

Evaluation of Interlayer Bond Strength for C55 Emulsion Prime Bituminous Binders with Aggregates

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Abstract. The use of an environmentally and green friendly product for improved interlayer bond strength in recent times has gained interest in the construction industry. This study investigates the performance of the C55 Emulsion Prime when compared with the conventional MC30 prime in enhancing interlayer bond strength and overall adhesion potency with aggregate particles. The C55 Emulsion Prime is a bituminous-based binder designed to penetrate aggregate layers creating a cohesive bond that improves structural integrity and adhesion potency of the binder with aggregates. Through a series of laboratory tests conducted on the two samples, the study provides detailed results on the penetration depth, interlayer bond strength and application under wet conditions. The test results indicated that the C55 emulsion prime significantly enhanced interlayer bond strength with the G1 dolerite aggregate with notable improvement to moisturized or wet surfaces. The C55 Emulsion Prime demonstrates superior interlayer bond strength compared to MC30 Cutback Bitumen Prime in wet regions or when dry aggregate condition is not feasible. The C55 Emulsion prime has a rapid curing rate within 60mins of application to a wet surface making it an efficient protective layer over granular surfaces to adhere and form a good bond strength property with the asphalt layer. This superiority is evident in both the direct shear test, rolling bottle tests, penetration power test and Zeta Potential test making C55 Emulsion Prime a more reliable choice for enhancing pavement performance in accordance with environmental friendliness and climate change sequences. Furthermore, the adhesive strength of the emulsions can be determined by identifying the isoelectric point (IEP). IEP is the pH condition where the surface charge = 0 mV. The IEP of C55 is approximately at pH 4.1. The IEP of the MC30 has been extrapolated to be approximately at pH 2.1. Material where the IEP is at higher pH form the strongest bond because they have a high proton acceptability. It can be predicted that the C55 forms a stronger bond with the aggregate when compared to MC30.

Introduction

The interlayer bond strength for bituminous products for either a prime or tack-coat is a critical factor in pavement performance. This property has the potential to affect the durability, stability in relation to the bond force and longevity of the pavement layers [1]. In some instances, this results to slippage failure as presented in Fig 1. This failure mode is a type of delamination of the surface layer that has come loose from the subsequent or interacting pavement layer when subjected to traffic loading. Furthermore, this may be as a result of poor bond strength between the pavement interlayers.





Figure 1: Slippage failure and surface layer delamination of pavement surfaces [2;3]

The interlayer bond strength between asphalt layers is crucial for maintaining the structural continuity of the pavement. A weak bond can lead to slippage between layers, causing premature failures such as shear deformation, reflective cracking, and even delamination under repeated traffic loads [4]. The integrity of the bond is particularly important in high-stress areas, such as curves, intersections, and areas subjected to heavy traffic loads, where the pavement is more susceptible to damage [5]. This study developed by CSIR for EP International compares the interlayer bond strength between two prime coat products: C55 Emulsion Prime and MC30 Cutback Bitumen Prime. The C55 Emulsion Prime is a cationic based emulsion prime while the MC30 is a Cut-Back Bitumen product. Although, bitumen emulsions have been in use for more than a decade and over time proven to fulfil performance requirements for liquid bitumen applications [6]. Fig 2 and 3 provide a global use for bitumen. During this period the most widely used liquid bitumen is Cut Back Bitumen with the MC30 Primer used to bind granular layers to asphalt layers. The formulations and material specification data to develop MC30 bitumen with hazardous effects has prohibited its use in many countries. Thus, global use, production and application of liquid bitumen (emulsions) has resulted to the development of various types of environmentally and economically friendly bituminous emulsion products which makes it a stable use in road construction products.

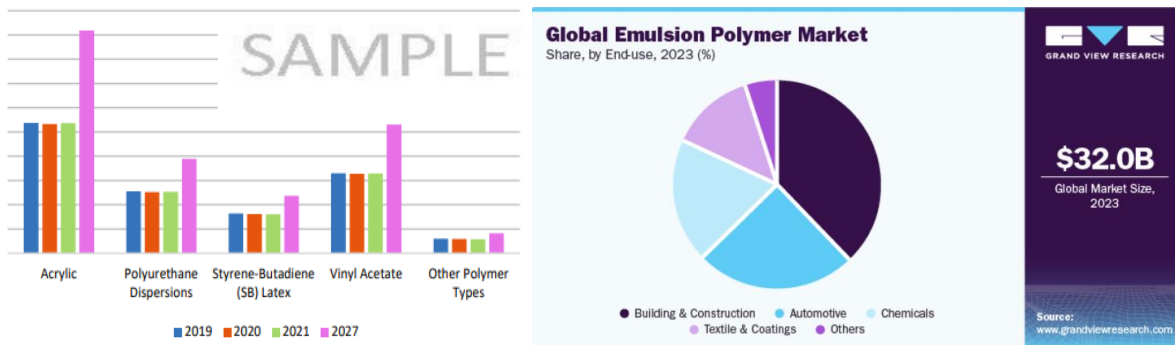


Figure 2: Global Emulsion usage by type. [7], Figure 3: Global Emulsion usage by volumes. [8]

Bituminous emulsions are colloidal dispersions of (*conventional or modified*) bitumen droplets in an aqueous phase, composed of water and one or more anionic and cationic emulsifying agents, in addition to other additives such as latex for modified emulsions, which have the purpose of dispersing the bitumen, ensuring the emulsion is stable and guaranteeing adhesion to aggregates at room temperature [9]. The main characteristic of bituminous emulsions is that they can be used as a binder at lower temperatures than other grades of bitumen, even at room temperature. Furthermore, emulsion bituminous consistency allows them to be used as a tack coat or prime coat to improve adhesion between the different layers of the road surface courses bound with aggregates layer or asphalt layer. This is achieved during the emulsion-breaking process, where the free bitumen particles provide cohesion to the pavement. Bituminous emulsions are the fundamental factors in the development of cold-mix technology for roads. Although, modified bituminous

emulsions can be used in road surface layers that require high performance in the presence of heavy-duty traffic and adverse weather conditions, guaranteeing excellent bonding between layers and exceptional cohesion to aggregates [10]. The primary objective of this study is to evaluate and compare the interlayer bond strength property between C55 Emulsion Prime and MC30 Cutback Bitumen Prime under controlled laboratory conditions. However, field representation on a pilot site is still anticipated as essential for the localization of the C55 Emulsion product for African and Tropical regions as well as its application over swampy or wet granular layers. In addition to also evaluate C55 emulsion Prime product application on damp or wet surfaces; enhanced performance of the prime product regarding trafficability within 60 minutes without tyre pickups; Evaluation for same-day paving of asphalt layer over primed surface. Furthermore, a preliminary classification of the Emulsion was conducted based on the BT4 test [11]. The results from the SANS 4001 BT4 emulsion test report indicates that the 55% by proportion of Binder content is also in accordance with [12] and 56.17% in accordance with [13].

Literature Review

C55 emulsion prime and MC30 cutback bitumen are both used as prime coats in pavement construction to promote adhesion between the base layer and the asphalt overlay [10]. However, bituminous emulsion binders chemical compositions, application techniques (*wet and dry conditions*), and environmental impacts differ significantly, leading to varying performance characteristics in pavement applications. This study explores the differences between C55 emulsion prime and MC30 cutback bitumen prime, focusing on their performance effectiveness in enhancing interlayer bond strength, durability, and environmental considerations. C55 emulsion prime is a water-based bitumen emulsion that is designed to penetrate and bind with the aggregate base [14]. It consists of fine bitumen droplets suspended in water, stabilized by emulsifying agents. Upon application, the water evaporates, leaving behind a bitumen film that adheres to the aggregate particles. The use of water as a carrier medium makes C55 emulsion prime more environmentally friendly, as it emits fewer volatile organic compounds (VOCs) compared to solvent-based alternatives [15]. MC30 cutback bitumen, on the other hand, is a solvent-based material, where bitumen is dissolved in a petroleum-based solvent to reduce its viscosity for easier application. After application, the solvent evaporates, leaving a bitumen residue that acts as a binding agent for the aggregate. While MC30 cutback bitumen has been widely used due to its effective penetration and strong bonding properties, its use raises environmental concerns due to the release of VOCs during solvent evaporation [16]. The durability of prime coats is crucial for the longevity of pavement structures. C55 emulsion prime, with its water-based formulation, tends to be more environmentally friendly and less hazardous than solvent-based MC30 cutback bitumen. The reduced environmental impact of C55 is due to the absence of VOCs, which are significant contributors to air pollution and health risks [17]. Moreover, C55 emulsion primes have been found to perform well under a variety of environmental conditions, maintaining their bonding properties even in the presence of moisture. This characteristic is particularly advantageous in areas with high rainfall or where construction timelines are tight, and the base layer may be exposed to moisture before the asphalt overlay is applied [18]. On the other hand, the durability of MC30 cutback bitumen is influenced by the rate of solvent evaporation and the subsequent curing process. In a case where the solvent does not fully evaporate before the asphalt overlay is applied, it can result to reduced interlayer bond effectiveness and potential bleeding of the bitumen into the overlay [19]. Additionally, the environmental concerns associated with VOC emissions has resulted to increased global green gas regulatory scrutiny and a gradual shift towards the use of emulsion-based primes like C55 in many regions [20]. [21], conducted field studies comparing C55 emulsion

prime and MC30 cutback bitumen aimed to provide valuable insights into their real-world performance. In general, C55 emulsion prime in this study investigates consistent performance with good penetration and effective bonding under a wide range of temperatures. The ease of application and quick curing time make it a practical choice for projects with tight schedules or environmental restrictions. On the other hand, MC30 cutback bitumen, while effective in achieving deep penetration and strong initial bonds, has shown variability in performance depending on environmental conditions. In warmer climates, the solvent can evaporate too quickly, leading to reduced penetration and potential issues with bonding [22]. Conversely, in cooler climates, slow evaporation can delay construction timelines and lead to weaker bonds.

Overall, the trend in the industry is moving towards greater use of environmentally friendly options like C55 emulsion prime, particularly as sustainability and regulatory compliance become increasingly important in construction practices [23].

Methodology and Testing

This study highlights several tests to aid in the evaluation of the adhesion of the C55 and MC30 prime with aggregates as this synonymously serves as the basis for improving interlayer bond force between a granular layer and an asphalt layer. The following tests to measure interlayer bond strength considered were Direct shear test, Rolling Bottle Test, Zeta Potential Test on aggregate adhesion.

Direct Shear Bond Test: The Direct Shear Test was one of the selected laboratory procedures used to evaluate the interlayer bond strength of bituminous materials. This test measures the shear strength between layers in a bituminous pavement structure, providing valuable data for assessing the performance and durability of the pavement.

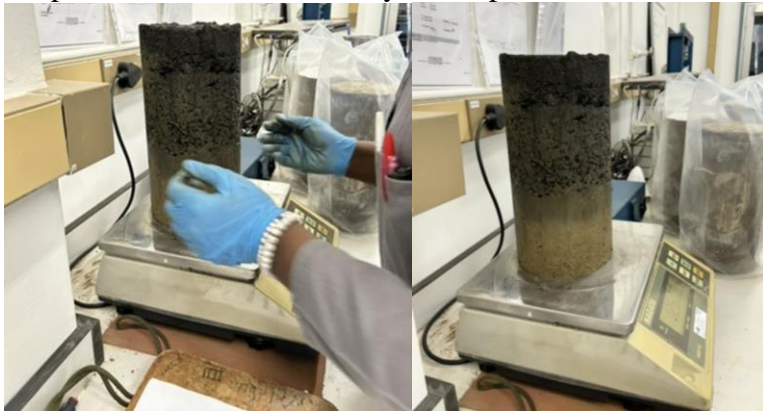


Figure 3: Direct Shear Sample Preparation for C55 and MC30

Asphalt specimens were prepared using a standard shear mold, with each specimen consisting of three layers with the top asphalt layer bonded to a granular G1 layer by the two prime coats (C55 emulsion Prime and MC30 Prime) Fig 3. The two granular layers used were G1 (Dolerite) for the base and G5 as the subbase (SANS 3001). The C55 emulsion prime specimens was applied at room temperature to the surface of the G1 material and this cured within 60mins after being applied to the wet/moist G1 granular surface, afterwards the asphalt layer was applied and compacted ready to be tested in the shear machine. The MC30 prime was applied to the surface of the G1 material at room temperature. Due to the nature of Cut-Back bitumen products, the MC30 prime was only applied to the surface G1 material after 72 hours to a dry surface. Although, this did not provide sufficient time for the G1 material to be dried enough to ensure a stable bond between the asphalt layer and the G1 granular layer while in the mold. Three samples each were prepared to be

tested for the two products (C55 Emulsion Prime and MC30 Prime). The peak shear load at which failure occurs for each of the samples on each of the three load cells (50MPa, 100MPa and 150MPa) was identified and recorded Fig 4a and 4b.

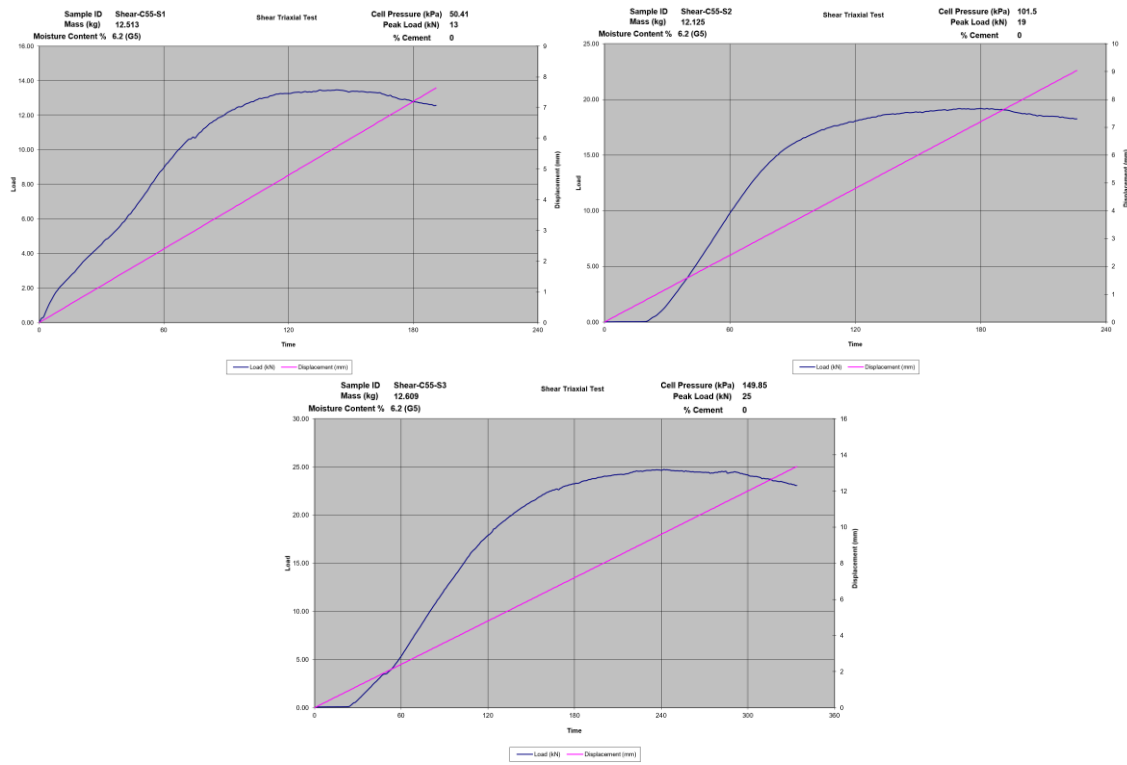


Figure 4b: Shear Test Results for three different load cells MC30

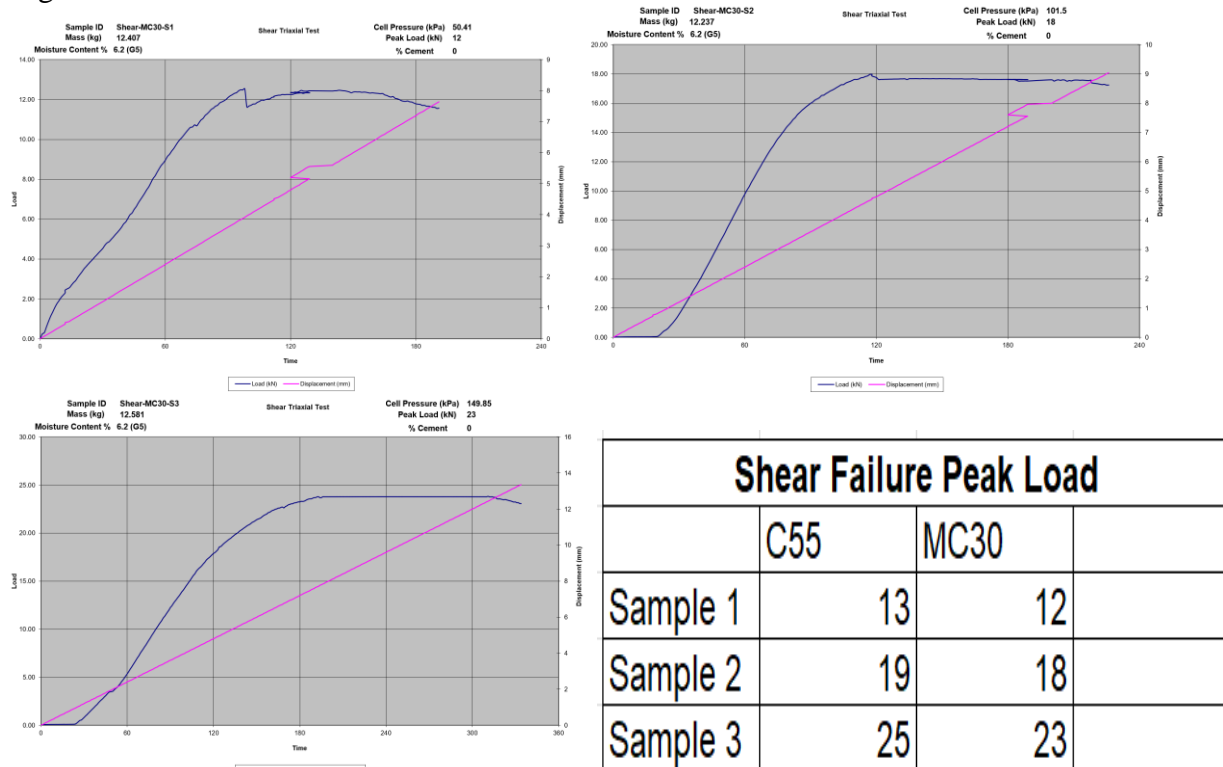


Figure 4b: Shear Test Results for three different load cells MC30 and Comparison
Each sample was tested on three different load cells 50MPa, 100MPa and 150MPa load application rates to failure. The shear failure for each of the comparative specimens are as presented in Fig 4b.

Rolling Bottle test sample preparation: The rolling bottle test procedure was further recommended to provide a verification of the results of interlayer bond strength on the two products. The Rolling Bottle Test was used to evaluate the adhesive properties and bond strength of bitumen to aggregate. This test simulates the interaction between bitumen and aggregate under dynamic conditions, providing insight into the effectiveness of the bitumen as a bonding agent. Two samples of 194g of aggregate passing 14mm, retained on 10mm were washed and preheated for 1 hour at 163°C. 6g of C55 and MC30 were also heated at 163°C separately. The aggregate and C55 were mixed thoroughly and reheated at 163°C. The MC30 and the other aggregate samples were also mixed thoroughly and reheated at 163°C for 15 minutes Fig 5.



Figure 5: The coated aggregates before rolling bottle test

The two mixtures were then placed in two separate 1 liter glass jars filled with distilled water and allowed to cool for 24 hours. After cooling, the two glass bottle samples were placed in a rolling machine and allowed to roll for 96 hours Fig 6.



Figure 6: Rolling Bottle test with the C55 and MC30 Prime subjected to the mechanical rolling machine

The specimens were subjected to an aggregate conditioning dynamic rolling to determine the interaction and adhesion property between the two bituminous samples (C55 Emulsion Prime and the MC30 Prime). The two bituminous prime samples (C55 and MC30) were conditioned over the aggregate. The conditioning process was taken to ensure proper coating of the aggregates. The coated aggregates were allowed to cool to room temperature. A specified amount (mass by weight) of coated aggregates was placed into each rolling bottle. The bottles were then rotated at a constant speed of 60 rpm for a specified duration (of 72 hours). After the rolling period, the bottles were carefully opened, and loose material was collected Fig 7. The coated G1 aggregate sample was inspected for signs of stripping or loss of bitumen adhesion during the mechanical rolling stage.



Figure 7: Visual Investigation of the adhesion of the prime products: A. C55 Emulsion Prime and B. MC30 Cut-Back Bitumen Prime.

Zeta Potential Test: The Zeta Potential test procedure was also recommended to provide a verification of the results of adhesion of the Bituminous product to aggregates. Zeta potential is one of the key indicators of the electrostatic interactions between particles in a suspension. This was used to assess the adhesion properties of the C55 and MC30 Prime on aggregate samples and to reflect the stability and behavior of the bitumen-aggregate interface. The measurement of zeta potential provides compatibility and bonding efficiency between bitumen products and aggregates, which is a crucial factor in evaluating the adhesive durability of asphalt pavements. In addition, Zeta potential is an indication of the electrical potential on surfaces of materials at the slipping plane. This plane is usually the interface which separates mobile fluids from fluids that remain attached to the surface of another medium in this case bitumen prime (C55 and MC30) and aggregate medium. The zeta potential for macroscopic solid surfaces of aggregates and bitumen binder (C55 and MC30) at different pH levels were measured using the SurPASSTM 3 device. The [24] device for zeta potential analysis of macroscopic solid surfaces is shown in Fig 8. [24] was used to analyze the samples in this study.



Figure 8: SurPASSTM 3 series [24]

The zeta potential definition by [25] is the charging behavior at a solid-liquid interface that can be generated by either acid-base reactions of functional groups and/or the adsorption of ions. Usually, it is observed that the zeta potential is determined by the measurement of an electrokinetic effect generated by a tangential flow of liquid across the solid surface in this case the aggregate material (G1-Dolerite), the method is referred to as the streaming potential technique.

The surface potential (bond strength on aggregates) was determined as a function of pH in a 0.001 Potassium chloride (KCl) electrolyte solution. Measurements for zeta potential were carried out at each pH point. An electrolyte solution was passed through the aggregate sample. The aggregate samples were cautiously washed with sodium chloride (NaCl) electrolyte solution to exclude particle sizes less than 25 μm before conducting the test. The permeability index was monitored and adjusted to fit a range of 85 – 115 to acquire accurate zeta-potential readings. A pressure range of 100 mbar – 400 mbar was then applied between both ends of the aggregate sample plug. The bitumen sample was measured using a gap cell and followed a similar procedure as used for aggregates samples, with the same electrolyte solution. The equipment pH electrode was calibrated at three buffer standard solutions of known pH value (pH 4, pH 7 and pH 10). The conductivity electrode was calibrated using a 0.1 mol/l KCl solution or a conductivity standard solution. Electrokinetic techniques were used to determine the measurement of the zeta potential of the aggregate particles and the Bituminous Primes as a function of the pH of the electrolyte. A representation of the zeta potential vs pH curve with three separate pH regions that characterize the aggregate surface chemistry under different aqueous conditions is shown in Fig 9.

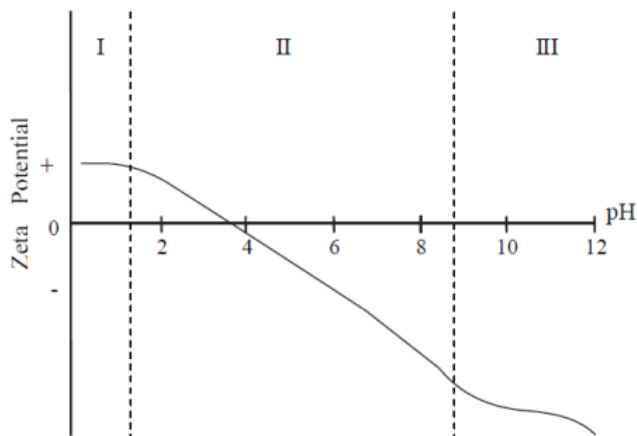


Figure 9: A characterization of aggregate surface chemistry pH regions [26]

The representation of the test results indicates that a relationship is established on the rate of adhesion between aggregates and binders by correlating its behavior with fundamental relationship between zeta potential, isoelectric point and acid base protons transfer properties with increasing pH levels. For this test, the zeta potential was performed on the aggregate and bitumen samples at various pH levels. The relationship between the zeta potential and pH of the aggregates is shown in Fig 10.

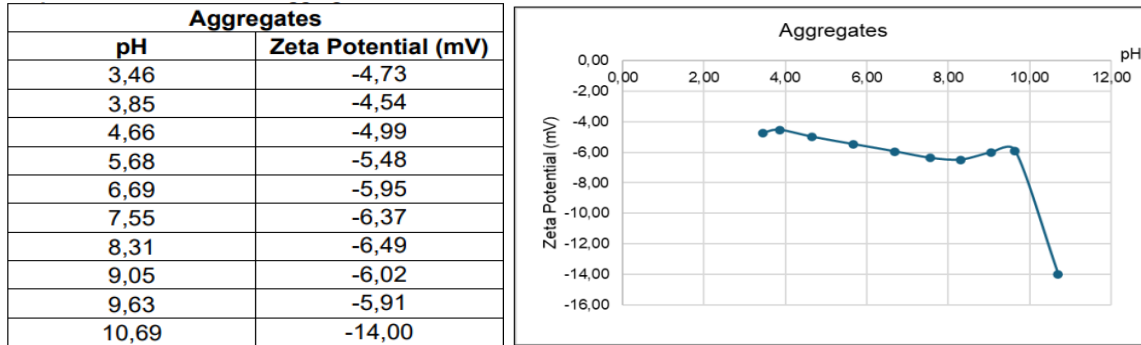


Figure 10: Relationship between the Zeta potential and pH of the aggregates

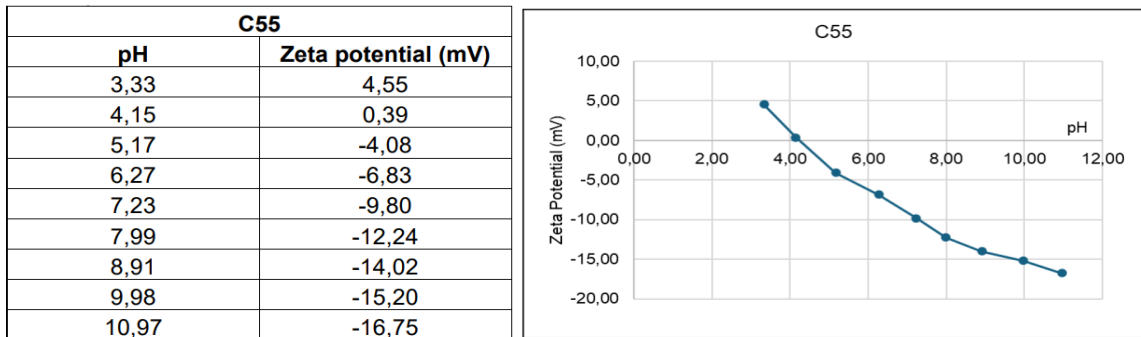


Figure 11: Relationship between the Zeta potential and pH of the C55 Emulsion Prime

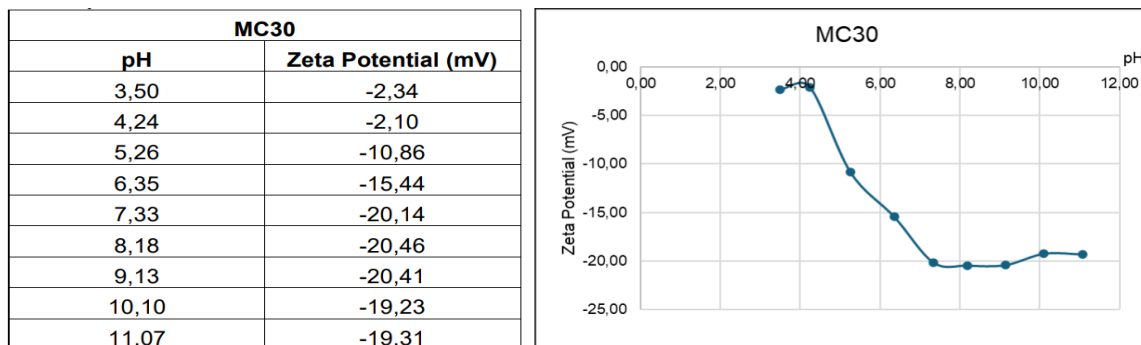


Figure 12: Relationship between the Zeta potential and pH of the MC30 Prime

The relationship between the Zeta potential and pH of the Bituminous products are shown in Fig 11 and 12 respectively. From the graphs, it is observed that the aggregates showed decreasing trend in Zeta potential with increasing pH from -4.73 to -14.00. Consequently, the Bituminous products showed differential behaviors in pH levels. The MC30 showed negatively charged surface with

increasing pH levels from -2.34 to -19.31. The C55 Emulsion Prime showed a positively charged surface levels from +4.55 to - 16.75. This relationship indicates that since the C55 Emulsion has more positively charges it has increased potential to adhere and bond with the aggregates compared to the MC30 Prime without stripping. This thus indicated that the formulation in the C55 Emulsion Prime has anti stripping agents that ensures improved adhesion of the bituminous Prime to aggregates. The [27] dissertation stated that bitumen conventionally has a net acidic character, where function groups such as carboxylic acids will act as proton donors. These proton donors tend to form more durable bonds with strong protons accepting aggregate surfaces. Thus, there is a higher susceptibility for proton acceptability between the C55 Emulsion prime and the aggregate material which has the potential to form stronger bonds compared with the MC30 prime.

Conclusion

Based on the test results, C55 Emulsion Prime demonstrates superior interlayer bond strength compared to MC30 Cutback Bitumen Prime in wet regions or when dry aggregate condition is not feasible. The C55 Emulsion prime has a rapid curing rate within 60mins of application to a wet surface making it an efficient protective layer over granular surfaces to adhere and form a good bond strength property with the asphalt layer. This superiority is evident in both the direct shear test, rolling bottle tests [28], penetration power test and Zeta Potential test making C55 Emulsion Prime a more reliable choice for enhancing pavement performance in accordance with environmental friendliness and climate change sequences. Furthermore, the adhesive strength of the emulsions can be determined by identifying the isoelectric point (IEP). IEP is the pH condition where the surface charge = 0 mV. The IEP of C55 is approximately at pH 4.1. The IEP of the MC30 has been extrapolated to be approximately at pH 2.1. Material where the IEP is at higher pH form the strongest bond because they have a high proton acceptability. It can be predicted that the C55 forms a stronger bond with the aggregate when compared to MC30. This consolidated technical report provides a comprehensive comparison of the interlayer bond strength of C55 Emulsion Prime and MC30 Cutback Bitumen Prime, offering valuable insights for pavement construction and maintenance. Previous study has indicated that more aggregate bonding can be achieved with other aggregate types [29] using the C55 Emulsion Prime with Limestone, Dolomite, Andesite or Quartzite. The penetration power test conducted in accordance to [30] demonstrates that the C55 emulsion prime has improved effective penetration depth compared to the MC30 prime.

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