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Improving the bitumen in HMA to resist the effect of Octahedral Shear Stresses on asphalt pavement surface layer

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Abstract: **For a long time, standard Egyptian penetration grade 60/70 bitumen which is actually equivalent to (PG64-22), used to provide a satisfactory ACP performance with current combination of (18t IWL ,1.35 MPa tire pressure). However, by the recent changing the bitumen fractional composition due to bitumen's origin or/ and different refining techniques, many shear related distresses has been reported. Moreover, top-down cracks (TDCs) have been also observed as one of the most surface distresses in this perspective. Moreover, creep has been reported also in (ACP) especially, in southern latitude airports, where surface layer is exposed excessively to high temperature ambient. In this decade, the criterion of admissible octahedral shear stresses (OSSs) in the flexible surface layer, has been used successfully as a judicious design tool, for the accurate assessment of ACP performance. Consequently, the aim of this work was to study the state of art of using bitumen products through different bitumen types modified by recycled low density polyethylene (LDPE), and its impact on the OSS resistance of ACP surface layer.**

Keywords: **Airfields AC pavement distresses, Enhanced PG LPDE modified binder, Octahedral shear stress.**

I. INTRODUCTION

In the current decade, there is a widely acknowledgement that AC quality has went down over the recent three decades. There are also considerable evidences to show that crude oil quality has decreased, oil refining processes have become more influencing and bitumen is extended by adding what would traditionally have been waste or by-product (G. White, 2016). Airports, compromising airport pavements, are internationally regulated to provide a minimum standardized level of infrastructure at the starting and destination of international flights. In the current decade, the new-type aircraft have become ever more demanding for the airport pavement. Meanwhile, the need to minimize runway occupancy duration of landing has pushed aircraft to use excessive braking stresses (White, 2014b). It is obvious that as aircraft continue to grow, their wheel loads and tire pressures will continue to increase. Consequently, an improved understanding of how the resulting shear stresses under extreme braking impact on the surface layer of the pavement is critical. Conventionally, Marshall designed dense graded AC (Asphalt Concrete) has been adopted to meet the international standard requirements. However, changes in bitumen quality dedicated for airport AC production and more demanding new-type aircraft, together, have been the main reason for notable falling below the standard requirements in some conventionally-designed airport AC surfaces (G. White, 2017). Since the year 1970, several design methods of flexible pavement have considered fatigue Bottom-Up Cracking (BUC) as the most critical deterioration mechanism. However, premature distresses have been observed recently close to the surface of AC pavement. Shear failure near the ACP surface is an actual dilemma caused by some factors such as: tire-pavement interaction, ACP rheological properties and environmental reasons. Top-down cracks (TDCs) have recently become a common deteriorates type and may be considered as a shear failure (Joao R.

Mattos et al, 2016). Currently, a significant shortage of bitumen supply has been observed in Egyptian Market due to the tremendous road construction works associated with the current national megaprojects. Consequently, the government attempted to troubleshoot the problem by increasing the local bitumen production through the main two local production companies (Suez and Alexandria) as well as importing more crude oil from different countries to cover the lack in production. A remarkable difference in AC performance has been observed when changing the bitumen feedstock through the two aforementioned companies in Egypt for the same pavement construction criteria. On the other hand, Mechanistic-Empirical Design Guide (MEPDG) has defined three distinct stages for the permanent deformation behavior of AC pavement materials under a given set of material, load and environmental conditions. Primary stage includes a high initial value of rutting, with a reduction rate of plastic deformations, often associated with volumetric change. Secondary compromises a small rate of rutting exhibiting a constant rate of change of rutting that is also associated with volumetric changes; however, shear deformations increase in acceleration. While the tertiary stage has a high level of rutting often associated with plastic shear deformations under no volume changes (AASHTO Design Guide, 2002). For a generally cross-anisotropic material such as asphalt, the direction of the shear stress with maximum magnitude is the orientation of critical asphalt performance. In order to evaluate and compare the complex combinations of 3D stresses in a simplified way, the OSS is recommended and also represents the actual stress state better than any other single parameter (Ameri-Gaznon & Little, 1990). It is known that the maximum calculated OSS associated with a heavy braking truck was just 53% of that for typical aircraft during its moderate braking process (Greg White et al, 2016). Therefore, Aircraft loads have been considered as the worst case when studying the tire-pavement interaction. This phenomenon has become so urgent that caused severe deformation distresses in asphalt pavement and requires more maintenance/ rehabilitation which affects directly on the economic assessments and a significant growing up in the annual rate of traffic accidents. Furthermore, the increasing cost of the pavement routine maintenance or rehabilitation works especially in the airports in which the specific restricted standards are required. Therefore, finding feasible solutions by developing a reasonable modified HMA that capable of resisting the effect of OSSs associated with the maneuver of the new-type aircraft, has become a real challenge to the researchers.

1.1 Summary of Relevant Studies

According to (Roberts et al., 2009), the reasons for incorporating modifiers into an asphalt are:

- Increase the stiffness of the mixture to minimize rutting
- Soften and increase the elasticity of the mixture to minimize cracking
- Improve the fatigue resistance of the mixture
- Improve asphalt-aggregate binding to reduce stripping or moisture sensitivity
- Improve abrasion resistance to reduce raveling
- Rejuvenate aged asphalt binders
- Reduce flushing or bleeding
- Improve resistance to aging or oxidation
- Reduce the structural thickness of pavement layers
- Reduce life-cycle costs of HMA pavements
- Improve overall performance of HMA pavements.

The addition of PE to bitumen results in a remarkable medication of its rheological response. In high and intermediate in-service temperature territories, recycled PE medication leads to the following:

- An increase in the values of the storage and loss moduli, and viscosity, as well as an apparent decrease in thermal susceptibility.
- Reduction of the mechanical glass transition temperature and, consequently, the glassy region is shifted to lower temperatures.

- As a result, bitumen modification with PE yields enhanced mechanical characteristics, hence higher resistance to permanent deformation or rutting, and also to thermal and fatigue cracking
- (Ghuzlan et al, 2014), concluded that the PE addition decreased the phase angle (δ), improved the binder elasticity and increased its stiffness exponentially, raised the rutting parameter (G*/sinδ) at high temperatures, improved the rutting resistance and increased exponentially the binder rotational viscosity.

They found also that, a PE content of 6% or more was not applicable because of the high rotational viscosity values, but a PE content of 3% could be suggested to be the optimum content for the high-performance grade at a maximum temperature of 76°C. The stresses have been calculated near the surface, at both surface layer interface and subgrade. Aircraft tire pressure and individual wheel load combinations included current (18 t and 1.35 MPa), imminent (33 t and 1.75 MPa) and future (40 t and 2.15 MPa). Surface layer stress increased significantly (20-30%) with increases in both tire pressure and wheel load. The subgrade stress increased near-equally (97%) with wheel load but was insensitive (<1%) to tire pressure changes. The capability of the current aircraft pavement strength rating system to protect pavements from the increasing demands of aircraft has been demonstrated to be limited to the subgrade. It is recommended that the pavement strength rating be amended to reflect the combined impact of both tire pressure and individual wheel load. It is also recommended that ongoing efforts to incorporate additional asphalt surface failure types into routine pavement design be given high priority. The importance of these issues is reinforced by the limited availability of remedies to counter any negative impacts of increased surface layer stresses especially in hot climates (G. White, 2017).

1.2 Asphalt Pavement

HMA, by definition, is a composite material made up of aggregate particles, bitumen, air and other components such as additives, modifiers, fines and water in either liquid or vapor form (Lytton, 2009). It is also acknowledged that AC is a complex heterogeneous material consisting of aggregates, air voids and binder (Zelelew & Papagiannakis, 2012). The bitumen, which is dark brown or black in color, contributes as an adhesive material which glues the aggregates and other components into a dense mass and also acts as a waterproof material to protect the pavement against water. Mineral aggregates, when bonded together, perform as a stone framework to give both strength and toughness to the composite structure. HMA performance is influenced by the individual characteristic of each component (aggregate and bitumen) as well as the interaction between them. However, asphalt binder requires a special attention, as its properties always change dramatically with the changes in loading, temperature and/or ageing state (Reubush, 1999). ACP design is the key factor in achieving the longest service life and the lowest (maintenance/rehabilitation) costs. For more than 50 years, several design methods of flexible pavement have considered fatigue; bottom-up cracking as the most critical degradation mechanism. However, recently, premature deteriorations have been observed close to the surface of AC pavement, especially in those with thick AC layers. These deteriorations are rutting and near surface cracks, which are considered as shear failures.

1.2.1 Bitumen Fractional Composition

Bitumen (C. Nicholls, 1998) is a complex mixture consists of the following:

- Asphaltenes: brown/black amorphous solids of high molecular weight, typically 1000 – 50 000. They are precipitated from bitumen by dissolving in a paraffinic solvent such as n-heptane. Asphaltenes generally comprise 5-25 % by weight of the bitumen.

- Resins: dark brown solids or semi-solids, which are soluble in heptane. They are adhesive and very polar in nature. Molecular weights are typically 900-1300. Resins may comprise 5-50 % by weight of the bitumen.

- Aromatics: generally dark brown viscous liquids. Molecular weight is typically 500-900. Usually present at 40-60 % by weight in the bitumen.

- Saturates: solids or viscous liquids, light colored with molecular weights in the range 500-800. This fraction may be present from 1 to 25 % by weight in the bitumen. The resins, aromatics and saturates fractions are often known collectively as the “maltenes” fraction. These four general compound types are considered as making up bitumen in the colloidal system in which the asphaltenes are present as “micelles” dispersed in the lower molecular weight maltenes. It is generally acknowledged that the asphaltene micelles are stabilized by a cover of compounds often found in the resins fraction. The covered asphaltenes are dispersed in the “oily” medium of aromatics and saturates.

1.3 Isotropy

1.3.1 Overview

Isotropy is uniformity in all orientations; it is derived from the Greek isos (ἴσος, "equal") and tropos (τρόπος, "way"). ... Isotropic radiation has the same intensity regardless the direction of measurement, and an isotropic field exerts the same action regardless how the test particle is oriented.

Isotropic: Properties of a material are identical in all directions. Anisotropic: Properties of a material depend on the direction; for example, wood. In a piece of wood, you can see lines going in one direction; this direction is referred to as "with the grain". The wood is stronger with the grain than "against the grain". Strength is a property of the wood and this property depends on the direction; thus it is anisotropic.

1.3.2 Anisotropy of ACP

Asphalt concrete has been recognized as an anisotropic material, but the degree of anisotropy and its implications for pavement design and analysis have not been well understood. (Wang et al, 2005) illustrated the difference between the stress fields of an isotropic and an anisotropic pavement under wheel load through analytical solution and finite-element simulation for several cases. A servo controlled true tri-axial (cubical) testing device was used to test 4-in. X 4-in. cubical asphalt concrete specimens under general stress states to characterize the anisotropic properties of asphalt concrete. It was discovered that (1) the stiffness of a cored field specimen has significant differences in the vertical and horizontal direction; and (2) the significant difference may result in larger shear stress and tensile stress in a pavement. These findings indicate that characterization and modeling of the anisotropic properties of asphalt concrete are an important area that deserves further investigation.

II. AIRPORT PAVEMENT STRUCTURE

Traditionally, unmodified bitumen (typically 60/70 penetration graded in Egypt) used to be the regular binder for AC pavement and for many years provided an acceptable performance. However, around the year 2000, horizontal deformation, and early ageing prompted many AC pavement designers all over the world to move to premium or modified binders. Since then, premium (often PMBs) has been adopted for the majority of highways and airports paving. A serious problem has been observed lately on the most of the newly constructed Egyptian AC pavements which is the rutting distress, due to the dramatic increasing in the total amount of traffic volume via the Egyptian roads network, moreover, the parallel Egyptian new policy of increasing and upgrading the airports to receive the anticipated number of new-type aircraft which generated a remarkable increasing in gross weights, axle loads and tire pressures. On the other hand, the relative amount of asphaltenes, resins, aromatics and saturates depends on the origin source of the crude oil, the refinery treatment and the finishing process of the final bitumen production (Allen, R. G.; Little, D. N.; Bhasin, A.; Glover, Ch. J. 2014). The fact of difference in bitumen fractional composition (for the same penetration grade) leads to a deep thinking of new trend for bitumen modification concept that is: "Diagnosis before Treatment" especially with the insufficient observations on the recent traditional modification techniques due to bad compatibility between bitumen and modifiers. Actually, changes in bitumen supply and quality have narratively been linked to many AC pavement degradations in Airports, compromising premature ageing and early life top-down cracking (G. White & K. Embleton, 2015). This phenomenon has become so urgent that caused severe deformation distresses in asphalt pavement as well as a significant growing up in the rate of annually traffic accidents as a result. Therefore, finding out a solution to develop an advisable HMA (Hot Mix Asphalt) that capable of enhancing the asphalt pavement against horizontal deformation due to heavy trucks/ Aircraft braking systems has becomes a challenge to the government. In countries where the PG (Performance Grading) system (developed in the USA) is used, one or two grade-bumps are required for airport pavement accommodating more demanding aircraft with significant wheel loads and tire pressures (J. Gagnon, 2016). (Wang & Al-Qadi, 2010) reported that near-surface failure is a complex phenomenon that results from various factors such as asphalt characteristics, pavement structural design, tire-pressure contact stress, and environmental conditions. Most traditional AC pavement design methods have assumed simplified loading (circular and stationary, inflation pressure equal to contact stress), elastic materials properties of asphalt, and full-bonded layer interface. However, as pointed out by (Wang & Al-Qadi, 2010), these assumptions are inconsistent with realistic tire loading conditions and may results in erroneous pavement response calculation and AC pavement performance prediction, especially at the near-surface, where the effect of tire-pavement interaction is significant. They and also (Drakos et al, 2001) explained that the tinsel or shear stress-strain near the pavement surface caused by tire-pavement interfacial contact stresses is one of the main factors causing near-surface pavement failure. Actually, tires produce highly non-uniform vertical contact stresses under each tire rib and also under the tire edges, creating a complex 3-D stress state near the surface. Therefore, instead of considering only one-dimensional tensile or shear stress-strain, the multi-axial stress state needs to be considered when analyzing the failure potential at pavement near-surface. Rutting, one of the most important failure distresses caused by heavy loads on asphalt pavement, is related to shear strain in asphalt layer. TDC (Top-Down Cracking) generally in longitudinal direction has become a more common distress in recent years and may also be considered as shear failure (Joao R. Mattos et al, 2016).

2.1 Aircraft Pavement Strength Rating System

It is acknowledged that as aircraft continue to grow, their wheel load and tire pressure continue to increase. While higher tire pressures do not impact on the ACN of aircraft, the ACN-PCN system does not actually protect the asphalt surface from near-surface shear stresses. This issue should be addressed thoroughly. An improved understanding of how the resulting shear stresses under typical and extreme braking impact on both surface layer and its interface with the underlying pavement layer is critical (Al-Qadi et al., 2011).

2.2 Aircraft Ground Maneuvering Operations

Airport ACP is subjected to repeated aircraft ground maneuvering operations, such as, braking during landing or before the evacuation through rapid exits on the taxiways as well as steep turning between runways and taxiways or turn pads. It's anticipated that the aforementioned maneuvering operations may cause high OSS at the ACP's near-surface, especially, in rapid exits and in push-back operations areas with lateral wheel skid. A slippage distresses in the Newark Liberty international airport runway was reported in the interface between the first and second layers of ACP in the section just before a high-speed taxiway (Bennert, Bogncki & Frisvold, 2007).

2.2.1 Aircraft loading at maneuvering operations

The parameters of IWL according to the aircraft manual for Boeing 737-600 as one of the most famous aircraft for its large hub airports (Boing, 2013). The coefficient of friction always goes down as the sliding speed goes high. A discussion with more details on the influence of friction on tire-ACP contact stresses is illustrated through the state of art (Wang, Al-Qadi, & Stanciulescu, 2014).

2.2.2 Vehicle/ Aircraft Braking Condition

The distribution and relative magnitude of stresses in various directions changes significantly under braking conditions as demonstrated by (Wang et al., 2012). (Uzan et al., 1978) also suggested that tire pressure distribution would only ever be relatively uniform in heavy braking or skidding conditions. Certainly under braking conditions, the longitudinal stresses have been shown to be of the same order of magnitude as the vertical pressure (Horak et al., 2009a); (Wang et al., 2012; Diakhate et al., 2006). (Horak et al., 2009a) and (Mooren et al., 2014) both concluded that a braking aircraft induced longitudinal stresses to be critical to surface shear resistance. Certainly under braking conditions, the longitudinal stresses have been shown to be of the same order of magnitude as a vertical pressure (Horak et al., 2009a; Wang et al., 2012; Diakhate et al., 2006).

2.2.3 Aircraft configurations and braking

(G.White, 2015) studied the braking forces at a major Australian airport for different aircraft under regular and severe landing conditions. The calculations of the foregoing investigation were based on the data collected from experienced pilots. Under maximum severe braking conditions, the majority of aircraft auto brake systems are designed to reach a deceleration rate of 4.3 m/s^2 as a target.

III. THE INTERACTION BETWEEN TIRES AND FLEXIBLE PAVEMENT

The proper understanding of tire-pavement interaction is essential for the accurate analysis of load-induced stresses and strains in the flexible pavement structure (Wang et al, 2011). The traditional pavement design ignores the non-vertical forces such as those associated with braking and turning vehicle/ aircraft which reflects the fact that current design methodology considers only the thickness of the pavement to protect both the subgrade from vertical deformation and the bound layers (such as asphalt surface) from flexural fatigue. On the other hand, the contact between aircraft and pavement surface has traditionally been considered to be a circular area with uniform contact stress or pressure (Horak et al., 2009a). Since the tire-pavement interaction is a very complicated process, the traditional design procedures (with the simplification of uniform contact pressure over a circular area) have no longer accepted. The contact area between aircraft tires and pavement surface has been calculated as a ratio between the vertical force resulting from aircraft mass acting on the tire and tire pressure. Non-vertical forces are rarely considered for practical design purposes (Yoo et al, 2006). The developed tire-pavement interaction models are used to evaluate the mechanism of load distribution at the tire-pavement interface under different loading and rolling conditions. It is now universally acknowledged that the interaction between tires and pavement is extremely complex (Horak et al., 2009a; Su et al., 2008; Yoo et al., 2006; Wang et al., 2012; Maina et al., 2012; Al-Qadi & Wang, 2011;Hernandez & Al-Qadi, 2014; Wang et al., 2014; De Beer et al., 2011). The inclusion of non-circular, non-uniform and non-vertical interactions between tires and pavement is largely the realm of Finite Element (FE) model researchers, as such modeling is beyond the capability of more traditional layered elastic design tools. In order to realize the potential benefit of finite element analysis tools, the shape, arrangement and magnitude of tire-pavement interaction zones have to be well understood. Both aircraft tiers and the forces applied by them have to be defined. Despite significant efforts in this area, such understanding remains elusive and such interactions cannot yet efficiently be incorporated into routine pavement design (Al-Qadi & Wang, 2011). Since 1996, arrays of five-axial pressure transducers were embedded in pavement to measure vertical, transverse and longitudinal stresses under slow moving tires of various types, including aircraft tires, using a heavy vehicle simulator (De Beer et al, 1997) and later in full-scale pavement (De Beer et al, 2011). It is possible to measure the contact stresses imparted by stationary and very slow moving tire. (Su et al, 2008) measured vertical contact pressure over the tire-contact area using pressure sensitive pins embedded in asphalt slab. Other researchers have simply placed a loaded tire with painted treads on a piece of paper to better understand the shape and size of the footprint (Yoo et al, 2006). Aircraft tires are complex structures and they are composite materials consisting of reinforcing steel and rubber compounds (Al-Qadi & Wang 2011). As the tire rolls forwards, significant distortion of the tire wall occurs and this should be accounted for in any tire model development (Wang et al, 2012). The reluctance of the tire industry to disclose details in relation to the structure and materials within their products creates a challenge for tire-pavement interaction modelers (Al-Qadi &Wang, 2011). (Uzen et al, 1978) suggested that tire pressure distribution would only ever be relatively uniform in heavy braking or skidding conditions. Various tire-pavement interaction studies have obviously shown the three dimensional nature of the stresses imposed on a pavement surface by a free rolling tire. Longitudinal stresses were found to be compressive at the leading edge and tensile at the trailing edge, while they were maximal at the centre of each rib and minimal at the edge of each rib (Yoo et al, 2006). The opposite trends were shown for transverse stresses which were maximum at rib edges and minimum at the rib centers. (De Beer et al, 2011) reported similar trends from their results of tire pressure measuring study. The distribution and relative magnitude of stresses in various directions changes significantly under braking conditions as demonstrated by (Wang et al, 2012). Also, in a comprehensive study (Wang et al, 2012) calculated contact stresses during static, free-rolling and heavy braking conditions. In static mode, the maximum transverse and longitudinal stresses were around 25% and 12% of the maximum vertical stresses, respectively. In free-rolling mode, the transverse stresses remained significant but the longitudinal stresses become small, due to the reduction in frictional resistance. However, during heavy braking, the transverse stresses were transferred to the longitudinal direction which then peaked at around 30% of the maximum vertical stresses. In all cases distribution of these surface stresses was complex and generally following the shape and orientation of the tire ribs. (Horak et al, 2009a) and (Mooren et al, 2014) both found that a braking aircraft induced longitudinal stresses to be critical to surface shear resistance. Modeling of the tire-pavement interaction has demonstrated that the stress imparted onto the pavement surface by rolling tire acts in all three dimensions and not just vertically. During braking operations, the horizontal stress has been calculated to be as high as 30% of the vertical stress. When shear stress in the pavement surface is being investigated, understanding the non-vertical surface stress is critical. The measurements made by various researchers and subsequent tire modeling have led to a commonly accepted theory of tire-pavement interaction. The model is based on (Hernandez & Al-Qadi, 2014):

- A series of rectangular ribs on which loads are applied with unloaded gaps between.
- Each gap has a mathematically calculated vertical stresses distribution along its area.
- The transverse contact stress is 40% of the corresponding vertical contact stress.
- The longitudinal contact stress is calculated as two skewed parabolic distributions with a peak positive stress equal to 20% of the maximum vertical stress.
- A time-stepped loading and unloading process where the loaded area increases until the tire is fully covering the analysis portion of pavement and then incremental unloading as a tire processes on. The duration of each time-step is adjusted to reflect the simulated aircraft velocity.

IV. OCTAHEDRAL SHEAR STRESSES (OSS)

OSS can be calculated as Equation 1. When referring to the plane across which the shear stresses are zero, the OSS will be greatest and Equation 1 reduces to Equation 2. This is known as the principal stress plane as follows:

$\tau OCT = \tfrac{1}{3} [(\sigma x - \sigma y) 2 + (\sigma y - \sigma z) 2 + (\sigma z - \sigma x) 2 + (\delta xy2 + \delta yz2 + \delta zx2)] \tfrac{1}{2}$ Equation1

$\tau OCT = \tfrac{1}{3} [(\sigma 1 - \sigma 2)2 + (\sigma 2 - \sigma 3)2 + (\sigma 3 - \sigma 1)2]\tfrac{1}{2}$ Equation 2

Where: τOCT = octahedral shear stress

σx σy σz = normal stresses

δxy δxy δxy = shear stresses

$\sigma 1$ $\sigma 2$ $\sigma 3$ = major, intermediate and minor principal stresses

Octahedral shear stress is a realistic criterion by which to evaluate the deformation potential of asphalt concrete overlays over rigid (PCC) bases. The value is a scalar quantity which represents the nine stresses which fully define the stress condition of any point within the pavement. The modified finite element program ILLIPAVE provides the ability to model pavement structures and to account for the effects of interface bonding and surface shear which influence the octahedral stress distribution within the asphalt concrete overlay as much or more than do the material properties of the overlay. The tri-axial shear strength test, performed at confining pressures ranging from 0 to 20 psi, can be used to develop a Mohr-Coulomb failure envelop and hence, to identify the magnitude of the strength parameters of C and φ. Based on these strength parameters and the actual stress condition induced in a selected pavement, octahedral shear strength under the actual stress conditions within the pavement can be defined. The ratio of the induced octahedral shear stress to the failure octahedral stress under these stress conditions provides a measure of the safety factor of the mixture against permanent deformation. The octahedral stress ratio (OSR) should be used as a tool by which to evaluate the under traffic. This tool potential of asphalt concrete mixtures to deform or rut. Octahedral planes and stresses: Any complex three-dimensional stress system produces three mutually perpendicular principal stresses Associated with this stress state are so-called OCTAHEDRAL PLANES each of which cuts across the corners of a principal element.

V. WASTE PLASTIC

5.1 Background

As a matter of fact, plastic is significant and growing environmental challenge moreover it is the common term used for the wide range of organic solid materials derived from oil and natural gas. (Appiah et al., 2017) explained that in a marvel of polymer chemistry, plastic has become an essential part of our daily life. Plastics are the materials which consists of a variety range of synthetic or semi-synthetic organic compounds with a high molecular weight, it is a solid in its finished state or it can be shaped by its flow when it is manufactured or processed into its finished state. The production rate of plastic is getting increased lately day by day in all parts of the world. Due to the giant growth in population, consumerism, industrialization and technological development, there has been a corresponding increase in the rate of the production. a large number of items that are either partially or completely made of plastic are used and these plastics eventually end up in the landfills. (Rajput P.S. et al., 2016) have mentioned that to break down the plastic which is present in the places where trash and garbage are dumped, it may take time either from a few days to several years depending on the quality of the plastic, but it will never break down completely into particles that can be used in nature.

5.1.1 Application of Waste Plastic in Asphalt

As stated, this technology has grown in popularity and there are several applications of waste plastic in asphalt around the world. The UK based company Macrebur have developed three products for the extension and modification of bitumen sourced from 100% waste plastics. The company was formed in 2015 and have since successfully resurfaced and laid roads in the UK, Australia, Slovakia, Turkey, and New Zealand containing their waste plastic products (Macrebur 2020). In the Netherlands, the construction firm VolkerWessels constructed a bike lane manufactured from waste plastics with the aim to reduce the volume of plastics sent to landfill. Recycled plastics were manufactured into prefabricated road parts and then installed piece by piece, reducing the construction time and cost. It has been claimed that this bike lane will be maintenance free, with further cost reductions as a result (VolkerWessels 2018). Chennai is known for the first application of plastic in roads in India, with a project dating back to 2002. The road uses waste plastic as a polymer glue, similarly to how conventional PMBs work. This project has been praised for offering a viable solution to Chennai's growing problem of plastic pollution and has yet to show signs of rutting and distress (Subramanian 2016). Other examples of waste plastics in roads include Australia, where a combination of plastic bags, glass bottles and printer cartridges were used to enhance the fatigue life of a road 3 North of Melbourne (Australian Government 2019) and New Zealand where nearly 500kg of shredded recycled plastic was used in resurfacing a road in New Plymouth (Satherley and Grace 2019). Both roads have been reported to be performing well. Performance of Waste Plastics in Asphalt for a technology to be considered viable, performance must not be compromised. In light of this and due to an increased demand for environmentally friendly technologies, the number of publications studying the performance of waste plastic in asphalt has grown in recent years. (Raouf et al., 2018) found that recycled polypropylene as an additive can enhance various physical properties of asphalt through adhesion between asphalt and PP. The asphalt modulus increased and when a typical asphalt pavement was modelled in a pavement management model, the predicted rut depth and top-down longitudinal cracking were both predicted to reduce significantly (Dalhat & Wahhub, 2017). Reduction in cracking and rutting is not exclusively associated with polypropylene, as (Ziari et al., 2016) deduced through laboratory testing that waste PET as an additive can improve fatigue life and deformation resistance of asphalt mixtures. This supports the findings of (Moghaddam et al., 2015), who found that waste PET particles used as additives had positive effects on asphalt fatigue properties and saw a significant improvement when compared to an unmodified control. (Abu Abdo, 2017) studied the effect of waste PET additives in hot-mix asphalt in superpave mixes and reached conclusions consistent with the publications specified supporting the use of waste plastics to improve performance properties of asphalt. (Hamedi and Modarres, 2014) argue that the addition of waste PET can result in an asphalt mixture with performance properties similar to conventional polymer SBS modified mixes, particularly in stiffness and fatigue behavior. SBS is a virgin polymer and so if comparable performance can be reached using a recycled polymer, the latter boasts performance enhancement and environmental benefit. As stated above, comparing the effect of a commercial and widely available waste polymer product supplied by Macrebur and manufactured from industrial waste known as MR6, to a similar modifier sourced from municipal waste known as MR6*. As it stands there is no data on MR6* but there are various publications studying the effects of MR6. (White and Magee, 2018) found that MR6 modification resulted in a binder with a higher softening point and with a viscosity comparable to conventional plastomeric binder modifiers. Similarly, (White and Reid, 2018) found that MR6 modified binders showed comparable properties to conventional Australian PMBs which support the previous findings. It was concluded that the effect of MR6 on binder properties was not detrimental. (White and Reid, 2018) investigated the impact of MR6 on various performance properties of asphalt and associated an increase in asphalt modulus of 120-150% with MR6 addition. Rutting depth reduced significantly, and fracture toughness increased. This is consistent with the findings of (White, 2018) who observed a 58% reduction in rut depth and a 73% reduction in rut rate associated with MR6 addition and compared to an unmodified control. It was also concluded in that MR6 added at 6% of binder weight resulted in a significant increase in stiffness modulus, and an improvement in moisture damage resistance. This is further supported by (White and Magee, 2018) who in their study associated MR6 with various performance enhancements, including a reduction in wheel track rutting and in increase in resilient modulus which is indicative of pavement strength. The findings of the papers discussed support the use of MR6 to enhance asphalt performance. Most recently, (White and Hall, 2021) concluded that the improvement in binder and asphalt properties are not significantly different when the plastic was added through the wet process or the dry process. Finally, it was concluded that the improvement associated with MR6 modification to the binder properties were comparable to commercial virgin PMBs, most notably EVA (White and Hall, 2020). The publications reviewed focus on MR6 which as stated is made from industrial waste plastic. There appears to be a lack of data on waste plastic modifiers sourced from household waste, which this study has aimed to address. In the review of the literature, most studies revealed the use of HDPE, LDPE and PET for binder and asphalt modification.

5.1.2 Classification of Plastics

Plastics are classified into seven different categories based on material composition (KS Environmental Group 2015). Each category has been given a product symbol from 1–7. Each has different properties which makes it suitable for different applications.

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