

Rheological criteria assessment of a rapid setting emulsion as compared to quick set for emulsified asphalt cold mixes

K R Usman^{1,2}, M R Hainin^{1*}, M K I Satar¹, M Naquiuddin M Warid¹, Grawira Ganjur Giwangkara¹

¹School of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

²Department of Civil Engineering Technology, School of Engineering Technology, Nuhu Bamalli Polytechnic Zaria, P.M.B 1061, Zaria, Kaduna State, Nigeria

Email: mrosli@utm.my

Abstract. Pavement deterioration is inevitable on roads. Unlike structural failures that can only be remedied by total reconstruction, road's functional failures are corrected through effective maintenance works. Preventive maintenance in the form of an emulsified asphalt cold slurry micro-surfacing is considered superior to corrective maintenance – which is a reactive approach. Exploring alternative(s) to the normal quick setting emulsion used for pavement preservation maintenance will make it more robust and cost-effective. This study conducted an assessment of the key parameters specified by the department of public works (Jabatan Kerja Raya) JKR-2008 and International Slurry Surfacing Association (ISSA A143) specifications for emulsified asphalts emulsions used for cold mixes, specifically, emulsified asphalt micro-surfacing mixtures used for pavement maintenance. Cationic quick set (CQS-1h) and Rapid Set (RS-1k) emulsions were tested in the Transportation laboratory of UTM under controlled laboratory conditions. Tests include settlement and storage stability, particle charge, residue by evaporation, sieve test, and Say bolt Furol viscosity, while the residue from evaporation was tested for microstructural and mechanical performance, results were compared with JKR-2008 and ISSA A143 standard specifications. The result indicated that although the desirability for opening traffic within 1hr is not guaranteed with RS-1k, yet, it gives promising similar properties with CQS whilst satisfying cold mix requirement.

1. Introduction

Cold mixtures comprise unheated aggregate, emulsified asphalt, water, filler and a hydraulic binder mixed and laid at ambient temperatures. 'Micro surfacing' or micro-surfacing as interchangeably written by researchers is a form of cold emulsified mixture which received accolades as the advanced form of slurry seals, being applied to a structurally viable pavement wearing course to restore back the desirable riding features of a typical wearing course and to ultimately extending the life of the pavement. It is typically a mixture of quick setting polymer modified emulsified asphalt emulsion, cement or inert mineral filler, portable water, chemical additives, and bulk of good well-graded fine aggregate (coarse aggregate may be used depending on the gradation type, extent of road's pretreatment condition and intended distress types to be addressed) [1]. It is favoured as a better option amongst other pavement preventive maintenance techniques as it requires less energy for application



and less setting time. This will enable the road to be open to traffic in less than an hour. Furthermore, cold mix micro surfacing requires minimal non-renewable resources, can be applied in double stone thickness, viable for night-time applications, and produces zero greenhouse gas emission as it is cold mixed and laid [2]. It is applied basically for road's cross-section profile restoration, rut filling, and weatherproofing [3].

However, the usual practice is to use a quick set emulsion as the binder in the mixture and lack of investigation on the suitability of emulsions with similar properties to the quick set emulsions for use in micro-surfacing. The fact that set control additives are added to quick set emulsions [4] in order to slow their fast set to enable thorough laying may serve as a yardstick for exploring emulsions with a bit slower setting rate than the quicksets which would invariably not need additives to retard setting. In addition, specially formulated polymers like Styrene-Butadiene Rubber (SBR) and many others are used to cause desired changes in cold mixtures [5]. These perhaps, add a wide-ranging option available to contractors when undertaking maintenance works, especially cold mixtures.

Preventive maintenance is a facelift strategy geared towards restoring the functional performance of the existing pavement. Thus, it is applied to structurally sound roads. The justification for adopting preventive maintenance technique has long been established [6]. The fact that government transportation agencies could not bear the burden of enormous expenditure on rehabilitation, reconstruction or resurfacing of deteriorated pavements alone, coupled with the need for energy-saving, cost-efficient, environmentally friendly, and sustainable road maintenance program, it is well justified to be adopting preventive maintenance. Preventive maintenance is applied for certain specific candidate roads, at some point in their life cycle, using specially formulated material (cold mix) and techniques, and suited for specific weather conditions. The functional parameters to restore include skid resistance, re-profiling and correcting rut depths, enhancing water resistance, curbing ageing and oxidation whilst restoring aesthetics [7]. Though, the success of these treatments is rated based on its long term performance, amongst other numerous criteria [8]. These criteria includes cost-effectiveness [9,10] and life cycle costing [11], material type effect [12] or even pavement pretreatment condition [1].

Micro-surfacing is a favoured technique amongst its pairs of pavement preventive maintenance for it could be applied at night, laid in double stone thickness, saves the expensive road markings on expressways or autobahns (as in Germany), minimal traffic interruption – roads can be open to traffic within 45 minutes to one hour of application and could ultimately fill rut up to one-inch (1”) depth. Micro-surfacing employs the use of a mixture of well-graded aggregates and filler, polymer modified emulsified asphalt emulsions – notably cationic quick set, water, set control additives, and latex (either natural or synthetic). It is a rejuvenating asphalt layer used to prevent moisture damage, restore functional features of the pavement including skid resistance, ageing, and raveling.

An appreciable effort has been geared towards improving the performance of emulsified asphalt cold mixtures [13], especially, its low early strength [14], slow strength development [15], poor adhesion [16], moisture susceptibility [17] and rutting resistance. In spite of these efforts, yet, one major problem remains the slow rate of curing of the slow and medium set emulsions used traditionally for cold mixtures. Hence, the need to explore alternative options polymer modified emulsified micro surfacing mixtures utilises quick set emulsions.

2. State-of-the-art

One of the reasons for checking the suitability of rapid set emulsion is to serve as a paradigm shift of usage from the traditional quick set emulsion – which is always regarded as the only type of emulsion suitable for micro-surfacing. So far, numerous researches and even the industry uses polymer-modified quick set and slow to medium set emulsions [18] for micro-surfacing and cold mix maintenance mixtures respectively [1,2,5,19]. Among the overarching issues with cold mix patching mixtures remains the low early strength, slow rate of curing, slow rate of strength gain, high void/porosity, and high moisture susceptibility.

Table 1. Requirements for emulsified asphalts and residue for use in cold mix.

TEST	STANDARD SPECIFICATION		SPECIFICATION JKR/ISSA A 143
	ASTM	AASHTO	
TEST ON EMULSIFIED ASPHALT			
Particle charge	D7402		Positive
Saybolt Furol Viscosity	D 7496	T 59	15 – 50 secs
Storage stability (1 day)	D 6930	T 59	1% Maximum
Settlement test (5 days)	D 6930	T 59	1% Maximum
Residue by evaporation	D 6934		62% Minimum
TEST ON EMULSIFIED ASPHALT RESIDUE			
Penetration	D5		40 - 90 mm
Softening point	D 36		57 °C/54 °C (135 °F) Min.
Viscosity (rotational)	D 4402		NA
Solubility in trichloroethylene	D 2042		90% min

For decades, the tradition has been the use of quick set emulsion in cold mix pavement maintenance and micro surfacing mixtures [20,21], in addition, medium to slow set is also applicable in patching cold mixtures, but no identifiable evidence of the use of rapid set emulsion in cold mixtures. Thus, the standard requirements pulled from both ISSA A143 and JKR as depicted in table 1 is used as a guide to access the potentiality of RS-1k emulsion in comparison to CQS-1h for such purposes.

3. Materials and experimental detail

3.1. Rapid set emulsion (RS-1k) and Quickset emulsion CQS-1h

Historically, emulsions were developed in the early nineteenth century for dust control in farms and rural roads in line with environmental pollution concerns associated with volatile solvent associated with cutbacks, eventually gaining recognition for use for paving applications in the twentieth century. Asphalt emulsions are a dispersion of bitumen in water with the aid of a surface-action agent (SurFactAnt) popularly known as an emulsifier. The emulsifier imparts charge on the surface of the tiny globules of bitumen, making these particles to repel one another and remain in suspension, it actually keeps the asphalt particles stable in suspension. Emulsions become destabilised in three ways; by chemical alteration, contact with aggregate (opposite charge), and mechanical agitation [22]. Thus, for this reason, this study adopted a placid agitation on the emulsion each time the emulsion will be used for testing/mixing to ensure proper even distribution of asphalt particles and water, whilst avoiding destabilisation. Both samples of emulsions were obtained from Johor state of southern Malaysia.

The rapid set emulsion RS-1k was obtained from Viking Sdn. Bhd., Johor Bahru in Southern Malaysia. The emulsion is a cationic rapid set type emulsion with medium to low viscosity – as the designation ‘1k’ implies, this means storage is required at lower temperatures. Bina Masyhur Sdn. Bhd. provided the quick setting polymer modified emulsified asphalt, it is a medium viscosity hard grade emulsion designated as CQS-1h.

Traditionally, rapid set emulsions are formulated for use in spray applications meant to revert quickly to the base bitumen upon contact with the substrate in a similar manner to a quick set asphalt emulsion which sets immediately upon contact with an aggregate surface. The notable difference is that the quick set emulsion must be modified to suit emulsified asphalt micro-surfacing cold mix applications [23][24]. While rapid set emulsions may or may not be polymer-modified, oftentimes it is

not. Polymer modification is done to effect changes in the rheological characteristics of the emulsion, which eventually enhances mechanical performances of asphalt mixes in form of greater rutting and thermal cracking coupled with reduced temperature/moisture susceptibility, raveling and fatigue cracking. A number of varying polymer types, either natural or synthetic are in use over decades, ranging from thermoplastic to thermosetting [5,25,26] to waterborne epoxies [27,28].

Laboratory tests conducted include in addition to those specified by the JKR [29] viz; particle charge, Say bolt Furol viscosity, Storage stability, settlement test, and residue by evaporation. Subsequently, the residue sample is subjected to further testing including penetration test, viscosity, solubility in trichloroethylene, and softening point.

3.1.1. Particle Charge (ASTM D 7402-09). All emulsified asphalts with low viscosities are conditioned and tested at a temperature of 25⁰C in water bath. The temperature was monitored with both thermometer and hand-held temperature measuring device in this study. The sample was initially stirred thoroughly to achieve homogeneity before conditioning. Conditioning and testing were conducted based on ASTM D 244 [30] and later ASTM D 7402-09. the sample was placed in a clean beaker 250ml or 500ml and placed under the apparatus' electrodes for immersion of more than 25mm. the electrodes were previously cleaned with distilled water, asphalt solvent and finally with distilled water and a clean towel. The device was set at 8 mA with the help of a variable resistor and timed for a minimum period of 30minutes. The test was ended when either of the current or time reaches 2 mA or 30 min, whichever comes first. After which the electrodes were raised, rinsed with a gentle flow of distilled water and deposition observed. Cationic emulsions register visible deposition of asphalt particles on the negatively charged cathode as in figure 1(b), the experimental set up is illustrated in figure 1(a).

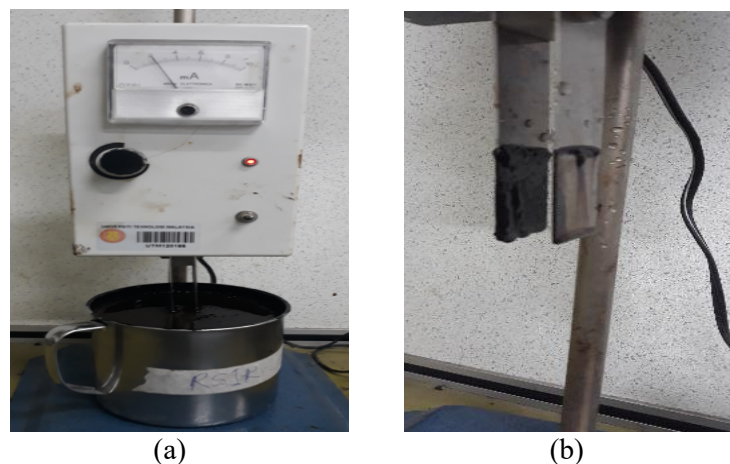


Figure 1. (a) Particle charge analyser (test in progress), (b) visible deposition on electrode after test.

3.1.2. Say Bolt Furol Viscosity (ASTM D2397 -13). This test was conducted on a representative, stable and unbroken sample of both emulsions. As specified in ASTM D2397 - 13, the specification for cationic emulsified asphalt the minimum and maximum Say bolt Furol Seconds (SFS) to be 20s and 100s respectively, whilst the testing temperature is either 25⁰C or 50⁰C. Both emulsion samples were conditioned and tested at 25⁰C in a water bath ensuring homogeneity throughout by constant stirring and checking the temperature for compliance. The test was conducted using the set up in figure 2, which measures the time, T within which a specified quantity of asphalt emulsion (filling the top funnel) at certain standard temperature, flows freely under gravity via a specified sized orifice to fill a glass bottle of known volume.

It works on the basis that interfacial shearing stresses of a highly viscous fluid against the walls of the apparatus' orifice will reduce flow that filling a standard 60ml pycnometer, which means longer time taken to fill the bottle. A less viscous fluid will flow faster to fill up the pycnometer, thus, less time to fill up. A stop-clock was used to monitor the time between initial releases to the point when the emulsion fills up the glass 60ml pycnometer.



Figure 2. Experimental set-up for Say Bolt Furol Viscosity test.

3.1.3. Storage Stability and Settlement Tests (ASTM D6930-10). Emulsion's ability to remain stable by the continuous dispersion of asphalt globules in the continuous phase can appreciably be determined with the help of storage stability tests faster than with other methods. The destabilisation of asphalt emulsions passes through sedimentation, flocculation, and coalescence with the first two reversible, while the last non-reversible, it is a phenomenon that occurs by either chemical/pH imbalance [31,32], mechanical causes and quantity of bitumen in the emulsion which determines how the dispersed particles regain energy to overcome the charges that keep them afloat [19,33].

The extent of agglomeration and eventual settlement of asphalt globules between the bottom and top of a storage container was simulated using a glass cylinder of 500ml capacity with or without siphon tubes. The siphon tubes are equally spaced in such a way that at least 50ml or 50g of settled sample can be siphoned from the top of the glass while 390 ml in between the top and lower siphon arms, hence the remaining sample below the lower arm can be mixed thoroughly and removed too.

The test set-up with the previously conditioned emulsions was placed on a flat surface, maintained undisturbed at room temperature and left to stand for 24 hours for storage stability and five days for settlement. 50g of the emulsion was extracted or siphoned from the top of the settled column as the case may be and placed in a previously weighed clean 1000ml glass beaker containing a glass rod. The top and bottom extracted samples were then subjected to 3hours oven drying at 165°C, after which the percentage residue in each beaker calculated. Though a temperature of 163°C + 30°C is specified in ASTM, the samples were in this study subjected to 165°C.

JKR [29] and ASTM [30] specification requires that this percentage be less than 1% in any case, else the emulsion has started to set, hence it could not be used for cold mixtures.

3.1.4. Residue by evaporation (ASTM D6934-08). A triplicate set of samples in beakers for each type of emulsion is used for this test. After conditioning the previously stirred emulsion to achieve homogeneity, 50g each was weighed into a clean 1000ml glass beaker weighed empty and together with a glass rod. A total of six beakers – three each for RS-1K and CQS-1h emulsions were placed in an oven set at 165°C and heated for 2 hours. Then samples were taken out stirred vigorously and placed back into the oven for an additional period of 1 hour. At the end of the three hours' period, the

beakers and their content were removed from the oven, allowed to cool to room temperature and weighed.

Care was exercised to ensure at least three sets of measurements recorded at an interval of five minutes do not differ from each other by more than 0.01g. The result is reported in percentage representing the amount of asphalt cement in the initial emulsion by using the expression in equation 1.

$$\text{Percentage Residue (\%)} = 2(A - B) \quad (1)$$

3.1.5. Penetration test on residue (ASTM D5-08). The residue obtained from both emulsions was sieved through a 300 μ m sieve, cooled and stored in clean labelled containers for subsequent testing. Penetration test generally appraises the consistency of bituminous semi-solid asphalt material by the depth (in a tenth of a millimeter) to which a standard needle vertically penetrates through the sample under controlled temperature, time and loading. Thus, low penetration values indicate hard viscosities and vice versa. The residue from polymer modified emulsified asphalt emulsions like the CQS-1h is expected to have less penetration due to the viscous nature of their residues, however, RS-1k may perhaps have higher penetration values.

The residue was made sufficiently fluid by heating it to less than 60°C and then poured into 55 x 35mm containers allowed to cool at ambient temperature for 1.5 hours. Triplicate samples were prepared for both RS-1k and CQS-1h emulsion residues in labelled penetration cups as specified in ASTM D5.



Figure 3. Penetration test set-up: (a) samples water bath conditioning (b) digital penetrometer device.

The cups were transferred into a thermostatically controlled water bath set at 25.0 °C \pm 0.10 °C as in Figure 3(a) to condition for 1.5 hours to 2 hours. Each of the cups are removed from the water bath for testing on the penetrometer one after the other and placed under the standard needle, with the needle making contact with the surface of the specimen with the help of image cast on the sample from the illumination of the lamp on the device as can be seen in Figure 3(b). The test was then run by pressing the start button on the device thereby allowing the needle to freely drop and penetrate the sample, three different positions each 10mm apart and 10mm away from the walls of the cup were tested. The penetration of the needle is displayed digitally in tenths of a millimeter on the device as can be seen in figure 3. An average value for three readings is taken to be the penetration value.

3.1.6. Softening point test (ASTM D36-08). Ring and ball apparatus as in Figure 4 were used for the softening point tests on residues from both RS-1k and CQS-1h emulsions because it is the common method employed to estimate the minimum temperature at which a Newtonian viscoelastic fluid can flow under its own weight. It gives an indication to which a bituminous material will flow during the service condition. It records the average temperature at which two steel balls, housed on brass rings supported on a flat metal plate passes through the softened bitumen and just touches the base of the apparatus. In Figure 4 (b), the ball on the right-hand side touches the bottom earlier than the ball on the left-hand side. Figure 4 (a) indicates the starting point of the test when heating was gradually applied and its rate was maintained.

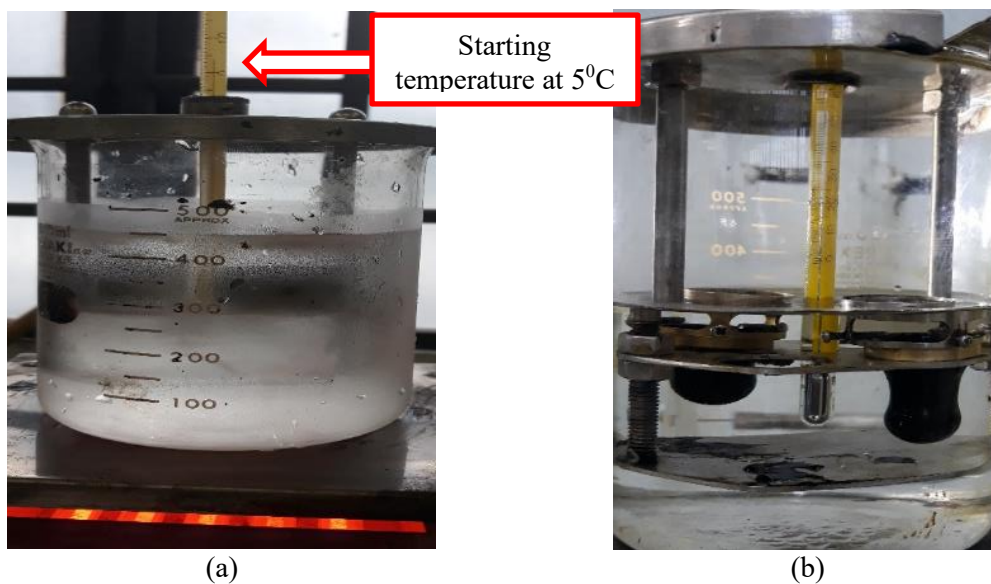


Figure 4. Softening point on residue: (a) initial point of the test, (b) visible failure point.

Distilled water was used in a 500ml beaker, whilst a central metal cover guides a centrally placed thermometer to the top surface of the plate holding the rings which also supports the two balls on either side. The temperature of the water was brought to 5°C at the beginning of the test as in figure 4(a), and a rate of heating of 5°C + per minute was maintained up to the point of failure. Two number of test set-ups were conducted and the average was reported.

3.1.7. Viscosity test (ASTM D4402-02). Measurement of the ratio between the force per unit area (shear stress) and the rate of speed at which the intermediate layers of the asphalt move with respect to each other measured in reciprocal second (sec^{-1}) respectively gives the apparent viscosity of the Newtonian or non-Newtonian fluid. It is an important test to know the behaviour of the binder during handling, mixing and compaction on site.

Triplicate samples of 11g each were prepared in steel moulds, conditioned in the oven at 135°C for 2 hours, transferred into a thermostatically controlled chamber, normalised before running the test. Spindle number 24 was used and a starting temperature of 135°C and 165°C at 20 revolutions per minute, as depicted in figure 5.



Figure 5. Rotational viscosity apparatus.

3.1.8. Solubility in trichloroethylene (ASTM D6934-08). The ability of the asphalt emulsion residue to dissolve in technical grade trichloroethylene signifies the presence or otherwise of active to non-active components in the emulsion. A high percentage of insoluble material signifies the inability of the binder to efficiently coat aggregate – which is regarded as an important parameter in cold mixes [34], especially in quantifying moisture susceptibility [35].

The emulsion residue was heated to attain fluidity, then 2 g was measured in a conical flask. Prior to that, a filter paper inserted in the Gooch crucible was conditioned in the oven at $110^{\circ}\text{C} \pm 5^{\circ}\text{C}$ which was subsequently cooled to 30 minutes. It was weighed and noted as ‘A’, the weight of the conical flask with the 2g residue was weighed and noted as ‘B’. 100 ml of trichloroethylene was poured into the 2g sample in the flask, continuously agitated until no visible lumps then stoppered and allowed to stand for 15 minutes. The conditioned filter paper was removed from the oven soaked with a little solution and the dissolved residue was decanted through it, a clear gentle stream of trichloroethylene ensured that all dissolved bitumen was decanted. The mass of the retained residue – as seen in figure 6 on the filter was dried, weighed and recorded as ‘C’. The percentage of insoluble material in the residue is computed using equation 2.

$$\text{Percentage Insoluble (\%)} = (C - A)/B \times 100 \quad (2)$$



Figure 6. Dissolved Emulsion residue passed through a filter paper.

4. Results and discussion

Result obtained is compared with both specifications set in JKR-2008 (the Malaysian Road Transport standard specification for Roads – section 4: flexible pavements) and the ISSA A143 standard as depicted in table 2. A result comparison of the two emulsions were conducted to ascertain the level of correlation or otherwise of the two results.

A minimum of three replicate samples/tests were utilised for all the laboratory tests conducted even though not reported as such within this work, thus, no statistical tool was used to evaluate any extent

of deviation or reliability was done. Both emulsions were tested positive (cationic) emulsions as anticipated prior to testing. Gross deposition of the binder was visible at the cathode electrode of the particle charge device, more so, the deposition was larger with the CQS-1h, perhaps due to the presence of polymer.

Furthermore, the lesser Saybolt Furol Seconds (SFS) for CQS-1h as compared to RS-1k could not be far-fetched from the fact that globules of asphalt were well dispersed within the continuous phase (water) more than RS-1k leading to a frictionless and fast flow in lesser time (sec) than RS-1k. Moreover, CQS-1h proved to be more stable in terms of long term storage, though the result also affirmed that the narrow margin of 0.1 between the two emulsions should not be a yardstick for disqualification of RS-1k, nonetheless, the latter exhibits a good feature similar to CQS-1h whilst satisfying the minimum requirement of 1.0 minimum residue value set by both JKR 2008 and ISSA A143. Generally, the five (5) days settlement result for both emulsions werethe same, coinciding with the peak limit of the specification of 1.0%.

The result indicated a narrow gap of requirement fulfillment by both the emulsions in all the parameters with the exception of particle charge and Say bolt Furol viscosity tests which give a clear-cut distinction and margin respectively. Interestingly, the residue by evaporation result for RS-1k was above the minimum requirement of 62% by a unit increase, in spite of the fact that CQS-1h has a very thick viscous residue which literally ought to be heavier than RS-1k residue, but, the reverse was the case in actuality.

The hard grade nature of CQS-1h residue as demonstrated by the result of the penetration test is a lucid fact corroborating the aforementioned fact of a thick residue. Perhaps, the result of the penetration on the RS-1k is an indication that the base bitumen used for the emulsification process was a penetration grade 60/70 bitumen because the penetration of 68×10^{-1} mm is within the penetration grade 60-70 for this binder.

The measured viscosity – though not a criterion set by either of the earlier mentioned specifications, yet, it gives a vital information for mixing and compaction, especially, if modified Marshall test is intended to further study the mechanical behaviour of the emulsion residue as suggested by Kumar and Ryntathieng [36] and highlighted in ISSA A143.

4.1. Comparison of the rheological and mechanical properties of the rapid set and quick set emulsions

Both RS-1k and CQS-1h exhibited similar rheological characteristics, perhaps, owing to the nature of their respective formulation parameters. The two emulsions are both cationic, exhibited a medium to hard viscosity and did not exhibit signs of breaking/segregation or even settling. The major significant margin between the two emulsions was seen in the viscosity of their residues and penetration test.

The penetration value for CQS-1h was rather harder than RS-1k, but more promising was the fact that the result for solubility in trichloroethylene indicated that RS-1k has a more active constituent than CQS-1h as it dissolved fully in this hydrocarbon solvent as presented in Table 2. Despite the high viscosity residue of CQS-1h, both residues from the two emulsions passed the set requirement for the softening point of residue with appreciable margins. This means both emulsions/residues can withstand high service temperatures without flowing, thus, less prone to temperature susceptibility. Conversely, lower softening points are not desirable, in that, it signifies that the material can easily flow at relatively elevated temperatures leading to bleeding oftentimes.

Figure 7 depicts a bar chart summary of the entire tests conducted on the emulsions and their residue, it present side-by-side result obtained for CQS-1h and RS-1k. Significant margins are noticeable in the viscosity of residue, followed by a penetration and solubility test. However, no marked difference was recorded for the remaining tests yet both emulsions have passed minimum requirements set by the requirements as in Table 2.

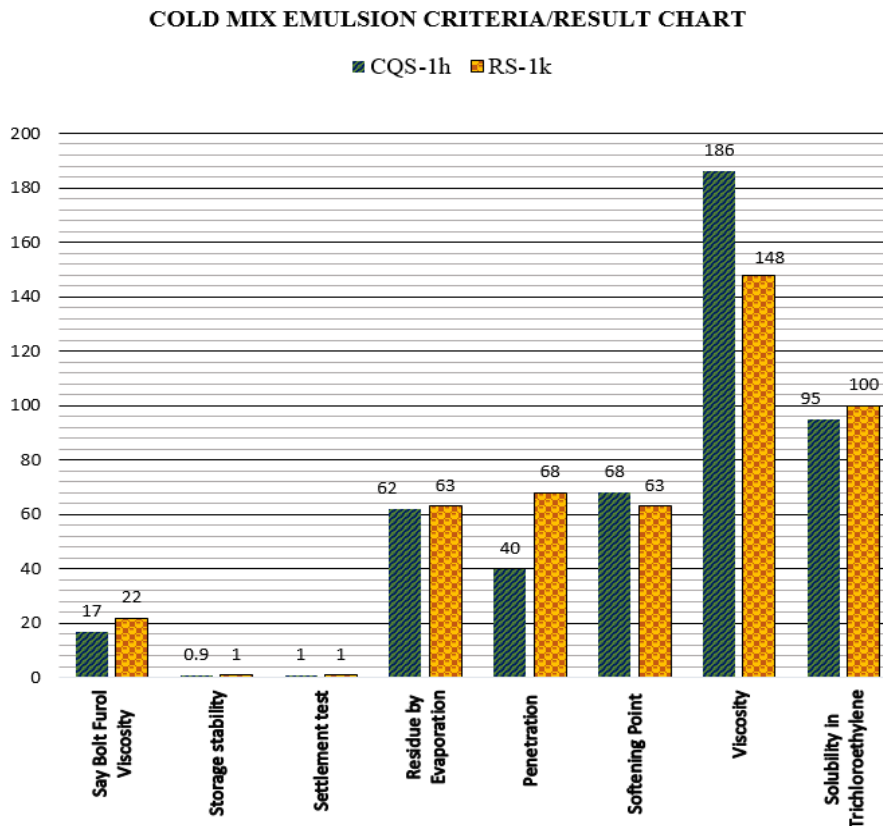


Figure 7. Emulsion and residue test result.

Table 2. Rheological result of emulsion and their residues.

TEST ON EMULSIFIED ASPHALT					
TEST	STANDARD SPECIFICATION		RESULT		JKR/ISSA A143 SPECIFICATION
	ASTM	AASHTO	CQS-1h	RS-1k	
Particle charge	D7402	-	Positive	Positive	Positive
Saybolt Furol Viscosity	D 7496	T 59	17	22	15 – 50 secs
Storage stability (1 day)	D 6930	T 59	0.9	1.0	1% Maximum
Settlement test (5 days)	D 6930	T 59	1.0	1.0	1% Maximum
Residue by evaporation	D 6934	-	62	63	62% Minimum
TEST ON EMULSIFIED ASPHALT RESIDUE					
Penetration (mm)	D 5	T 49	40	68	40 - 90
Softening point	D 36	T 53	68	63	54%/57% minimum
Viscosity (rotational)	D 4402	-	186/198*	148/160*	NA
Solubility in trichloroethylene	D 2042	-	95	100	95% minimum

* these means mixing/compaction temperature

5. Conclusion

The rheological evaluation of the two grades of emulsion indicated a high potentiality of rapid set emulsion RS-1k to be used for both cold mix asphalt and in emulsified micro-surfacing mixture with a little or without any polymer modification. The residue base of RS-1k was 1% higher than the specified minimum and that for CQS-1h as well, perhaps, the little higher Say bolt Furol seconds of 5 second signifies a more viscous feature than the CQS-1h, with 17 seconds. It can be concluded that

RS-1k emulsion and its residue exhibit similar behaviour to CQS-1h, as such can be tried for use in cold mix emulsified asphalts and even micro-surfacing mixtures. Though, the latter may require some form of polymer modification as post-modification blending. The penetration values of the residues indicated that RS-1k could have been formulated from a 60/70 penetration grade bitumen, as such can render self for further testing like the modified Marshall test for slurry micro-surfacing mixtures. RS-1k has satisfied all the minimum criteria requirements set by JKRS PJ2008-S4 for emulsified asphalt cold mix applications.

Acknowledgement

The authors would like to thank Universiti Teknologi Malaysia (UTM) for providing the Research grants No. Q.J130000.2651.16J30 as financial support to this research project. In addition, the main Author wish to appreciate the support from Nigeria's Tertiary Education Trust (TET Fund) for the sponsorship and Nuhu Bamalli Polytechnic for the study leave with pay accorded me.

References

- [1] Jamion N Hainin M R and Yaacob H 2014 *J. Teknol.* **70** 125–9
- [2] Wang A Shen S Li X and Song B 2019 *Constr. Build. Mater.*
- [3] Kavanagh L Shalaby A and Deane L 2010 *Proceedings, Annual Conference - Canadian Society for Civil Engineering*
- [4] Ronald M and Luis F P 2016 *Constr. Build. Mater.* **123** 162–73
- [5] Warid M N M Hainin M R Yaacob H Aziz M M A Idham M K Raman N A A and Mamat R 2015 *J. Teknol.* **77** 1–5
- [6] Zaniewski J and Mamlouk M 1999 *Transp. Res. Rec. J. Transp. Res. Board*
- [7] Simões D Almeida-Costa A and Benta A 2017 *Int. J. Sustain. Transp.*
- [8] Jamal Khattak M and Alrashidi M 2013 *Int. J. Pavement Res. Technol.*
- [9] Li H 2014 Investigation of Cost-effectiveness and Application Time of Pavement Maintenance Treatments in Jiangsu, China *TRB*
- [10] Labi S and Sinha K C 2004 Cost and Effectiveness Models for Selected Preventive Maintenance Treatments *TRB 2004 Annual Meeting*
- [11] Ding T Sun L and Chen Z 2013 *Procedia - Soc. Behav. Sci.*
- [12] Lonbar S M and Nazirizad M 2016 *Civ. Eng. J.* **2** 86–94
- [13] Warid M N M Hainin M R Yaacob H Aziz M M A and Idham M K 2014 *Mater. Res. Innov.* **18** S6-303-S6-306
- [14] S Al-Busaltan, H Al Nageim, W Atherton, G P Sharples G 2010 *Material Science*
- [15] Lin J Wei T Hong J Zhao Y and Liu J 2015 *Constr. Build. Mater.* **99** 137–42
- [16] Guo M Tan Y and Zhou S 2014 *Constr. Build. Mater.* **68** 769–76
- [17] Ling C Hanz A and Bahia H 2016 *Constr. Build. Mater.* **105** 391–9
- [18] Muhammad Naquiddin Bin Mohd Warid 2017 *Performance of cold stone mastic asphalt mixture* (Dissertation: Universiti Teknologi Malaysia)
- [19] Yaacob H Hainin M R Aziz M M A Warid M N M Chang F L Ismail C R and Hassan N A 2013 *J. Teknol. (Sciences Eng).*
- [20] Saadoon T Garcia A and Gómez-Mejide B 2017 *Mater. Des.* **134** 196–206
- [21] Dash S S and Panda M 2018 *Constr. Build. Mater.* **191** 376–85
- [22] Ronald M and Luis F P 2016 *Constr. Build. Mater.* **123** 162–73
- [23] Becker Y Méndez M P and Rodríguez Y 2001 *Vis. Tecnol.* **9** 39–50
- [24] Li H P Zhao H Liao K J Li Y G and Li X Q 2012 *Pet. Sci. Technol.* **30** 699–708
- [25] Tabatabaei S A Kiasat A and Alkouhi F K 2013 *World Acad. Sci. Eng. Technol. Int. J. Mater. Metall. Eng.* **7** 785–8
- [26] Abedini M Hassani A Kaymanesh M R and Yousefi A A 2016 *Pet. Sci. Technol.* **34** 1589–94
- [27] Ji J Liu L-H Suo Z Xu Y Yang S and Xu S-F 2017 *Chang. Daxue Xuebao (Ziran Kexue Ban)/ Journal Chang. Univ. Natural Sci. Ed.* **37** 23–30

- [28] Hu C Zhao J Leng Z Partl M N and Li R 2019 *Constr. Build. Mater.* **197** 220–7
- [29] JKR 2008 JKR/SPJ/2008-S4 Standard Specification for Road Works Part4 Flexible Pavement 1–187
- [30] Methods S T 2009 ASTM Designation No. D244-09 Standard Test Methods and Practices for Emulsified Asphalts 1–9
- [31] Mercado R A Salager J L Sadtler V Marchal P and Choplin L 2014 *Colloids Surfaces A Physicochem. Eng. Asp.* **458** 63–8
- [32] Mercado R A Sadtler V Marchal P Choplin L and Salager J L 2012 *Ind. Eng. Chem. Res.*
- [33] Usman K R Hainin M R Idham M K Warid M N M Yaacob H Hassan N A, Azman M and Puan O C 2019 *IOP Conf. Ser. Mater. Sci. Eng.* **527** 012052
- [34] Ling C Moraes R Swiertz D and Bahia H 2013 *Transp. Res. Rec. J. Transp. Res. Board* **2372** 46–52
- [35] Ling C Hanz A and Bahia H 2016 *Constr. Build. Mater.*
- [36] Kumar R and Ryntathieng T L 2016 *Transp. Res. Procedia* **17** 488–97