 5.0%	T.C.R	1: MT. 2: WT.	1: increase Stability for Marshall by 26.80%. 2: Decrease deepness of rutting about 23.50%
Hernandez et al., 2009 [47]	1.0 and 20%	T.C.R	1: M.S.T. 2: ICT. 3: LBCT. 4: WTT.	1: Incorporating rubber raises the ideal bitumen proportion from 5.10% (wanting rubber) to 5.50%. 2: chiefly, all samples tests illustrates assent with similar field rates on specimens.
Fontes et al., 2010 [48]	15 and 20%	C.R	1: Shear test (ST). 2: Wheel tracking (WT).	1: utilizing of bitumen rubber binders results in a marked enhancement in rutting impedance. 2: Mixtures produced through continuous blending and gap-graded aggregate gradation has the highest resistance.
Al-Ani and Ahmed, 2011 [49]	2.0, 4.0 and 8.0%	T.C.R	1: plastic flow resistance at 600ºC. 2: (ITS) at (250C).	1: raised stability. 2: raised Flow (75.0 to 100%) & elevated AV%. 3: elevated CR amount decreases ITS among10 to 30%.

Table (5).Previous studies that discuss the influence of various ratios for crumb rubber modified bituminous mixtures.

Author & year	Additive %	Material	Test	Results & summary
Mashaan et al., 2013 [50]	6.0, 12.0, 16.0, and 20%	T.C.R	1: Marshall. T 2: ITS.	1: Mixing of CR-modified asphalt to stone mix asphalt raises stability through improved adhesion. 2: optimal CR concentration is 12% by weight of bitumen.
Hamad et al., 2014 [51]	2%	C.R	1: (ITS) 2: Resilient. M.T 3: Stability. T 4: (DCT)	1: big CR rate improves the density. 2: the acceptable range of CR size is 0.425 mm. 3: Stability reduces which CR sizes raises.
Chen et al., 2015 [52]	(0 – 50)%	Shredded C.R	1: Thermal P.T. 2: Moisture S.T.	1: CR elevates the softening- temperature while simultaneously reducing penetration & ductility. 2: bituminous mixes containing 100% recycled T.R as filler have lesser thermal conductivity and diffusivity. 3: Asphalt mix with 100% recycled –T has elevated heat capacity at variance mix including 100% lime-stone.
Moreno et al., 2016 [53]	1.5%	T.C.R	1: fatigue-cracking data test.	1: CR can prohibit fatigue- cracking. 2: Mixing CR at dry state produces asphalt mix with a more elastic. Moreover, and prevents cracking. 3: C.R raises adhesion between aggregates and bitumen.

Table (6).Previous studies that discuss the influence of various ratios for crumb rubber modified asphalt mixtures.

Author & year	Additive %	Material	Test	Results & summary
Arabani et al., 2018 [54]	(1.0, 3.0 and 5.0)%	C.R with zycosoil	1: (CAPT). 2: (DSRT). 3: (MST). 4: (ITSMT). 5: (DCT). 6: (ITFT).	1: Elevated Zycosoil concentration rises softening. P & reduces penetration of asphalt mix. 2: Zycosoil - improves adhesion force between aggregates& CR and bituminous binder, so improving (ITS). 3: Addition of CR reduces cohesion.
Franesqui et al., 2019 [55]	0.50%	C.R	1: (M.T). 2: (ITS). 3: (WTT).	1: The moisture damage resistance is enhanced. 2: Lesser temper-ature makes mini amelioration in plastic deformation resistance.
Ržek et al., 2020 [56]	10.0 and 18.0%	C.R	1: (DHR).	1: The blends dissolution is robustly affected by stock pilling temperature and grinding techno. . 2: Decreasing the temperature of storage tank at 150 °C reduces rate of dissolution. Thus, producing CR binder with bestead quality.

5-Types of Polyethylene Additive

Polyethylene (PE), a polymer used to modify bituminous binders, plays a significant role in producing everyday items such as shampoo bottles, toys, and plastic bags. Its molecular structure is straightforward, composed of carbon atoms each bonded to two hydrogen atoms. P.E is classified into two primary types: low-density polyethylene (LDPE) and high-density polyethylene (HDPE). LDPE features a branched chain structure with a density ranging from 0.91 to 0.94, whereas HDPE has a linear, un branched structure with a density exceeding 0.94. Although HDPE is more durable than LDPE, it is also costlier and more challenging to produce. LDPE is synthesized through high-pressure and high-temperature polymerization, while HDPE forms under comparatively lower pressure and temperature conditions. Figures (1) and (2) illustrate the differences between LDPE and HDPE additives [57].

Fig (1) Low density polyethylene additive

Fig (2) High density polyethylene additive

5.1 Advantages and Dis-advantages of PE and Other Forms of Polymer as Bitumen Modifiers

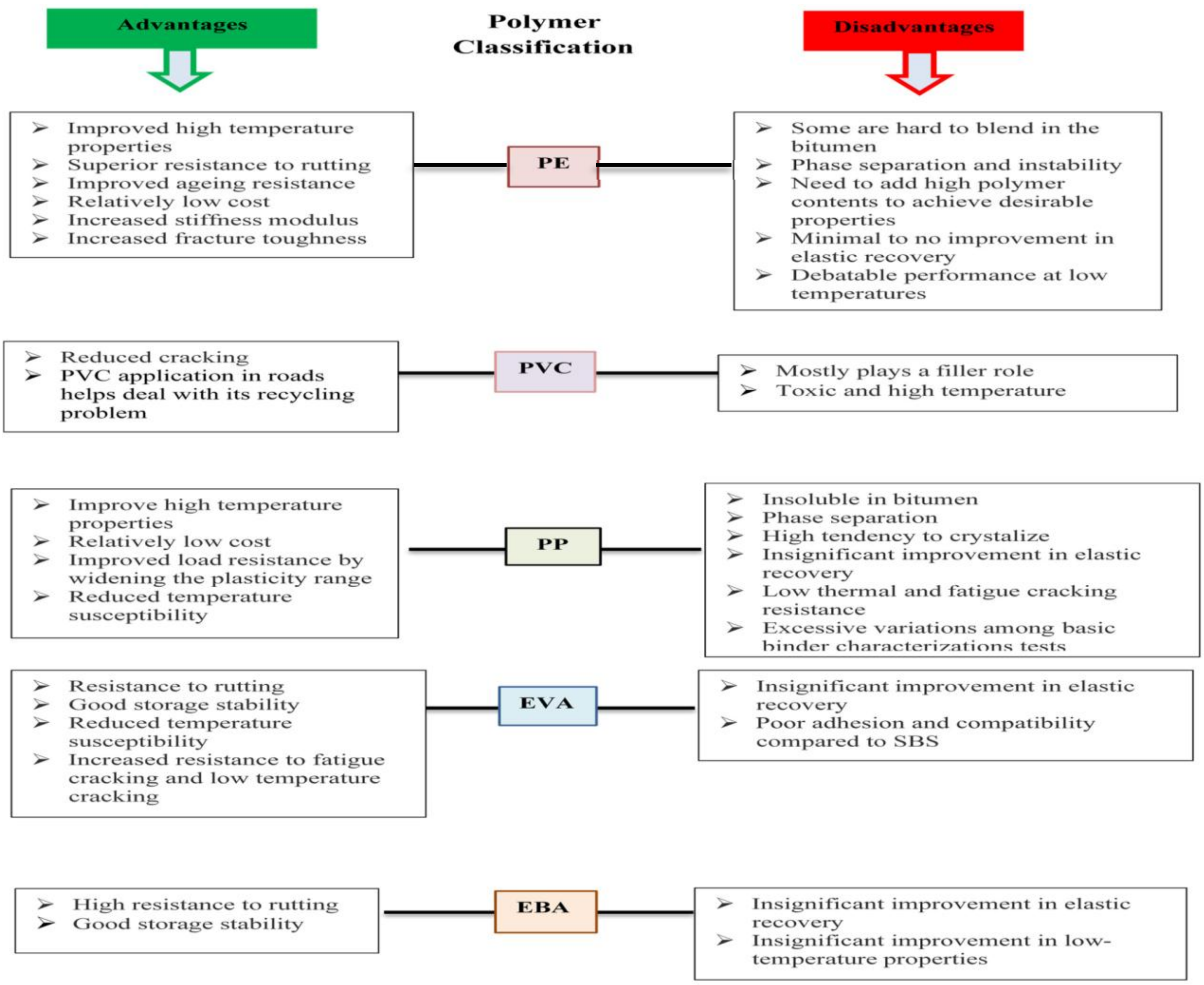

Fig (3) Advantages and dis-advantages of vary plastomers forms as bitumen modifiers [58].

5.2 Influence High Density Polyethylene on the Performance of Asphalt Mix

Ahmed A. L. (2007) discussed influence of utilizing P.E on the characteristics of pavement. Elevated amount of (MS) appeared at 10% P.E. Appending P.E raised mix workability and adequacy of comp-action for modified mixes, [59]. Hinisloglu et al. (2005) investigated the impact of using (HDPE) in grind shape as a binder modifier on the permanent deformation of the asphalt mixtures using Marshall Parameters (Stability, Flow, Density, A.V%, V.M.A% and V.F.A %) and creep behaviour. The asphalt binder's properties—including penetration, (SP), and ductility were evaluated. The bitumen was blended with HDPE at concentrations of 1.0%, 2.0%, 3.0%, and 4.0% (by bitumen dry weight) using a high-shear mixer at 185°C for 60 minutes. Results specified that the maxi-stability appeared at 3% HDPE, while the better progression in permanent deformation happened at 2% HDPE, so it was complicated to examine the optimum HDPE content. It was derived that the stability incensement from (3 - 21%) while flow reduced from (17.0 to 25.0%). The crawl resistance of the modified models was better than the values of the conventional models, [60]. Moatasim et al (2011) attempted to inspect the viability of utilizing (HDPE) as a modifier for asphalt pavement. Various ratios of HDPE by weight of bituminous binder were mixed with 80/100 paving grade bitumen. Original and polymer-modified asphalt binders underwent both physical-chemical and uniformity assessments. Performance evaluations such as Marshall Stability, Marshall Quotient (MQ), (TS), (TSR), flexural strength, and (MR) were conducted on both conventional and modified hot asphalt mixtures. Test data analysis revealed that mixtures modified with high-density polyethylene (HDPE) outperform traditional ones. For optimal improvement in asphalt concrete performance, a 5.0% HDPE content by weight of bitumen is advised [61]. Moghadas Nejad et al. explored the effects of (HDPE) on the performance attributes of bituminous mixes, focusing on aspects like fatigue cracking and rutting. Their findings indicate that mixtures with HDPE exhibit a longer fatigue-life compared to control mix. Furthermore, the HDPE-modified mixes demonstrate enhanced resistance to rutting, attributed to their increased stiffness. Additionally, the study revealed that as temper-ature and fatigue life rise, the permanent deformation resistance in all samples diminishes, with HDPE-containing mixtures showing less sensitivity to temperature changes [62]. Diab et al. investigated the influence of various polymeric additives on the performance of polymer-modified asphalt, utilizing concentrations of 2.0% and 5.0% by the asphalt binder weight. Their results showed that the sample with 5% high-density polyethylene (HDPE) achieved the highest resilient modulus. Additionally, they provided a detailed analysis of the physical, mechanical, and structural characteristics of the modified asphalt cement. [63]. According to Perez-Lepe et al. (2005) and Razak (2015), high-density polyethylene (HDPE) enhances the asphalt cement elastic properties at elevated temperatures, where permanent deformation affects the pavement. An increase in the HDPE percentage correlates with improved mechanical behaviour [64]. Zahra Kalantar et al. (2009) modified bitumen (80/100) with HDPE concentrations ranging from 0.5% to 4% at a temperature of 180°C and a mixing duration of 60 minutes. Their results indicated that higher contents of HDPE significantly enhanced the modified binder's resistance to temperature fluctuations. [65]. Nahla Yassoub et al (2014) utilized the wet state to blend HDPE with ratios (2.0, 5.0, and 7.0%) by the bitumen weight (40/50) and 90 minutes mixing period at a temper-ature of 180° C. They observed that (HDPE) enhanced the Marshall stability of the bituminous mix and also contributed to a reduction in rutting depth. [66].

6. Previous Studies on the Use of Both PE and CR and Their Effect on the Asphalt Mixture

Hussein A.A. Gibreil and Cheng Pei Feng (2017) found that as the amounts of (HDPE) and (CRP) increased, the rutting-depth decreased. Conversely, the asphalt mixture dynamic stability improved with the incorporation of HDPE and CRP. Additionally, the permanent deformation resistance, or rutting resistance, was enhanced by the addition of these materials. The optimal concentrations of the additives were determined to be 5% for HDPE and 10% for CRP, based on bitumen weight. [67]. Kezhen Yan (2015) the elevated and intermediate temperature rheological properties of asphalts are enhanced by the addition of W.T.R and R.P.E. After blended with W.T.R and R.P.E, the asphalts present reduced penetration, increased S.P and viscosity, this indicates that the asphalts modified with WTR/RPE become more rigid and exhibit greater resistance to deformation in both intermediate and elevated temper-ature ranges. [68].

7. Economic Evaluation of Modified Mixtures with LDPE and CRP

An economic analysis is being conducted to compare the direct costs associated with producing a consistent volume of bituminous mix ($1m^3$) utilizing various estimated additives. This cost assessment focuses solely on the materials direct expenses that make up the mixes, which include (CA), (FA), (MF), (AC), and the modifiers utilized. Indirect production costs and profits are not factored into this analysis, as these are expected to remain relatively constant across all mixtures. As indicated in Table 7, the production cost for 1 ton of the unmodified mix is 503 L.E. In contrast, the cost for the mix containing LDPE rises to 537 L.E, reflecting an increase of 6.76%.

Meanwhile, the cost for the rubber-modified mix reaches 672 L.E, showing a significant increase of 33.60% compared to the control mix.

Table (7). The increment in cost for producing 1 ton of modified mixtures [69]

Additive	Inclusive Cost (LE/ton)	% increment ratio
No Additive	503	0.00
LDPE	537	6.76
Rubber	672	33.60

8. Economic Evaluation of Modified Mixtures with Different Types of Polymer

A cost analysis was conducted to compare the expenses associated with modified bituminous mixes to those of nominal mixes. Table 8 presents the costs of various materials, which were obtained from the Laboratory of (GARB) in Sharqia-Governorate and plastic factories in 10th of Ramadan- City, along with the costs of hot mix asphalt. [70].

Table (8). A cost analysis was performed for hot mix asphalt-modified with various types of poly. [70]

1- Various materials Cost			2- HMA- modified with various polymers types cost					
Item	Unit	Cost (LE/unit)	Item	Cost (LE/m^3)				
				No additive	P.V.C	Novolac epoxy	H.D.P.E	Plastic. B
Bitumen	Ton	4000	Bitumen	498.96	508.48	489.720	444.800	443.200
(CA)	m^3	75	(CA)	48.750	48.750	48.750	48.750	48.750
(FA)	m^3	37	(FA)	11.100	11.100	11.100	11.100	11.100
(MF)	Ton	300	(MF)	32.150	32.140	32.820	32.800	33.710
P.V.C	Ton	8000	Additive cost	----	40.640	122.250	55.600	13.290
Novolac epoxy	Ton	25000	Inclusive cost	590.960	641.0	704.640	593.050	550.050
H.D.P.E	Ton	10000						
Waste plastic bags	Ton	3000						

8.1 COST ANALYSIS RESULTS:

Fig (4) illustrates the effect of utilizing several types of polymer modified concrete mixtures for 1 m3 cost. Fig (4) illustrates that adding 4% P.V.C & 4% Novolac to HMA raised cost. By adding 5% HDPE to HMA partially raised cost. Appending 4% (WPB) to HMA decreased cost.

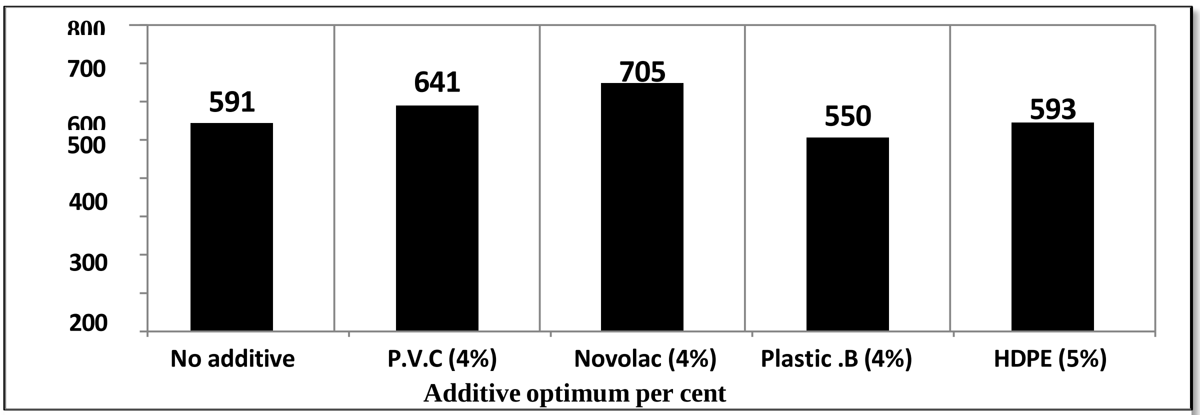

Figure (4): Mixes cost per 1 m^3 for each additive optimum ratio

9. Conclusions and recommendations

These paper objectives to analysis previous studies examined the effect of adding HDPE and CRP on enhancing resistance to abrasion, high temper-ature cracking, Rutting, moisture damage and fatigue cracking can be checked, that enhances the distress resistance happening in the pavement. According to previous reviews it is observed the major conclusions and recommendations can be summarized as follows:

1- The results obtained and the observations made in this study proposed that concrete incorporating HDPE and CRP could be used with satisfactory mechanical properties to enhance the Marshall properties for asphalt mixture.
2- The optimum ratio of using HDPE is 5% while the optimum ratio of using CRP is 10 %.
3- The incorporation of CRP by ratio 1.5% at dry state creates bituminous mix with a more flexible behaviour and prohibits cracking. Moreover, improves adhesion between the aggregates and the asphalt
4- TSR value of the asphalt admixtures modified with HDPE at wet state and CRP at dry state; there was a considerable improvement in the moisture damage resistance and rutting resistance after adding HDPE and CRP.
5- HDPE increased the bituminous mix Marshall Stability and improves the rutting depth as well. CRP prevents fatigue cracking, improve indirect tensile strength resistance and enhance asphalt mixture flexibility.

Finally, the results of this study support the idea that further research and practical application should be conducted regarding the usage of HDPE and CRP as admixtures in the Flexible pavement construction. These materials significantly improve the mechanical properties of flexible pavement' mechanical characteristics and longevity. To achieve the desired overall performance, more research is needed to determine the ideal incorporation rate and combination of these admixtures. Furthermore, to evaluate the long-term performance and cost-effectiveness of pavements modified with HDPE and CRP, long-term monitoring and assessment are required.

References

[1] Read, J.; Whiteoak, D. (2003) the Shell Bitumen Handbook; Thomas Telford: London, UK.

[2] Peshkin, D.G.; Hoerner, T.E.; Zimmerman, K.A. (2004)" Optimal Timing of Pavement Preventive Maintenance Treatment Applications; Transportation Research Board: Washington, DC, USA; Volume 523.

[3] Zhu, J.; Birgisson, B.; Kringos, N. (2014) Polymer modification of bitumen: Advances and challenges. Eur. Polymer. J, 54, 18–38.

[4] P. Giovanni, S. Jiri, B. Dario, A. Federico, V. Zora, Z. Ludovit, (2004) Rheology of asphalts modified with glycidyl methacrylate functionalized polymers, J. Colloid Interface Sci. 280 366–373.

[5] G. Polacco, S. Berlincioni, D. Biondi, J. Stastna, L. Zanzotto, (2005) Asphalt modification with different polyethylene-based polymers, J. Eur. Polymer 41 2831–2844.

[6] Moatasim Attaelmanan, Cheng Pei Feng, Ai. Al-Hadidy, (2011) "Laboratory evaluation of hma with high density polyethylene as a modifier.", Constr. Build. Mater 25 (5) 2764–2770.
https://doi.org/10.1016/j.conbuildmat.2010.12.037

[7] S. Hinishoglu, E. Agar, (2004) Use of waste high density polyethylene as bitumen modifier in asphalt concrete mix, Mater. Lett. 58 267–271.

[8] B. Piromanski, A. Chegenizadeh, N. Mashaan, H. Nikraz, (2020) Study on HDPE Effect on Rutting Resistance of Binder, Buildings 10 (9) 1–12, 156.

[9] A. K. Sarkar, (2019) “Analysis of Effects of High-Density and Low-Density Polyethylene Wastes on Bitumen for Highway Construction,” Int. Res. J. Eng. Technol., pp. 1057–1061, 2019.

[10] L. Zhou, W. Huang, Y. Zhang, Q. Lv, C. Yan, and Y. Jiao, (2020) “Evaluation of the

adhesion and healing properties of modified asphalt binders," Constr. Build. Mater., vol. 251, p. 119026.

[11] D. MacLeod, S. Ho, R. Wirth, L. Zanzotto, (2007) Study of crumb rubber materials as paving asphalt modifiers, J. Can. Civ. Eng. 34 1276–1288.

[12] T. McNally, (2011) Polymer Modified Bitumen: Properties and Characterization, Elsevier.

[13] .P. Cong, P. Xun, M. Xing, S. Chen, (2013) Investigation of asphalt binder containing various crumb rubbers and asphalts, J. Constr. Build Mater. 40 632–641.

[14] Al-Khateeb, G.G.; Ramadan, K.Z. (2015): Investigation of the effect of rubber on rheological properties of asphalt binders using superpave DSR. KSCE J. Civ. Eng. 19(1), 127–35

[15]. López-Moro, F.J.; Moro, M.C. (2013); Hernández-Olivares, F.;Witoszek- Schultz, B.; Alonso-Fernández, M.: Microscopic analysis of the interaction between crumb rubber and bitumen in asphalt mixtures using the dry process. Constr. Build. Mater. 48, 691–9

[16] .Miller and Bellinger. : Distress Identification Manual for the Long-Term Pavement Performance Program the Strategic Highway Research Program (SHRP), Report Number 645. 2003.

[17] .AASHTO (Association of State Highways and Transportation Officials)(2002): Pavement Design Guide. http://www.2002designguide.com

[18] .Monismith C.L., Epps J.A., and Finn F.N.(1985): Improved Asphalt Mix Design. Asphalt Pavement Technology; Volume 54, pp 347– 406.

[19] .Ogundipe, O. M. (2008). Road pavement failure caused by poor soil properties along Aramoko-Ilesha Highway, Nigeria. Journal of engineering and applied sciences, 3(3), 239-241.http:// ljournals/jeasci/2008/239-241.pdf

[20] .Behiry AE. (2012) Fatigue and rutting lives in flexible pavements. Ain Shams Eng J 3:367–374.

[21] .David P. Orr 2006," Pavement Maintenance Engineer Cornell Local Roads Program Cornell Local Roads Program" P.P: 17-40.

[22] .Kim, Y.R.(2008). Modeling of Asphalt Concrete; ASCE Press: Reston, VA, USA.

[23] .Sengoz, B.; Topal, A. Use of asphalt roofing shingle waste in HMA. Constr. Build. Mater. 2005, 19, 337–346.[CrossRef].

[24] .Fu, Z.; Shen, W.; Huang, Y.; Hang, G.; Li, X. (2017) Laboratory evaluation of pavement performance using modified asphalt mixture with a new composite reinforcing material. Int. J. Pavement Res. Technol, 10, 507–516.[CrossRef]

[25] .Lewandowski, L.H. (1994): Polymer Modification of Paving Asphalt Binders.Rubber Chemistry and Technology, Volume 67, PP435- 447.

[26] .Giavarini, C. (1998): Polymer-Modified Bitumen, Asphaltenes and Asphalts Association of Asphalt Paving Technologists, Report number, 381 pp, 57:-73.

[27] .Terrel, Ronald L., and Jon A. Epps, (1989) "Using Additives and Modifiers in Hot Mix Asphalt (Part A)", National Asphalt Pavement Association, Lanham, MD, Report No. QIP 114A.

[28]. Gowda, G.V.,K.D.Hall, and R.P.Elliott,(1996)" Arkansas Experiences with Crumb Rubber Modified Mixes Using Marshall and Strategic highway Research Program Level I design methods in transportation research record: journal of the Transportation research boardNo.1530,TRB,Nationalresearchcouncil,Washington,dc,pp.25-33.

[29] .Bahia H.B. and Zeng M., Zhai H., Turner P.(1999), and Hanson D.I., Quaterly Report for NCHRP 9-10 "Superpave Protocols for ModifiedBinders".

[30] .Hak-Seo Kim, Soon-Jae Lee, and Serji Amir khanian, (2010),"Rheology Investigation of Crumb Rubber Modified Asphalt Binders", KSCE Journal of Civil Engineering - 14(6):839-843.

[31] .Xiao F and Amirkhanian S N (2010), "Laboratory investigation of utilizing high percentage of RAP in rubberized asphalt mixture", Materials and Structures 43:223–233.

[32] .Xu,M.; Liu, J.;Li,W.;Duan,W.((2014):Novelmethod to prepare activated crumb rubber used for synthesis of activated crumb rubbermodified asphalt. J. Mater. Civ. Eng. 27(5), 04014173.

[33] .Dias, J.F.; Picado-Santos, L.; Capitão, S. (2014): Mechanical performance of dry process fine crumb rubber asphalt mixtures placed on the Portuguese road network. Constr. Build.Mater. 73, 247–54

[34] .Al-Khateeb, G.G.; Ramadan, K.Z. (2015): Investigation of the effect of rubber on rheological properties of asphalt binders using superpave DSR. KSCE J. Civ. Eng. 19(1), 127–35

[35] .López-Moro, F.J.; Moro, M.C. (2013); Hernández-Olivares, F.;Witoszek- Schultz, B.; Alonso-Fernández, M.: Microscopic analysis of the interaction between crumb rubber and bitumen in asphalt mixtures using the dry process. Constr. Build. Mater. 48, 691–9

[36] .Kim, H.H.; Lee, S.-J. (2016): Evaluation of rubber influence on cracking resistance of crumb rubber modified binders with wax additives. Can. J. Civ. Eng. 43(4), 326–33

[37] .Navarro, F.M.; Gámez, M.C.R. (2011): Influence of crumb rubber on the indirect tensile strength and stiffness modulus of hot bituminous mixes. J. Mater. Civ. Eng. 24(6), 715–24

[38] .F. Moreno, M. C. Rubio, M. J. Martinez-Echevarria. (2011). An5alysis of Digestion Time and the Crumb Rubber Percentage in Dry-Process Crumb Rubber Modified Hot Bituminous Mixes. Constr. Build. Mater (25): 2323.

[39]. F. J. López-Moro, M. C. Moro, F. Hernández-Olivares, B. Witoszek-Schultz, M. Alonso-Fernández. (2013) Microscopic Analysis of the Interaction Between Crumb Rubber and Bitumen in Asphalt Mixtures Using the Dry Process. Constr. Build. Mater. 48: 691.

[40]. Caltrans (2006) Asphalt Rubber Usage Guide. S.L.: State of California Department of Transportation, Materials Engineering and Testing Services.

[41]. Cao W (2007) Study on properties of recycled tire rubber modified asphalt mixtures using dry process. Constr Build Mater 21(5):1011–1015

[42]. HernԱndez-Olivares F, Witoszek-Schultz B, Alonso-Fernndez M, Benito-Moro C (2009) Rubber-modified hot-mix asphalt pavement by dry process. Int J Pavement Eng 10(4):277–288

[43]. Zaouai S, Tafraoui A, Makani A, Benmerioul F (2020) Hardened and transfer properties of self-compacting concretes containing pre-coated rubber aggregates with crushed dune sand. J Rubber Res 23(1):5–12

[44]. Tortum A, ˡelik C, Aydin AC (2005) Determination of the optimum conditions for tire rubber in asphalt concrete. Build Environ 40(11):1492–1504

[45]. Zhou H, Holikatti S, Vacura P (2014) Caltrans use of scrap tires in asphalt rubber products: a comprehensive review. J Traffic Transport Eng (English Edition) 1(1):39–48

[46]. Ghaly NF (2008) Effect of sulfur on the storage stability of tire rubber modified asphalt. World J Chem 3(2):42–50

[47]. Hernandez Olivares F, Witoszek-Schultz B, Alonso-Fernandez M, Benito-Moro C (2009) Rubber-modified hot-mix asphalt pavement by dry process. Int J Pavement Eng 10(4):277–288

[48]. Fontes LP, Trichês G, Pais JC, Pereira PA (2010) Evaluating permanent deformation in asphalt rubber mixtures. Constr Build Mater 24(7):1193–1200

[49]. Al-Ani TMA, Ahmed TY, Mahmood WM, Al-Ani SMA (2011) Using crumb of tyres in hot asphalt mixture as part of aggregate. ALRafdain Eng J 19(2):29–39

[50]. Mashaan NS, Ali AH, Koting S, Karim MR (2013) Performance evaluation of crumb rubber modified stone mastic asphalt pavement in Malaysia. Adv Mater Sci Eng. https ://doi. org/10.1155/2013/304676

[51]. Hamad GS, Jaya RP, Hassan NA, Aziz MMA, Mohd Yusak MI (2014) Influences of crumb rubber size on hot mix asphalt mixtures. Dissertation, Universiti Teknologi Malaysia

[52]. Chen M, Zheng J, Li F, Wu S, Lin J, Wan L (2015) Thermal performances of asphalt mixtures using recycled tyre rubber as mineral filler. Road Mater Pavement Des 16(2):379–391 https://doi.org/10.1080/14680 629.2014.1002524

[53]. Moreno-Navarro F, Rubio-GԱmez MC, Jiménez Del Barco-Carriớn A (2016) Tire crumb rubber effect on hot bituminous mixtures fatigue-cracking behaviour. J Civ Eng Manag 22(1):65–72

[54]. Arabani M, Tahami SA, Hamedi GH (2018) Performance evaluation of dry process crumb rubber-modified asphalt mixtures with nanomaterial. Road Mater Pavement Des 19(5):1241–1258

[55]. Franesqui MA, Yepes J, Garcia-Gonzalez C, Gallego J (2019) Sustainable low-temperature asphalt mixtures with marginal porous volcanic aggregates and crumb rubber modified bitumen. J Clean Prod 207:44–56

[56]. Ržek L, Turk MR, Tušar M (2020) Increasing the rate of reclaimed asphalt in asphalt mixture by using alternative rejuvenator produced by tire pyrolysis. Constr Build Mater 232:117177

[57].Ghuzlan et al. June (2015): "Rheological Properties of Polyethylene-Modified", Vol. 2, No. 2.

[58]. Behnood, A.; Gharehveran, M.M. (J. 2019) Morphology, rheology, and physical properties of polymer-modified asphalt binders. Eur. Polymer, 112, 766–791. [CrossRef]

[59] Ahmed A.L, (2007), "Improvement of Marshall Properties of the Asphalt Concrete Mixtures Using the Polyethylene as Additive", College of Engineering, Basrah University, Basrah-IRAQ Eng. & Technology, Vol. 25, No.3.

[60] Sinan Hinislioglu, Hatice Nur Aras and Osman Unsal bayrak ,(2005) ,"Effects of High Densit Polyethylene on Permanent Deformation of Asphalt Concrete", Department of Civil Engineering Faculty of Engineering – Ataturk University.

[61] Moatasim, A., Cheng, P. F., & Al-Hadidy, A. I. (2011). "Laboratory evaluation of HMA with high density polyethylene as a modifier. Journal of Construction and Building Materials" , 25, 2764–2770.

[62]. Moghadas Nejad, F., Azarhoosh, A. R., Hamedi, G. H.(2014) "Effect of high density polyethylene on the fatigue and rutting performance of hot mix asphalt– a laboratory study" Road Materials and Pavement Design, 15(3), pp.746–756. https://doi.org/10.1080/14680629.2013. 876443.

[63]. Diab, A.; Enieb, M.; Singh, D. (2019),"Influence

of aging on properties of polymer-modified asphalt". Constr. Build. Mater, 196, 54–65. [CrossRef]
[64] Razak, N. A. (2015).Utilization of Waste High Density Polyethylene (HDPE) as a Course Aggregate Replacement with Fly Ash Filler on Hot Mix Asphalt (Doctoral dissertation, UMP).
[65] Z. Kalantar, A. Mahrez, and M. R. Karim,(2009) "PROPERTIES OF BITUMINOUS BINDER MODIFIED WITH HIGH DENSITY Penetration Test Results," Int. Eng. Conv., no. May, pp. 11–14.

[66] N. Y. Ahmed and A. S. M. AL-Harbi, (2014) "Effect of Density of the Polyethylene Polymer on the Asphalt Mixtures," J. Univ. Babylon, vol. 22, no. 4, pp. 674–683.
[67] Hussein A.A. Gibreil , Cheng Pei Feng. (2017) Effects of high-density polyethylene and crumb rubber powder as modifiers on properties of hot mix asphalt ". Construction and Building Materials 142 -101–108.
[68] Kezhen Yan, Hongbin Xu, Lingyun You. (2015) Rheological properties of asphalts modified by waste tire rubber and reclaimed low density polyethylene" . Construction and Building Materials 83 -143–149
[69] Metwally G. Al-Taher1, Hassan D. Hassanin2, Mokhtar F. Ibrahim3 and Ahmed M. Sawan4, March (2018) "Comparative Study of Performance of Modified Asphalt Mixtures Using Different Traditional and Nano Additives", International Journal of Scientific & Engineering Research Volume 9, Issue 3, ISSN 2229-5518
[70] Ahmed Mohamady Abd-Allah a, Mohamed Ibrahim El-sharkawi Attia b, Mahmoud Fathy Abd-Elmaksoud Khamis b, Eslam Magdy Mohammed Deef-Allah c, September (2014) " Cost Analysis of Using Some Types of Polymers to Asphalt Concrete Mixtures", Mansoura Engineering Journal volume 39, Issue 3.Behiry, A. (2015). 3d finite element modeling of dowel jointed plain concrete pavement. Journal of Petroleum and Mining Engineering, 17(1), 59-65. https://doi.org/10.21608/jpme.2015.39928