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Performance evaluation of asphalt micro surfacing – a review

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Abstract In spite the fact that micro surfacing receives accolades by researchers of being the most cost-effective, environmentally friendly, and functionally viable pavement preventive maintenance amongst the various asphalt surface treatments (AST). However, there has not been a universally standardised mix design, acceptable material type, compatible polymer-binder combination, laboratory-field correlational performance tests, and its field dependency performance indicators. The requirements set by the International Slurry Surfacing Association (ISSA), Malaysian Jabatan Kerja Raya (JKR-public works department) and American Society for Testing and Materials (ASTM) are stated to be guides. This study brings to fore the challenges, methodologies adopted and successes recorded towards solving the aforementioned concerns by various researches globally from existing literatures with emphasis on material-type effects, mix design methodology, serviceability/environmental performance, incorporation of industrial wastes and emulsion-polymer compatibility amongst others in micro surfacing. Hence, the contents of relevant published journal articles, theses, academic and industrial reports published within the last two decades (1979 - 2019) that met the selection criteria aforementioned were critiqued. Result indicated improvement in key pavement surface functional performance parameters as a function of enhanced polymer(s) used in improving desired performance, type of aggregate and its gradation, pre-treatment condition and ultimately emulsion type. However, there is a lack of total consensus on the mix design, even though polymers are unanimously agreed by researchers to improve performance. Future advances in micro surfacing should focus on the use of industrial wastes, synthetic material and especially by-products from industrial processes.

1. Introduction

Micro surfacing is an improved slurry seal which dates back to the late 19th century and gradually gained wide usage for its obvious advantages [1], especially, in extending the life span of a structurally sound asphalt pavement [2]. To this end, out of the numerous ASTs, micro surfacing was concluded to offer higher performance at relatively low cost with a number of added advantages like ability to be cold applied, fast set and quick open to traffic, non-wind shield breakage as witnessed by chip seals, and it keeps road geometry unchanged due to its thin layer (6 mm – 12.5 mm) [3]. Due to the fact that asphaltic roads constitutes a larger proportion of the total paved roads globally, with a projection that by 2020, the total length of asphaltic paved roads will double in Asia's developing countries, whilst in three decades to come, the global total length of additional paved roads could reach 25 million kilometers - enough to encircle the globe more than 600 times [4]. Similarly, consequential to rapid urban growth in developing African countries has forced commensurate road networks to be built [5]. The construction of asphaltic pavements consumes enormous non-renewable resources [6] with attendant greenhouse emissions congruent to the energy consumption in the construction [7], if not more, and perhaps, in the processing of the raw materials [8]. Government's budgetary restrictions couple with the need to develop high performance, sustainable , and cost effective asphaltic materials [9,10] prompted the need to device various alternatives to hot mix asphalt (HMA) like the warm mix, and cold mixes at differing construction techniques viz; porous asphalt, cold-in place recycling [11], and lots others. More so, a lot of research work has been conducted on the modification of bituminous binders for use in asphaltic pavements, notably in form of polymer modification [12]. Similarly, sustainability drive warrant research into techniques of pavement construction based on the three Rs (reuse, reduce, and recycle) philosophy thereby reusing waste construction material [13] in technics like hot in-place or cold in-place recycling of bituminous materials and reducing the use of virgin materials notably natural sands and gravel aggregates. However, all these strides towards a structurally and functionally viable pavement having value for money to the client and standing the test of time in terms of increased axle loading, unpredictable climatic conditions, weak underlying layers, human flaws and plant deficiencies leaves policy makers with the inevitable choice of effectively managing existing roads in form of preventive maintenance. The reason could be that, in spite the significant resource needed for the construction of new pavements, yet, appreciable proportion of these constructed pavements experiences sudden deterioration and premature functional failure warranting the urgent need for maintenance measures. These measures are in the form preventive, corrective, and routine maintenance, of which micro surfacing preventive maintenance proves to be the most cost effective [14].

Advances in micro surfacing has seen differing perspectives in addressing its deficiencies, some of which includes inadequate mechanical strength, low early strength, ravelling due to poor binder-aggregate adhesion, dependence on crew expertise in its construction instead of an established standard operating procedures, lack of standard mix design and few others [15]. Contrary to the view that micro surfacing is a performance layer which relied for its strength on that of the underlying layers, it should have some strength, as it is the first layer that comes in contact with vehicle loads. Hence, the performance of a micro surfacing layer should have adequate strength in addition to providing functional riding surface. The performance of a micro surfacing layer is a sum total of the performances of the constituent parts that makes up the layer [16], which includes the type of aggregate gradation [17], aggregate characteristics and quality [18], properties of the emulsified binder [1], efficiency and nature of polymer [19] and other additives used, pre-treatment condition (condition of the existing pavement to receive the micro surfacing), environmental application condition and types of equipment/crew expertise or experience. In spite the successes recorded in improving micro surfacing over the years, researchers are still trying to have a universally accepted mix design methodology and mixture design criteria for micro surfacing. Most transportation agencies devices their own mixture designs. While this effort is on-going, researchers are rather reluctant to present a comprehensive account of these findings. Thus, this study aimed to bridge this loophole by reviewing relevant literatures in the area, and probable future directions of micro surfacing.

At this juncture, it is worth noting that the complexity in accessing the performance of a polymer modified emulsified asphalt micro surfacing is a multi-dimensional task reflecting the performances of its constituent material. Thus, there are many criteria to classify the performance of asphalt micro surfacing, but this study will view it from the perspective of material-types effects, mix design methodology, serviceability/environmental/locational performance, emulsion-polymer compatibility, aggregate-emulsion interaction and possible incorporation of industrial wastes.

2. Polymer modified emulsified asphalt micro surfacing as a pavement maintenance

Road network in the world are continuously built on a daily basis to meet the rising demands. Restricted budgetary allocations resultant from the world economic meltdown has made it necessary for stakeholders and government alike to look inward for the effective maintenance of infrastructures and road infrastructure in particular [20]. Micro surfacing generally comprises of an emulsified bitumen emulsion, modified by a number of polymer(s) in addition to special additives, mixed with well graded and proportioned aggregates, portable water and fillers, mixed and placed in a well prepared structurally sound pavement. The assembly depicted in figure 1 is an equipment view of how the mixture of densely graded clean aggregate between the range of 12.5mm to 4.75 mm, water, polymer modified bitumen emulsion, additive, mineral filler or fiber and emulsifiers are mixed in a pug mill and laid to a maximum thickness of 12.5mm as micro surfacing.

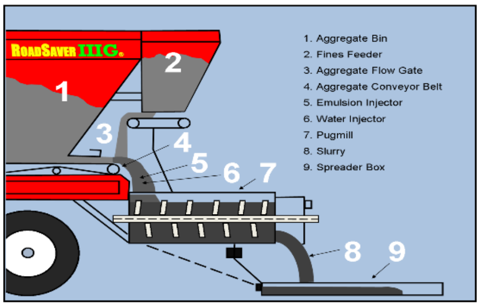

Figure 1. Schematic view of an asphalt micro surfacing paver (Source: California pavement maintenance).

The fact that reduced binder yields minimal rut depth by using the modified wheel tracking or Marshall tests, yet, optimal binder contents are better off [21].

In spite the improvement and advent of new polymers in improving micro surfacing mixtures, yet, the optimum desired performance level was deemed not to be attained. This prompted researchers to explore blending at least two polymers together. The concept of blending polymers with supplemental characteristics is gaining researcher's attention. The influence of Sulphur and Polyphosphoric (PPA) acid on the rheological and storage stability before and after aging on SBS and SBR modified emulsions concluded on the superior performance of SBR/PPA mixture over the SBS containing mixes [22]. Conversely, other studies viewed improvement in performance from the perspective of developing enhanced polymers like polyurethane [23–25]. A 40 years literature review on polymer modification of binders highlighted the merits and otherwise of the various plastomers and thermoplastic elastomers viz; styrene isoprene styrene (SIS), polyethylene (PE), polypropylene (PP), ethylene-vinyl acetate (EVA), ethylene-butyl acrylate (EBA), styrene-butadiene-styrene (SBS), and styrene-ethylene/butylene-styrene (SEBS) [26]. The over-arching set-back as witnessed in micro surfacing remains however; cost, low ageing resistance and adhesion loss due to storage, thereby suggesting saturation, sulphur vulcanization, adding antioxidants, use of hydrophobic clay minerals and reactive polymers as the way forward.

Not only the aforementioned issues, also the complex variables in emulsion performance could significantly mar the effectiveness of a micro surfacing mixture, even though it has all the desired constituents. As such, emulsion particle size and its distribution, water content, hydrophile-lipophile balance and deviation (HLB/HLD), pH level, and lots other emulsion characteristics do influence the performance of the final micro surfacing mix [27,28]. To limit the scope, certain key criteria is adopted by this study as delineated below in categorising research studies conducted on the performance of polymer modified emulsified asphalt micro surfacing.

2.1. Criteria for evaluating the performance of a micro surfacing mix

2.1.1. Micro surfacing Mix Design. The performance of micro surfacing largely depends on the proper proportioning of the constituent material. The most widely used specification is that which is spelt out in the ISSA A 143 guideline (Performance specifications for asphalt micro surfacing [29], in Malaysia guidelines for mix design is given in JKR/SPJ/2008-S4 [30]. Mix design specifications may range from loosely defined guidelines in industry reports and workshops. Furthermore, each state transportation departments in the United States, Canada [31] devices mix design tailored to suit peculiar application requirements. Table 1 gives a comparison of some major mix design criteria. Numerous researches were conducted towards the improvement and definition of key performance criteria in relation to mix design, after rigorous appraisal of the current ISSA mix design a suggestion was given for a modified mix design [32]. Despite the limitation of this study of restricting the research based on only one type of binder and aggregate, yet, it has significant findings suggesting a variation in the mix design tests ISSA TB 100, 109, 113, and 139 considering the effect of added water content, asphalt emulsion, and Portland cement on the design parameters. However, the study found that ISSA TB 139 can be used to define the optimum water content at which samples should be tested, whilst ISSA TB 147 mix design test for optimum asphalt emulsion content. Furthermore, the same author argued on the repeatability of the ISSA performance test series, hence, the coherence of cohesion, wet track abrasion, loaded wheel, and resistance to compaction tests results conducted by four technicians between two laboratories in Quebec were analysed. Aggregate gradation and sample preparation method were varied, and the responses for various ISSA mix design test for micro-surfacing were examined. Result suggested the significance of using sieve analysis in the grading for mix design yielded better consistency result, also, finer aggregate gradation gives the best rutting, bleeding, abrasion and moisture susceptibility resistance [33].

Conclusively, a unanimous consensus among researchers could not be reached as to the definite influence of a particular mix design on identified performances of micro surfacing, thus, exploring in depth evaluation of this parameter, especially, with respect to varying aggregate gradations will be a laudable breakthrough.

Table 1. Comparison of some key Micro surfacing specifications

TESTS		TEST METHODS		SPECIFICATIONS			
		AASHTO	ASTM	ISSA A 134	JKR	VDoT	TxDoT
Settlement and Storage stability of emulsified asphalt, 24-h	Raw emulsion	T 59	D 6930	1% Maximum	-	1hr Maximum	1% Maximum
Distillation of emulsified asphalt		T59	D 6997	62% Minimum	-	62% Minimum	62% Minimum
Viscosity @ 25^0C SSF, seconds			D 244	-	15 - 50	20 – 100 sec	
Water Content			D 244	-	40 Maximum	12 – 20 %	
Residue on 850 µm					0.1% Maximum	0.1% Maximum	0.3% Maximum
Softening point of Bitumen (ring and ball apparatus)	Tests on Emulsified asphalt residue	T 53	D 36	57 ^0C Minimum	54^0C Minimum	54^0C Minimum	57^0C Minimum
Penetration of Bituminous Materials		T 49	D 5	40 – 90	40 – 90	40 – 90	-
Polymer content			D 6372	-	-	-	3% Minimum

It is glaring form table 1 that there is no unified performance criteria among the various specifications as specified by American Association of State Highway and Transportation Official (AASHTO), ASTM, and Malaysian Standard (M.S). Table 1 is a tip of an iceberg considering the numerous country -centred micro surfacing specifications. These state transportation departments accessed the performance of micro surfacing after years of field studies against certain performance indicators, and in Canada, despite the uncertainties in performance outcome of micro surfacing, yet, it recorded continual successes. Perhaps, this could not be far-fetched from the strategy used among which includes robust material selection and placement techniques [31].

2.1.2. Materials-type effects on micro surfacing. While enhanced performance of micro surfacing was argued to be dependent on improved emulsion rheology [34,35] and are perceived to significantly contribute to key surface desirable qualities required of an excellent functional pavement viz; rutting resistance couple with less noise, excellent skid resistance enabled by high surface texture, less disruption to the road user during application, ability to maintain road geometry and ultimately less energy requirements [36]. Indeed, emulsions plays vital role in determining the performance of micro surfacing, but polymers largely effect these desirable feature of emulsions. Polymers reinforce bitumen by improving cohesive strength, making it more resilient and tougher, this may be the reason why nano clays are utilised in modifying warm mix asphalts [37,38] whilst fibre is employed in emulsified micro surfacing [39].

Researches have established the influence aggregate gradation has on the performance of HMA mixes, in that, thin lift thickness with coarser gradation were found be more prone to moisture damage than thicker lifts of finer gradation [40], similarly in micro surfacing mixtures as well [17]. The electric charge imparted by surfactants in emulsions determines how efficient it combines with emulsions, thus, variability in chemical composition of aggregate and emulsion type as studied based on cohesion, wet track abrasion loss, excess asphalt and compaction of micro surfacing proved that granite aggregate and quick set emulsion gave the best adhesiveness against abrasion, which is a major challenge in micro surfacing [41]. The limitation of such study arises is the inability for a level benchmark to compare two or more binder types [21] and the failure to link the aggregate type to a particular gradation, as specified by ISSA. More detailed aggregate/emulsion and emulsion/polymer interactions as highlighted by various studies is further discussed with a view to deriving a more apt explanation on the influence of material type effect on micro surfacing.

*2.1.2.1 Alternative Aggregates.*Alternative aggregates represents the type of aggregates used in place of natural aggregates. The unprecedented technological advancement witnessed since the first industrial revolution to the most recent drastic shift and research breakthroughs in the fourth industrial revolution has attained exponential heights in improved construction materials [42]. Other advances are in the area of Nano technology [43], enhanced waste management [44,45], sophisticated techniques; tools; methods; and machinery in various facets of human endeavour. This lead to a dramatic consumption of natural non-renewable resources in the building of infrastructures in a rate that supersedes natural replenishing rates. These infrastructures ranges from buildings, roads, bridges, dams, and lots others which conclusively agreed by scholars to largely contain greater proportion of aggregate in their construction. Among the various construction materials, aggregates accounts for a larger proportion of most structures and are arguably said to account for 90 to 95 percent by weight of a total asphalt mixture which largely forms the load bearing medium in an asphaltic mixture. Construction aggregates plays a crucial role in road transportation as 90% of the total road in Europe alone is asphaltic-base, whilst more than 40% of goods are transported by road [46]. The enormous amount of aggregates needed for construction of new roads worldwide coupled with huge budgetary and energy requirements makes it imperative to adequate maintain this valuable infrastructural asset in the most cost-effective, environmental friendly and sustainable manner [13,47,48]. The road infrastructure is among key infrastructures that directly or indirectly affects many other fields, it is also critical to a nation's development indices [49].

Coarse and fine aggregates forms the two broad categories of aggregates, however, numerous array of size range exists which helps in further classifying gradations base on specific usage. Dense graded, gap-graded, open-graded, all-in aggregate and poorly-graded aggregates owed their identity from the extent of distribution of the various aggregate sizes present in a particular sample [50], thus, often careful sampling is required in accessing a representative portion of a batch in testing. Less attention is given to the behaviour and technical performance of aggregates in construction in spite, the role they play in building structures and pavements of load-carrying, stability and robustness, yet, researches on performance improvement of asphalt materials largely focuses on binder improvement through modification. Asphalt materials, in addition to the aggregates, includes bitumen of various types to which bitumen emulsion belongs [51]. Spent garnet is a non-hazardous fine aggregate waste generated from abrasive blasting in shipping industry and on-shore oil installation maintenance, water filtration granules and water jet cutting. The business boom in Malaysia warranted the freight of bulk goods via sea, thus, the demand for shipping services increased with a consequential rise in the need for abrasive blasting. The fresh garnet comes in varying grain sizes to suit peculiar usage conditions and technical specifications for the intended use. It has a particle size of less than 4.75 mm depending on the number of cycles it is used for the blasting process, thus, fit into fine aggregate size.

Increased abrasive blasting resulted in huge amount of waste abrasives generation, yet, this increased generation coupled with landfill disposal restrictions or transportation and handling costs makes it necessary to device alternative utilisation [52,53] or minimization techniques.

Numerous alternative aggregates belonging to the same class of abrasive materials to which garnet belongs have long gained researcher's attention. Research results indicated suitability for use of these waste abrasive materials as a natural fine aggregates replacement in asphaltic concrete pavement construction. These spent abrasives include; nickel slag [54,55], copper slag [56–59], coal slag [60,61], steel slag [62] or even. In fact, the philosophy behind the use of slags generally stems from the need to curtail menace caused by its dumping in landfills, reduce the use of natural construction material and ultimately devise an enhanced aggregate by altering the slag's chemistry to suit specific construction purposes [63]. Glass bead has round texture and largely used for smoothing operations in abrasive blasting, its waste is not pronounced and has not yet been used in construction, aluminium oxide [64], silica sand and steel grit [65] and more recently the result of researches on the use of crumb rubber in other forms of construction is worthy of trying in polymer modified micro surfacing [66]. A drastic shift from the norm prompted binder modification with a type of clay known as montmorillonite [67] resulting in significant improvement in short and long term ageing of binders. Aside the use of other forms of abrasives, the use of waste garnet for road construction started on a trivial note, with its application as a soil stabilisation for road shoulder construction of village road [68]. This effort triggered swift response by researchers, especially in Malaysia, whom explored further the use of waste garnet in asphalt and concrete applications.

A recent study on the Marshall properties of AC 14 asphalt mixture incorporating spent garnet as fine aggregate replacement in Hot Mix Asphalt revealed that garnet waste could favourably replace fine aggregate up to 25% by weight and give the desired volumetric properties [69]. In concrete, the high angular fracture, texture and density/specific gravity of waste garnet has produced the desired workability in geopolymer self-compacting concrete at an optimal percentage replacement of 25% by weight [70]. The chemical analysis employed in the research using toxicity characteristics leaching procedure (TLCP) placed spent garnet as a non-hazardous material thus, safe to use in construction.

2.1.2.2 Polymer modified asphalt emulsions and their application in micro surfacing. The use for polymers in asphalt aroused from the need to improve both low and high temperature performances of asphalt mixtures against cracking and rutting respectively. There exist a number of asphalt emulsions depending on the application requirement, setting and breaking time Asphalt emulsions constitutes a stable dispersion of asphalt globules less than 50µm in water, with asphalt content ranging from 50% to 80% depending on application [28]. In general, the use of a particular asphalt emulsion type or grade depends on the viscosity primarily, and to the nature and extent of distribution of emulsion globule sizes, its stability and rheological behaviour. Invariably, the type of emulsion produce will depend on the emulsifier "surfactant" used; the surfactant is the chemical added which defines the type of emulsion. There exist three basic categories of emulsions viz; cationic, anionic, and nonionic emulsions depending on the type of emulsifier used and desired emulsion sought to produce. Polymers have a variety of applications attempts at entraining micro capsules in resins resulted in reduced ductility, low temperature crack resistance and slight increase in rutting & softening point [71].

3. Compatible polymer-binder combination, laboratory-field correlational performance tests

While performance in asphalt surfacing in forms slurry seals is always attributed to the type, properties and qualities of the binder [72], nonetheless other important factors plays significant roles like durability measures, water content moisture susceptibility and fatigue [73]. Thermoplastic polymers are believed to improve strength and bond of micro surfacing, but the challenge is the rheological compatibility between these polymers and the emulsion. As such several attempts at improving micro surfacing performance reached the extent of combining polymers two or more polymers in a mix.

3.1 Important parameters to modify in Asphalt Emulsions and their use

The parameters to be modified in emulsions are categorised into three, viz; composition, mechanical and formulation parameters. The two most important parameters to control in emulsion formulation and handling are the stability and breaking. Stability here means storage stability, as emulsions are sensitive to mechanical agitation, PH change of the continuous phase, polymer-emulsifier interaction and size of the dispersed bitumen globules, which entails the rate of agglomeration. Asphalt modification effects key performance parameters of micro surfacing including via interaction of the constituent materials, in form of aggregate-binder adhesion, polymer-emulsion compatibility, and surfactant characteristics and its effects on emulsion.

3.1.1 Aggregate-binder adhesion. The bond that exist between the aggregates (coarse, fine and filler) and binder (emulsions) with its other constituents like additives, polymers and emulsifiers is termed as 'adhesion'. This is a significant parameter that determines the performance of asphalt mixtures as well as micro surfacing, it is a loss of adhesion between the aggregate and the binder that results in stripping of asphalt surfaces, hence, improved mixtures incorporate adhesion promoters as additives [74], alternatively, improve binder rheology was achieved by chemically modifying waste cooking oil [75].
Aggregate-binder adhesion is a very important property indicating stripping resistance, thus, it must be evaluated during mix design to avert the effect of stripping in asphaltic pavement surfaces. To this end, a number of laboratory tests including Rolling-Bottle-Test, static water storage, and detachment in boiling water test. In spite, the established widespread usage of detachment in boiling water, the study concluded that Rolling-Bottle test gives the best adhesion result. Furthermore, polymer modified asphalt with adhesion promoters employing granite aggregate yields improved adhesion properties [76].
The fact that polymer modified bitumen enhances emulsion-aggregate adhesion is not a refutable fact, however, the debatable issue among researchers is the accuracy (repeatability and reproducibility) of a test that could quantify the adhesion. Although, there exists a number of tests for this purpose, but the most widely accepted, especially in the US is the total water immersion test (TWIT). The test involves a visual assessment of bitumen-coated aggregates before and after soaking in water for a pre-determined period. Water seepage via cracked pavement surfaces is often associated with resulting from weaker adhesion, more so, compatibility between binder chemical constituent and aggregate mineralogy often dictates adhesion [77].

Aggregate chemical composition and type contributes to the final adhesion of characteristics of micro surfacing mixtures. It was opined that anionic emulsions are suited to positively charged calcareous aggregates like limestone while cationic emulsions are suited to negatively charged aggregates like granite [78]. However, contrary to that view, both negatively charged (alkaline) and acidic-nature aggregate (positively charged) aggregates are suitable for mixing with cationic emulsion whilst producing the desired adhesion in cold mixes [28].The great challenge with bitumen emulsion in the asphalt surfacing treatments industry is the pre-mature coalescence during mixing with aggregates, which hampers good binder-aggregate adhesion, hence, remains a subject among researchers [79]. Compatibility between emulsifiers/surfactants and aggregate chemical constituents contribute to the adhesion properties in the final micro surfacing mixture. Spent abrasives exhibits good adhesion, as mentioned earlier that the negative charge on aggregate binds with the positive charge of the emulsion. The fact is that garnet contains complex silicate mineral of divalent or trivalent ions $(SiO_2)^{-2 \text{ or } -3}$ which possess high affinity to cationic bitumen emulsion.

3.1.2 Curing and hardening process of emulsions. Depending on the category of the emulsion, (either Water in oil (W/O), oil in water (O/W), or multiple emulsions (W/O/W)) in addition to the type of the emulsion, the curing and hardening process is largely influenced by the nature of emulsion in terms of setting rates. The type of bitumen emulsion could be slow setting, medium setting or rapid setting either cationic or anionic, and surfactant's chemical composition influences curing and hardening of emulsions. Curing itself is a process of strength gain of the finally placed emulsion treatment, and it involves two distinct phases – breaking and setting [78]. It is similar to the curing of concrete, which entails increase in strength due to continuous chemical reaction between the binder (cement) and the continuous phase (water, chemicals, or steam).

Breaking refers to the loose of oil-oil repulsive forces when mixed with aggregate. In a cationic emulsion, the surface charge is positive and individual emulsion droplets repels one another, but when mixed with aggregate, say granite, the negative charges on the aggregates get attached to the positive cationic of the emulsion and adhere. Figure 2 depicts the charge transfer type between aggregate and emulsion.

The breaking and subsequent hardening process of emulsions in micro surfacing mixtures is practically characterised by a change in colour from brown to black.

The rate of breaking of cationic and anionic emulsions differs, the latter been slower, due to the fact that almost all surfaces are negatively charged, and with addition of an anionic emulsion the breaking process is forced by water evaporation [80].

An enhanced feature of bitumen emulsion is the polymer modified emulsions which incorporate either latex (natural or synthetic), or polymers. The addition of polymer enhances the rheological characteristics, reduces temperature susceptibility, and improved adhesion. These enhanced features makes polymer modified bitumen emulsions (PMBE) attractive for use in surface treatments for decades. PMBE are used for high performance heavy trafficked pavements in form of Microsurfacing and chip seals, the latter being less popular due to history of windshield breakage by loose aggregate [76].

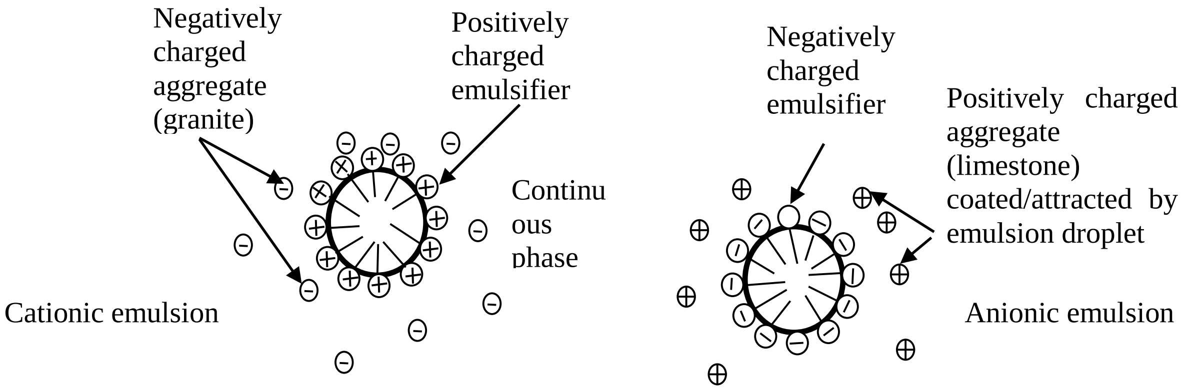

Figure 2. Ion exchange and curing process of cationic and anionic emulsions mixed with aggregate

The rate of strength gain or curing depends on how fast water escapes the surface from the emulsion, cationic quite set emulsions is a special type of emulsion specified in ASTM D 2397 which exhibit faster curing rate than normal emulsions [78]. The concentration of the cationic particles or anionic particles determines how fast an emulsion sets as well – the higher the charges the faster the setting.

The phenomenon of curing and hardening is a crucial aspect considered when choosing an emulsion for applications in peculiar situations like terrain, weather condition (humidity, wind speed, and temperature), available plant and pavement pre-treatment condition. Moreover, it depends on the emulsion viscosity which in turn is influenced by the water oil ratio (WOR), droplet size and its distribution and hydrophilic-lipophilic balance(HLB) [28], and discernably linked to the type of charge on the aggregate.

3.1.3 Aggregate-polymer-emulsion interaction. Waste Abrasive blast material are mostly of metamorphic origin in ultra-high pressure rocks, on a lesser scale in igneous rock formations as well

[81]. Polymer categories are distinct based on the charge of the emulsion by the surfactant used which invariably defines its category, whether cationic, anionic, non-ionic or amphoteric [28]. The charges on emulsions is lost when they contact with mineral aggregate – a process known as breaking of emulsions. The opposite charge from the aggregate hastens this process, thus, the compatibility between the charges on the emulsion and the aggregate is crucial in achieving the final desired micro surfaced pavement.

Waste abrasives are usually acidic in nature, thus, they are suited best with cationic emulsions. The opposite charge in the aggregate ensures better adhesion and retention properties.
The main concern in the use of bitumen emulsions is the stability under storage and during transportation, (Khan et al., 2016). However, other research reported rheological properties alleviation with the addition of SBR latex on unaged emulsion [82].

3.1.4 Emulsion-Aggregate adhesion influence on rut filling and skid resistance. As mentioned earlier, the chemical composition of aggregate and surfactant in a micro surfacing mix determines the quality of asphalt-solid adhesion. The bonding is attained through a destabilization of the emulsion, and this could take the form of chemical action, water evaporation or mechanically by contact with solid surface (aggregate). Quantifying adhesion in asphalt is important in understanding the stripping resistance of pavement, among the available tests for adhesion shear adhesion test and binder bond strength proved successful in this regard [83]. Heteroflocculation as opined to be a stepping stone to the destabilization of emulsions when mixed with aggregates, occurs only due to adsorption mechanism in the liquid-liquid interface of emulsion [84].

3.1.5 Advent of low-energy consuming binders. Asphalt binders that accommodate low temperature applications are often modified with specialized polymers to suit such requirements. Modification methods differs depending on the needed end result desired, while the chemical properties of some wastes like the waste cooking oil is altered to effect binder improvements [85], others are in form of additives like evotherm, cesabase are used to lower the mixing and placing temperature of asphalt mixtures, in addition, polymers are added to improve the rheological characteristics of such low-temperature binders [86]. This lowers the energy requirements, greenhouse gas emissions, construction cost, and health risks exposure to workers whilst improving workability, performance and sustainability [35,87]**.** However, achieving all these desirable functions relied on the quality of the emulsion itself, which also depends on the ingenuity of the formulator.

Production of asphalt emulsions is a daunting task which requires a lot of factors to be taken into cognizance, these includes the droplet sizes and their relative distribution, viscosity, chemical composition of the base asphalt and that of the surfactant [28]. Effect of SBR on emulsion is pronounced in terms of improving temperature susceptibility, but the high temperature performance is unsatisfactory, this led to using polyphosphoric acid in enhancing this property [88], so also adhesion and rheology [89].

4. The need to micro surfacing

The need for pavement maintenance argued to be required in curtailing the expensive rehabilitation and reconstruction strategy for deteriorated pavements [9]. Moreover, the extent of benefit from micro surfacing lies on the condition of existing surface, thus, in a highly deteriorated roads, the cost of maintenance far surpasses that for reconstruction. Choosing a timely application time is imperative to achieving value for money and optimal utilisation and service life extension of a pavement scheduled for maintenance [90], several other factors account to a sound pavement preservation treatment including weather, binder/emulsion type, and importantly material type/quality [90]. A rather divergent view of deciding/selecting suitable pavement maintenance is that which relies on intuitive technical considerations inclusive of two other factors highlighted by [91] as; top-management commitment to the program within the agency and a holistic enlightenment effort aimed at the end users. A larger proportion of the numerous pavement preservation treatments are applied at ambient temperatures, and provisions are made in regions where temperatures are expected to fall below 10^0C .However, the environmental condition, especially temperature, plays a vital role in the curing and hardening process in situations where water evaporation.

4.1 Qualities of a good micro surfacing mixture

The quality of a good micro surfacing treatment is measured by its resistance to wear from the tyres of moving vehicles over time. On the average, micro surfaced pavements should last for 5 to 7 years, however, deterioration may manifest before this time depending on a number of factors including surface pre-treatment condition. Moreover, skilled workmanship contribute to achieving a good micro surfacing mixture and surface.

Equally important to skilled operator is the quality of the constituent material in a micro surfacing mixture and the pretreatment condition of the pavement which the treatment is applied to, thus, the treatment will not last long in a structural defective roadway.

Several factors that culminates to limiting the power to control quality of a micro surfacing were researched into and solution proffered. Nonetheless, mix deign standardization is one that is still being explored

4.2 Significance of aggregate type, gradation and its influence in micro surfacing mixtures

The significance of gradation in the performance of micro surfacing is evident in the different classes of gradations set by the International Slurry Surfacing Association (ISSA A 134) in their technical bulletins where three varying gradations [17].

A number of research conducted on the suitable use of waste abrasives in construction revealed appealing results. Table 1 presents some researches on the use of spent abrasives' in construction applications. These abrasives belongs to the garnet family, and some possess less desirable characteristics than garnet.

Table 2. Selected researches on the use of some waste abrasives

Author/Year	Spent abrasive used	Methodology	Findings & future research
[63]	Nickel slag	Two grades of Nickel slag obtained from Air-cooled (AC) and Emergency Pit (EP) were used. Their mechanical and physical properties of the slag were studied. Asphalt pavement analyser (APA) was used to evaluate both Marshall and gyratory samples. In addition, autoclave disruption test for free lime detection was employed.	Both laboratory and field performance of a road in Duarte Highway near Bonao, Dominican Republic showed excellent performance after 5 years of construction
[92]	Nickel slag	The research aimed to develop a means of recycling ferrous nickel waste abrasive from the thousands of tons generated in Greek ship yards annually from open dry blasting. A mini blast laboratory was used to generate the blast waste using a grit size of 9.5mm nozzle at 100Psi pressure.	The study investigated the extent to which ferrous nickel slag could be recycled before being discarded as a waste abrasive. Result indicated an effective grit efficiency within the first three cycles of the blasting, also 80% reclamation can be achieved of the waste within the first 3 cycles.
[57]	Copper slag	Marshall stability, flow and volumetric parameters were studied on copper blast waste	Result suggested the favourable use of copper waste grit in asphalt concrete

		generated from Bahrain's ship yards	using 50/50 and 100/0 copper grit/sand ratio replacement by weight
[56]	Copper slag	Mortar cubes (25.4 x 25.4 mm) were casted using the grit and cement at various ratios by weight in (g/kg) as 1:1, 1:3, 1:4, of cement to grit, and a water/cement ratio of 0.5.	The use of copper spent grit in concrete was favourable, but the use of waste copper grit in reinforced concrete is discouraged.
[93]	Copper slag	Cement mortars and concrete mixes were prepared by replacing sand in percentages from 0 to 100%. Mortars were evaluated for compressive strength only, while concrete mixes were evaluated for flexural, tensile and compressive strength.	Mixes with 50% copper slag exhibited the highest compressive strength whilst, the durability, density, workability, flexural, tensile, and compressive strengths of concrete mixes with 40-50% copper replacement yielded better result than the control.
[94]	Spent garnet	Garnet was mixed with soil for road shoulder construction of village roads. Soil moisture content, CBR test, compaction, chemical content, Atterberg limits and gradation test.	Addition of waste garnet increased the Maximum dry density and an optimal 40 % by weight replacement of garnet yielded desired result.
[95]	Steel grit	Steel grit or hematite and garnet waste generation in comparison to the raw material feed in blasting was studied	All abrasive material could be recycled at least twice before loosing of blasting grit.
(Zakaria et al, 2016)	Aluminium oxide	Health risks associated to dry blasting in terms of particulate dust and respirable was studied	Airborne blast waste could be harmful to human.
(Khiyon, 2018) Garnet waste in concrete	Spent garnet	Influence of waste garnet in high strength concrete was studied using water/cement ratio of 0.33 and garnet replacement of 0% to 100% targeting a strength of 60MPa.	

4.3 Emulsion-Aggregate adhesion influence on rut filling and skid resistance
As mentioned earlier, the chemical composition of aggregate and surfactant in a micro surfacing mix determines the quality of asphalt-solid adhesion. The bonding is attained through a destabilization of the emulsion, and this could take the form of chemical action, water evaporation or mechanically by contact with solid surface (aggregate). Quantifying adhesion in asphalt is important in understanding the stripping resistance of pavement, among the available tests for adhesion shear adhesion test and binder bond strength proved successful in this regard [83]. Heteroflocculation as opined to be a stepping stone to the destabilization of emulsions when mixed with aggregates, occurs only due to adsorption mechanism in the liquid-liquid interface of emulsion [84].

5. Advances in micro-surfacing mixtures and way forward
Historical antecedents in pavement preservation started in the 1930s by using very fine aggregates, water and emulsion slurries has seen exponential advances courtesy of improvement in polymer science in the late 1960s. In addition to polymers, fibers and other specialised additives may also be added to suit peculiar situation [84]. Though a study that reviewed a forty years research effort towards formulating

a viable polymer with all the desired properties – which is rather not feasible, thus, some trade-offs must be made among the desired polymer features in selecting a suitable polymer type. Among the various methods of removing the setbacks in polymers viz; use of hydrophobic clay minerals, functionalisation, addition of antioxidants, the use of reactive polymers, saturation, and sulfur vulcanization, only functionalisation is recommended [26].

Functionalisation in terms of improving binder-aggregate adhesion, recyclability, and long-term performance was opined to be the best means of producing enhanced polymer to meet future challenges. United States remains a frontier in the use of micro surfacing for preserving its pavement, this is witnessed by its adoption among the departments of transportation (DoT) of virtually all the states [98]. Since micro surfacing uses typically quick set emulsions, future trends should be targeted towards functionalising emulsions in terms of adhesion with aggregates, long-term performance/ageing resistance, better storage stability and recyclability. Functionalisation is a means of discretely adding specific functional groups of some chemicals to polymers so as to effect specific changes or improvements. This is suggested to be a short term solution in the near future for solving the notable problems associated with emulsions [16,24].

6. Conclusion

Micro surfacing performance is a multi-dimensional and is viewed from varying perspectives ranging from type of gradation, characteristics of the constituent material, mixture performance, and on site performance. As bitumen modification unfolds and metamorphose to an advanced level in the near future, its application in emulsions for micro surfacing treatments will continue to witness varying researches in the area of industrial waste incorporation, use of bio oil-binders, recycling and many more. This is evident in the trend of studies in this areas highlighted in this review, though, not much work is done in the use of waste abrasive material like spent garnet in asphalt mixtures, yet, it is hoped future researches will explore the applicability of the numerous waste abrasives in pavement preservation treatments. The summary of researches conducted on other waste abrasives apart from garnet is a tip of an ice berg when compared to studies employing waste garnet. As highlighted numerous abrasive blast waste had gained application in pavement and concrete construction, thus, spent garnet which has some characteristic advantages over other abrasives can favourably be used as a replacement of fine aggregate in hot mix asphalt.

7. References

[1] Robinson H 2013 Slurry surfacing certification study guide *Highways* **82** 31–2
[2] Jamion N, Hainin M R and Yaacob H 2014 Performance of micro surfacing on expressway *J. Teknol.* **70** 125–9
[3] Zaniewski J and Mamlouk M 1999 Pavement Preventive Maintenance: Key to Quality Highways *Transp. Res. Rec. J. Transp. Res. Board*
[4] Laurance W F and Arrea I B 2017 Roads to riches or ruin? *Science (80-.).*
[5] Ismail M, Muhammed Z D, Farouk M, Usman K, Tanko A M and Adamu G 2014 Urban Growth and Housing Problems in Kubwa District of Bwari Area Council , Abuja , Nigeria *Glob. J. Res. Rev.* **1** 1–14
[6] Gautam P K, Kalla P, Nagar R, Agrawal R and Jethoo A S 2018 Laboratory investigations on hot mix asphalt containing mining waste as aggregates *Constr. Build. Mater.* **168** 143–52
[7] Capayova, S. Zuzulova, A. Schlosser T 2016 Road construction materials from the perspective of energy savings *16th Int. Mult. Sci. GeoConf. SGEM 2016, Book 4*
[8] Horvath A 2004 Construction Materials and the Environment *Annu. Rev. Environ. Resour.* **29** 181–204
[9] Torres-Machi C, Pellicer E, Yepes V and Chamorro A 2017 Towards a sustainable optimization of pavement maintenance programs under budgetary restrictions *J. Clean. Prod.* **148** 90–102
[10] Torres-Machi C, Osorio-Lird A, Chamorro A, Videla C, Tighe S L and Mourgues C 2018

Impact of environmental assessment and budgetary restrictions in pavement maintenance decisions: Application to an urban network *Transp. Res. Part D Transp. Environ.* **59** 192204
[11] Santos J, Flintsch G and Ferreira A 2017 Environmental and economic assessment of pavement construction and management practices for enhancing pavement sustainability *Resour. Conserv. Recycl.* **116** 15–31
[12] Bouteiller E L 2010 Asphalt Emulsion for Sustainable pavements *First Int. Conf. Pavement Preserv.*
[13] Santos J, Flintsch G and Ferreira A 2017 Environmental and economic assessment of pavement construction and management practices for enhancing pavement sustainability *Resour. Conserv. Recycl.*
[14] Labi S and Sinha K C 2005 Life-cycle evaluation of flexible pavement preventive maintenance *J. Transp. Eng.* **131** 744–51
[15] Hu C, Zhao J, Leng Z, Partl M N and Li R 2019 Laboratory evaluation of waterborne epoxy bitumen emulsion for pavement preventative maintenance application *Constr. Build. Mater.* **197** 220–7
[16] Sun Z H, Yu Q B, Wang T B, Yu B Y, Zhu G Q and Ma J 2014 The effect of asphalt and aggregate gradation on the low-temperature performance of asphalt mixtures for intermediate and underlying course
[17] Ye Y, Guo J and Hou F 2017 Effects of Aggregate Gradation on Drying Micro-Surfacing added by Waste Rubber Powders *IOP Conference Series: Materials Science and Engineering* vol 216 pp 0–5
[18] Lin C and Tongjing W 2018 Effect of fine aggregate angularity on skid-resistance of asphalt pavement using accelerated pavement testing *Constr. Build. Mater.* **168** 41–6
[19] McNally T 2011 *Polymer Modified Bitumen: Properties and Characterisation*
[20] Morian D A 2011 *Cost Benefit Analysis of Including Microsurfacing in Pavement Treatment Strategies & Cycle Maintenance.*
[21] Shafaghat A, Lonbar M S and Nasrazadani S M 2015 Investigation of aggregate and binder types effects on the microsurfacing rutting properties 0–12
[22] Zhang F and Hu C 2013 The research for SBS and SBR compound modified asphalts with polyphosphoric acid and sulfur *Constr. Build. Mater.*
[23] Sheng X, Wang M, Xu T and Chen J 2018 Preparation, properties and modification mechanism of polyurethane modified emulsified asphalt *Constr. Build. Mater.* **189** 375–83
[24] Yu R, Zhu X, Zhou X, Kou Y, Zhang M and Fang C 2018 Rheological properties and storage stability of asphalt modified with nanoscale polyurethane emulsion *Pet. Sci. Technol.* **36** 85–90
[25] Carrera V, Cuadri A A, García-Morales M and Partal P 2015 The development of polyurethane modified bitumen emulsions for cold mix applications *Mater. Struct. Constr.* **48** 3407–14
[26] Zhu J, Birgisson B and Kringos N 2014 Polymer modification of bitumen: Advances and challenges *Eur. Polym. J.* **54** 18–38
[27] Sufian Z, Aziz N A, Matori M Y, Hussain M Z, Hainin M R and Oluwasola E A 2014 Influence of active filler, Curing time and moisture content on the strength properties of emulsion and foamed bitumen stabilized mix *J. Teknol.* **70** 135–41
[28] Ronald M and Luis F P 2016 Asphalt emulsions formulation: State-of-the-art and dependency of formulation on emulsions properties *Constr. Build. Mater.* **123** 162–73
[29] McDonnell D E, Jabbari B, Spinella G, Mueller H G and Klara P M 1990 Delayed hearing loss after neurovascular decompression *Neurosurgery* **27** 997–1003
[30] JKR 2008 JKR/SPJ/2008-S4 Standard Specification for Road Works Part4 Flexible Pavement 1–187
[31] Kucharek A S, Keith Davidson J, Moore T and Linton T 2010 Performance Review of Micro Surfacing and Slurry Seal Applications in Canada *CTAA Annual Conference Proceedings-Canadian Technical Asphalt Association* vol 55 p 311

[32] Robati M, Carter A and Perraton D 2015 Evaluation of a modification of current micro-surfacing mix design procedures *Can. J. Civ. Eng.* **42** 319–28
[33] Robati M, Carter A and Perraton D 2013 Repeatability and reproducibility of micro-surfacing mixture design tests and effect of aggregates surface areas on test results *Aust. J. Civ. Eng.*
[34] Robati M 2014 Evaluation and Improvement of Micro-Surfacing Mix Design Method and Modelling of Asphalt Emulsion Mastic in Terms of Filler-Emulsion Interaction 238
[35] Gallegos C and García-Morales M 2011 Rheology of polymer-modified bitumens *Polymer Modified Bitumen* vol 1 pp 197–237
[36] FHWA 2009 *Polymer Modified Asphalt Emulsions - Google Scholar*
[37] Ezree M, Ahmad K, Rosli M, Akin E, Izzi N and Abdul N 2016 High temperature characteristics of warm mix asphalt mixtures with nanoclay and chemical warm mix asphalt modi fi ed binders *J. Clean. Prod.* **122** 326–34
[38] Abdullah M E, Zamhari K A, Hainin M R, Oluwasola E A, Hassan N A and Yusoff N I M 2016 Engineering properties of asphalt binders containing nanoclay and chemical warm-mix asphalt additives *Constr. Build. Mater.* **112** 232–40
[39] Wu Z 2015 Research on fiber micro-surfacing mixture design and pavement performance in interchange's connections *MATEC Web Conf.* **25** 1–6
[40] Hainin M R, Yusoff N I M, Mohd Satar M K I and Brown E R 2013 The effect of lift thickness on permeability and the time available for compaction of hot mix asphalt pavement under tropical climate condition *Constr. Build. Mater.* **48** 315–24
[41] Lonbar S M and Nazirizad M 2016 Laboratory Investigation of Materials Type Effects on the Microsurfacing Mixture *Civ. Eng. J.* **2** 86–94
[42] Huang S C and Di Benedetto H 2015 *Advances in asphalt materials: Road and pavement construction*
[43] Abdullah M E, Zamhari K A, Buhari R, Kamaruddin N H M, Nayan N, Hainin M R, Hassan N A, Jaya R P and Yusoff N I M 2015 A review on the exploration of nanomaterials application in pavement engineering *J. Teknol.* **73** 69–76
[44] Sin T J, Chen G K, Long K S, Goh I and Hwang H 2012 Current practice of waste management system in Malaysia : Towards sustainable waste management *1st FPTP Postgrad. Semin. "Towards Sustain. Manag.*
[45] Demirbas A 2011 Waste management, waste resource facilities and waste conversion processes *Energy Convers. Manag.*
[46] Kowalski K J, Król J, Radziszewski P, Casado R, Blanco V, Pérez D, Viñas V M, Brijsse Y, Frosch M, Le D M and Wayman M 2016 Eco-friendly Materials for a New Concept of Asphalt Pavement *Transportation Research Procedia*
[47] Huang Y and Parry T 2014 Pavement life cycle assessment *Green Energy Technol.*
[48] Inyim P, Pereyra J, Bienvenu M and Mostafavi A 2016 Environmental assessment of pavement infrastructure: A systematic review *J. Environ. Manage.* **176** 128–38
[49] Yamamoto T and Talvitie A 2011 Transport infrastructure and services: An Asia and developing world *Transportation (Amst).*
[50] Sangsefidi E, Ziari H and Mansourkhaki A 2014 The effect of aggregate gradation on creep and moisture susceptibility performance of warm mix asphalt *Int. J. Pavement Eng.*
[51] Mathew T V. and Rao K V K 2007 Pavement materials : Bitumen *Introd. to Transp. Eng.*
[52] Gautam P K, Kalla P, Jethoo A S, Agrawal R and Singh H 2018 Sustainable use of waste in flexible pavement: A review *Constr. Build. Mater.* **180** 239–53
[53] Johnny J . Bolden 2013 Innovative uses of Recycled and Waste Materials in Construction Application
[54] Wang G and Thompson R 2011 Slag Use in Highway Construction–the Philosophy and Technology of its Utilization *Int. J. Pavement Res. Technol.* **4** 97–103
[55] Oluwasola E A, Hainin M R and Aziz M M A 2015 Evaluation of asphalt mixtures incorporating electric arc furnace steel slag and copper mine tailings for road construction *Transp. Geotech.*

2 47–55
[56] Madany I M, Al-Sayed M H and Raveendran E 1991 Utilization of copper blasting grit waste as a construction material *Waste Manag.* **11** 35–40
[57] Al-Sayed M H and Madany I M 1992 Use of copper blasting grit waste in asphalt mixes in Bahrain *Constr. Build. Mater.* **6** 113–6
[58] Gorai B, Jana R K and Premchand 2003 Characteristics and utilisation of copper slag - A review *Resour. Conserv. Recycl.* **39** 299–313
[59] Murari K, Siddique R and Jain K K 2014 Use of waste copper slag, a sustainable material *J. Mater. Cycles Waste Manag.*
[60] Mroueh U M, Laine-Ylijoki J and Eskola P 2000 Life-cycle impacts of the use of industrial by-products in road and earth construction *Waste Manag. Ser.* **1** 438–48
[61] Modarres A and Rahmanzadeh M 2014 Application of coal waste powder as filler in hot mix asphalt *Constr. Build. Mater.* **66** 476–83
[62] Oluwasola E A and Hainin M R 2014 Jurnal Teknologi Characteristics and Utilization of Steel Slag in Road Construction **7** 117–23
[63] Wang G, Thompson R and Wang Y 2011 Hot-Mix Asphalt That Contains Nickel Slag Aggregate *Transp. Res. Rec. J. Transp. Res. Board* **2208** 1–8
[64] Bash E 2015 Abrasive Blasting *PhD Propos.* 97
[65] Buruiana D L and Bordei M 2011 Minimization and use of grit waste from surface cleaning operations *Metal. Int.* **16** 159–65
[66] Ling T C, Nor H M, Hainin M R and Lim S K 2010 Long-term strength of rubberised concrete paving blocks *Proc. Inst. Civ. Eng. - Constr. Mater.* **163** 19–26
[67] Abdullah M E, Zamhari K A, Buhari R, Nayan M N and Hainin M R 2013 Short Term and Long Term Aging Effects of Asphalt Binder Modified with Montmorillonite *Key Eng. Mater.* **594–595** 996–1002
[68] Noor W, Mior H and Mohamed A 2017 Characterization of Soil Mixed with Garnet Waste for Road Shoulder **9** 9–14
[69] Aletba S R, Hassan N A, Aminudin E and Jaya R P 2018 Marshall Properties of Asphalt Mixture Containing Garnet Waste *J. Adv. Res. Mater. Sci.* **43** 22–7
[70] Muttashar H L, Ariffin M A M, Hussein M N, Hussin M W and Ishaq S Bin 2018 Self-compacting geopolymer concrete with spend garnet as sand replacement *J. Build. Eng.* **15** 85–94
[71] Zhang H, Bai Y and Cheng F 2018 Rheological and self-healing properties of asphalt binder containing microcapsules *Constr. Build. Mater.* **187** 138–48
[72] Pal R 1996 Effect of Droplet Size on the Rheology of Emulsions *AIChE J.*
[73] Arshad A K, Ali N A, Shaffie E, Hashim W and Rahman Z A 2017 Rutting performance of cold bituminous emulsion mixtures *AIP Conference Proceedings*
[74] Oliviero Rossi C, Teltayev B and Angelico R 2017 Adhesion Promoters in Bituminous Road Materials: A Review *Appl. Sci.* **7** 524
[75] Materials K E, Nur W, Wan A, Universiti A, Bujang M, Putra R, Universiti J, Rosli M, Universiti H, Factor W, Highway G, View A, Material A, View E and Jaya R P 2016 Chemical Identification of Waste Cooking Oil as Additive in Bitumen 10–1
[76] Paliukaite M, Vorobjovas V, Bulevičius M and Andrejevas V 2016 Evaluation of Different Test Methods for Bitumen Adhesion Properties *Transportation Research Procedia* vol 14 pp 724–31
[77] Robinson H L 2004 *Polymers in Asphalt. Rapra Technology Limited* (United Kingdom)
[78] Yaacob H, Hainin M R, Aziz M M A, Warid M N M, Chang F L, Ismail C R and Hassan N A 2013 Bitumen emulsion in malaysia-a conspectus *J. Teknol. (Sciences Eng.*
[79] Khan A, Redelius P and Kringos N 2016 Toward understanding breaking and coalescence of bitumen emulsions for cold mix asphalts 1–13
[80] TxDOT 2005 Asphalt Emulsions. Construction Division, Texas Department of Transportation.

1–5
[81] Xia Q X and Zhou L G 2017 Different origins of garnet in high pressure to ultrahigh pressure metamorphic rocks *J. Asian Earth Sci.* **145** 130–48
[82] Warid M N M, Hainin M R, Yaacob H, Aziz M M A, Idham M K, Raman N A A and Mamat R 2015 Effect of styrene-butadiene on rheological properties of asphalt emulsion *J. Teknol.* **77** 1–5
[83] Zhou L, Huang W, Xiao F and Lv Q 2018 Shear adhesion evaluation of various modified asphalt binders by an innovative testing method *Constr. Build. Mater.* **183** 253–63
[84] Mercado R A, Sadtler V, Marchal P, Choplin L and Salager J L 2012 Heteroflocculation of a cationic oil-in-water emulsion resulting from fontainebleau's sandstone powder addition as a model for asphalt emulsion breakup *Ind. Eng. Chem. Res.*
[85] Maniruzzaman M A A, Rahman M T, Rosli Haininl M R and Abu W A W B 2016 Alternative binders for flexible pavement *ARPN J. Eng. Appl. Sci.* **11** 11868–71
[86] Yildirim Y 2007 Polymer modified asphalt binders *Constr. Build. Mater.* **21** 66–72
[87] Lu X and Redelius P 2002 Polymer modified bitumen *Recent Res. Dev. Appl. Polym. Sci.* **1** 501–28
[88] Tabatabaei S A, Kiasat A and Alkouhi F K 2013 The Effect of Styrene-Butadiene-Rubber (SBR) Polymer Modifier on Properties of Bitumen *World Acad. Sci. Eng. Technol. Int. J. Mater. Metall. Eng.* **7** 785–8
[89] Khattak M J, Baladi G Y and Drzal L T 2004 Binder Rheology, Morphology and Adhesion Effects on Asphalt Mixtures *Geotechnical Engineering for Transportation Projects*
[90] Dong Q and Huang B 2010 Cost-effectiveness evaluation of pavement maintenance treatments by OPTime *Geotechnical Special Publication*
[91] Hicks R, Moulthrop J and Daleiden J 1999 Selecting a preventive maintenance treatment for flexible pavements. *Transp. Res. Rec. J. Transp. Res. Board* **1680** 1–12
[92] Katsikaris K, Voutsas E, Magoulas K, Andronikos G and Stamataki S 2002 Recyling ferrous-nickel slag in blast cleaning *Waste Manag. Res.* **20** 269–78
[93] Al-Jabri K S, Al-Saidy A H and Taha R 2011 Effect of copper slag as a fine aggregate on the properties of cement mortars and concrete *Constr. Build. Mater.* **25** 933–8
[94] Noor W, Mior H and Mohamed A 2017 Characterization of Soil Mixed with Garnet Waste for Road Shoulder *UTM Colluquium* **9** 9–14
[95] Silvadasan X 2004 *Environmental Performance of Steel Grit and Specialty Sand as Abrasives*
[96] Zakaria H, Asmuin N, Ahmad M N, Hassan N and Sies M F 2016 Dust Monitoring Exposure: Abrasive Blasting Process *Int. J. Eng. Technol.* **8** 2537–40
[97] Khiyon M I 2018 *The Effects Of Spent Garnet In High Strength Concrete* (Universiti Teknologi Malaysia)
[98] Broughton B and Lee S 2012 *Microsurfacing in texas* vol 7

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