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Implementation of Waste Cooking Oil as RAP Rejuvenator

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Abstract: In this paper, the implementation of using waste cooking oil as a rejuvenating agent that used in RAP is investigated. The simulation of ageing process is accelerated by unconventional method using propeller mixer, (MIXER) and rolling thin film oven test, (RTFOT). The binder tests are by means of Penetration test, Softening Point test, Brookfield Viscosity test and Dynamic Shear Rheometer, (DSR) test to measure original bitumen, aged bitumen and rejuvenated bitumen properties. It was observed that unconventional method is produced aged bitumen pen-grade of 60/70, 50/60, 40/50 and 30/40 which have penetrations between of 60 to 70, 50 to 60, 40 to 50 and 30 to 40, respectively while RTFOT shown 50/60 aged penetration grade. The results indicate that the aged bitumen is rejuvenated by the waste cooking oil due to change in physical and rheological properties that revived to original bitumen (Fresh Bitumen).

Key Words: *rejuvenating agent, waste cooking oil, aged bitumen*

1. INTRODUCTION

Decreasing supplies of locally available quality aggregate in many regions around the world, growing concern over waste disposal, and the rising cost of bitumen binder have resulted in greater use of reclaimed asphalt pavement (RAP) for road construction. Recycling Hot Mix Asphalt (HMA) is the process in which reclaimed asphalt pavement (RAP) materials are combined with new materials (the virgin aggregates and asphalt binder) and a rejuvenating agent to produce HMA mixtures. Recycled HMA mixtures, properly designed, must have similar properties to those of conventional HMA, fulfilling the same technical prescriptions that are demanded for conventional ones. Experience has indicated that the recycling of asphalt pavements is a beneficial approach from technical, economical, and environmental perspectives (Chen *et al.* 2007; Romera *et al.* 2006). Furthermore, RAP can be acquired by several ways such as from removed or reconstructed asphalt pavement. In addition, the old asphalt pavement can be crushed and screened for use as future pavements consists of rejuvenator. In this research, old pavement or exist pavement is subject of RAP materials.

Bitumen has important role especially for coating in pavement construction. Bitumen functions as satisfactory binder in improvement of physical interlocking of bituminous mixtures. However, its properties changes as it age over time attributable to bulk storage, mixing, paving, transport and storage on site. Bitumen composition has its greatest influence on aging. Combination of oxidation and volatility are mainly cause physical and rheological properties change that induces to failure which is from hardening (consistency change) to embrittlement. Oxidation normally occurs simultaneously with loss of lower molecular weight volatiles. This loss rate is depending on the concentrations, temperature and environment. Because the loss rate is dependent on such conditions, volatility is important mainly in handling bitumen at elevated temperature. Consequently, the aging bitumen then leads to deterioration and major distress of pavement such as fatigue, rutting and cracking.

Rejuvenating hard bitumen is an industrial process used to recycle road materials. It consists in trying to recover the initial properties of the aged bitumen inside an old pavement by adding a small amount of viscous oil. The idea is then to dilute the asphaltenes, created as a consequence of ageing, by the addition of new maltenes (Lesueur (2009)). Waste cooking oil was assumed as rejuvenator as well as one of the recycling agent that possible to improve the aged bitumen properties as similar level as the virgin bitumen. Researchers have proved that using rejuvenator in aged bitumen binder can reach target PG grades when the optimum percentage of rejuvenator is achieved. This present work will investigate the possibility of using waste cooking oil as recycling/rejuvenating agent to restore the aged bitumen to a condition that resemble of the virgin bitumen. A commonly used rejuvenating agent is a low viscosity product obtained from crude oil distillation. The use of waste cooking oil is thought to provide an alternative rejuvenating agent, and to provide an agent that is considered as natural waste product.

2. MATERIAL AND EXPERIMENTAL

2.1 Material

Bitumen with penetration grade of 80/100 is used in this research has the most popular usage in Malaysia. Two method of accelerated ageing process on the virgin bitumen was undergone in laboratory which are unconventional method by using propeller mixer to attempt different classification of aged bitumen (i.e. aged bitumen grade 60/70, aged bitumen grade 50/60, aged bitumen grade 40/50 and aged bitumen grade 30/40) that have penetration in range of 60 to 70, 50 to 60, 40 to 50 and 30 to 40, respectively and standard ageing method based on ASTM which is rolling thin film oven test, (RTFOT).

As mentioned earlier, rejuvenator that used in this study was waste cooking oil, (WCO) that easily acquired from the residential houses, cafes or restaurants. The waste cooking oil has low viscosity rather than aged bitumen. The fresh bitumen will be compared to rejuvenated bitumen by blending the aged bitumen by various percentages of waste cooking oil which are 1%, 2%, 3%, 4% and 5% by weight of bitumen. The waste cooking oil is mixed with the aged bitumen simultaneously by propeller mixer for 15 minute each percentage for every condition by 200 revolutions per minute at fixed temperature, 160°C.

2.2 Ageing Procedures

2.2.1 Development of Propeller Mixer Ageing Method

Propeller mixer is a device comprising a rotating shaft with propeller blades attached, purposely for mixing and maintaining contents in suspension is used as a simulation of unconventional method to accelerate ageing process. The process is begin when the original bitumen filled in 4litre container volume with known weight is heated in the oven for 160°C approximately one hour to one hour an half. Then, placed it on the hot plate and stir it using the propeller mixer for different reaction time with 300 and 350 revolutions per minutes mixing speed (i.e. 300 and 350 rpm). Try and error process of reaction times have to be concerned to fabricate the dissimilar aged group of bitumen. Reaction time by between four hours to six hours is possible to be considered in this research.

2.2.2 Rolling Thin Film Oven (RTFOT) (ASTM D2872)
The Rolling Thin-Film Oven (RTFO) procedure provides simulated short term aged asphalt binder for physical property testing. Asphalt binder is exposed to elevated temperatures to simulate manufacturing and placement aging. The RTFO also provides a quantitative measure of the volatiles lost during the aging process. The basic RTFO procedure takes unaged asphalt binder samples in cylindrical glass bottles and places these bottles in a rotating carriage within an oven. The carriage rotates within the oven while the 325°F (163°C) temperature ages the samples for 85 minutes. The aging time of 85 minutes in the RTFOT is expected to produce aging effects comparable to average field conditions although given the number of variables the aging in the field is often different from that of RTFOT.

2.3 Binder tests
2.3.1 Penetration Test (ASTM D5-97)
The purpose of this test is to examine the consistency of a sample of bitumen by determining the distance in tenths of a millimetre that a standard needle vertically penetrates the bitumen specimen under known conditions of loading, time and temperature. The penetration test is simply a mean for grading bitumen at ambience temperature. This test is carried out under laboratory condition at 25°C, and the purpose of this experiment is to determine the depth that a weighted needle sinks into a bitumen specimen within 5 seconds.

2.3.2 Softening Point Test (ASTM D36-95)
Two horizontal disks of bitumen, cast in shouldered brass rings, are heated at a controlled rate in a liquid bath while each supports a steel ball. The softening point is reported as the mean of the temperatures at which the two disks soften enough to allow each ball, enveloped in bitumen, to fall at certain distance. To determine the softening point of bitumen within the range 30°C to 157°C by means of the Ring-and-Ball apparatus.

2.3.3 Brookfield Viscosity Test (ASTM D4402-87)
The Brookfield Thermosel Viscometer described in this procedure can be used to measure the viscosity of asphalt at elevated temperatures. The torque on a spindle rotating in a special thermostatically control sample holder containing a small sample of asphalt is used to measure the relative resistance to rotation. A factor is applied to the torque dial reading to yield the viscosity of the asphalt in millipascal seconds. This test method can be used to measure the apparent viscosity of asphalt at application temperatures.

2.3.4 Dynamic Shear Rheometer Test (ASTM D – 4 Proposal P246)
A Dynamic Shear Rheometer (DSR) may be used to determine the rheological properties of bituminous binders and it is generally assumed that a DSR can accurately measure binder properties over a wide range of conditions. Bitumen binders in the medium to high temperature range behave partly like an elastic solid (deformation due to loading is recoverable, it is able to return to its original shape after a load is removed) and a viscous liquid (deformation due to loading is non recoverable, it cannot return to its original shape after a load is removed). By measuring G^* and δ, the DSR is able to determine the total complex shear modulus as well as its elastic and viscous components. The basic DSR test uses a thin bitumen binder sample sandwiched between two plates. The lower plate is fixed while the upper plate oscillates back and forth across the sample at 1.59 Hz to create a shearing action. These oscillations at 1.59 Hz (10 radians/sec) are meant to simulate the

shearing action corresponding to a traffic speed of about 90 km/hr (55 mph) (Roberts et al., (1996)).

2.4 Chemical Test

The chemical test that used to determine chemical compound in waste cooking oil is gas chromatography mass spectrometry test, (GCMS). Major chemical compounds in this unknown waste cooking oil were oleic acid, 43.67% followed by palmitic acid, 38.35% and linoleic acid, 11.39% as shown in table 1. With long chain of palmitic acid and oleic acid, it has the potential to be cracked by thermal cracking or catalytic cracking for possible formation of hydrocarbon chain (Khalisanni *et al*. (2008)).

Table 1 Chemical compound on unknown waste cooking oil in this research

Fatty Acid	Cooking Oil, (%)
Lauric acid (C12:0)	0.34
Myristic acid (C14:0)	1.03
Palmitic acid (C16:0)	38.35
Stearic acid (C18:0)	4.33
Oleic acid (C18:1n9c)	43.47
Linoleic acid (C18:2n6c)	11.39
γ-Linolenic acid (C18:3n6)	0.37
Linolenic acid (C18:3n3)	0.29
Cis-11-Eicosenoic acid (C20:1)	0.16
Heneicosanoic acid (C21:0)	0.08
Total	**100**

3. RESULTS AND DISCUSSION

3.1 Significance of waste cooking oil on the penetration value

Consistency of fresh bitumen and rejuvenated bitumen is determined by penetration test (ASTM2000). In term of engineering, consistency is an empirical measure of the resistance offered by a fluid to continuous deformation when it is subjected to shearing stress. The effects of various percentages waste cooking oil (i.e. 1% - 5% by weight of bitumen) on the penetration value for four classification unconventional ageing method and RTFOT were presented in figure 1 and 2 respectively.

As can be seen from the graph below, with the increase amount of waste cooking oil, the penetration value for each condition was increased. The rejuvenated bitumen that has similar penetration value as original bitumen is achieved when a certain percentage of waste cooking oil is added. For example, from the figure 1, aged bitumen penetration grade of 30/40, approximately 3.6% added waste cooking oil is changed the brittle bitumen to soft bitumen as similar as fresh bitumen. Similarly, when 2.7% of waste cooking oil by weight of bitumen binder is added into the aged bitumen penetration grade 40/50, the penetration value is alike the original bitumen with the penetration value of 84. On the contrary, the penetration value for aged bitumen penetration grade of 60/70 and 50/60 is similar as the original bitumen after almost 1% of waste cooking oil is mixed together. Figure 2 shows with the addition of 2.4% of waste cooking oil cause penetration value of aged bitumen by RTFOT is equivalent to penetration value of original bitumen.

From the graph displayed below, it seems that the RTFOT ageing method is more efficient rather than propeller mixer. Rejuvenating agent such as waste cooking oil can be used in order to decrease the maintenance cost of asphalt pavement.

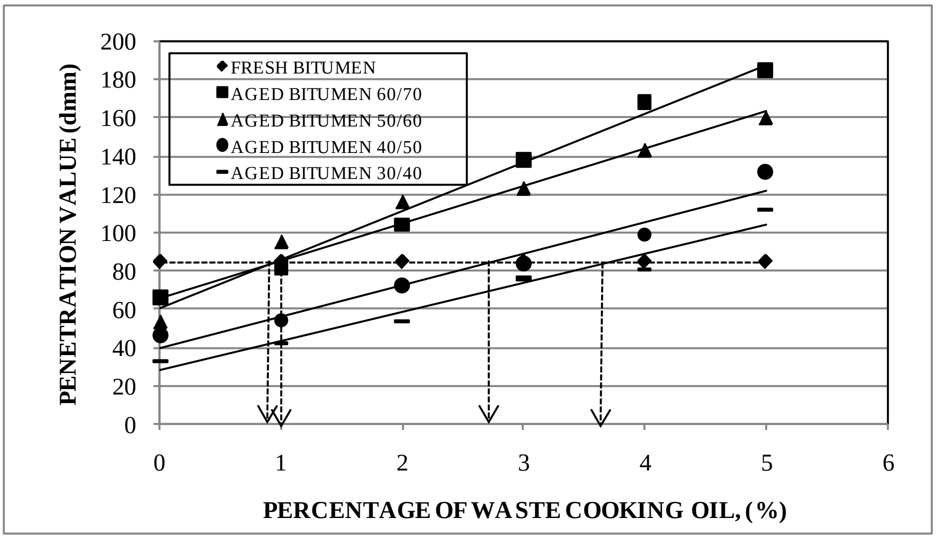

Figure 1 Comparison graph of penetration value, (dmm) against percentage of waste cooking oil, (%) for fresh bitumen and aged bitumen grade 60/70, 50/60, 40/50 and 30/40

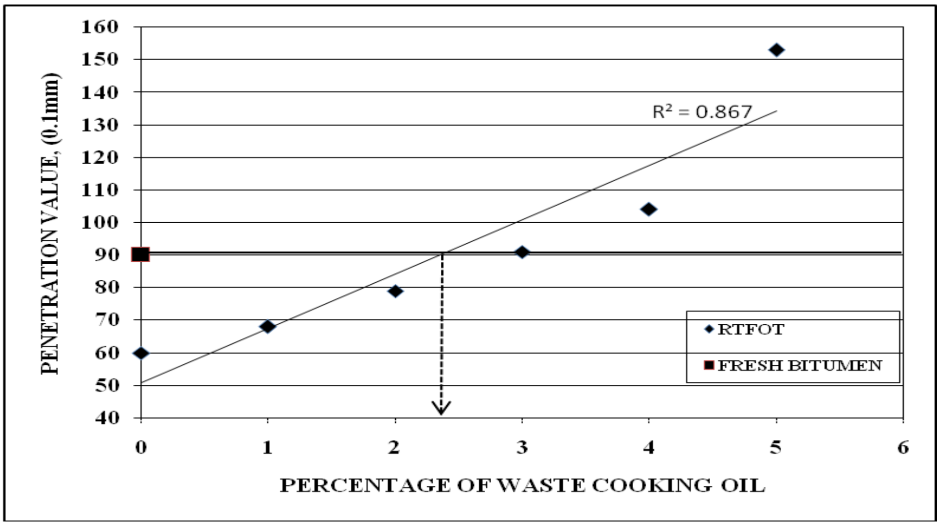

Figure 2 Comparison graph of penetration value, (0.1mm) against percentage of waste cooking oil, (%) for before (Fresh Bitumen) and after RTFOT aged binder

3.2 Significance of waste cooking oil on the softening point temperature

Bituminous materials do not have an exact melting point. Instead, as the temperatures rises, these materials slowly change from brittle or very thick and slowly-flowing materials to softer and less viscous liquids. In this study, the average softening point value for original bitumen is 46°C. Figure 3 representing the influence of different added of waste cooking oil to four degree of aged bitumen on the softening point value. Effect of waste cooking oil (by weight of bitumen binder) on the softening point for RTFOT ageing method is shown in figure 4.

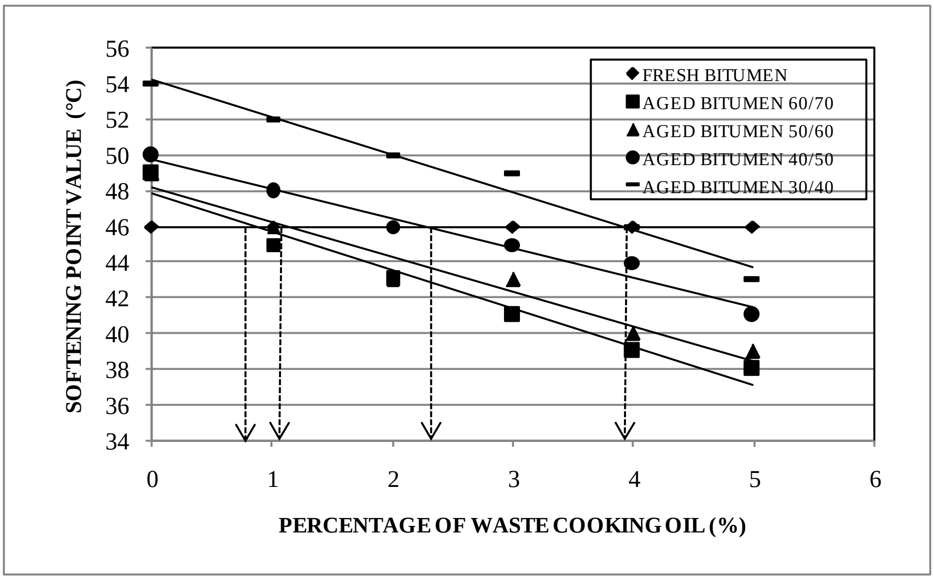

Figure 3 Comparison graph of softening point Temperature, (°C) against percentage of waste cooking oil, (%) for Fresh Bitumen (80/100) and aged bitumen grade 60/70, 50/60, 40/50 and 30/40

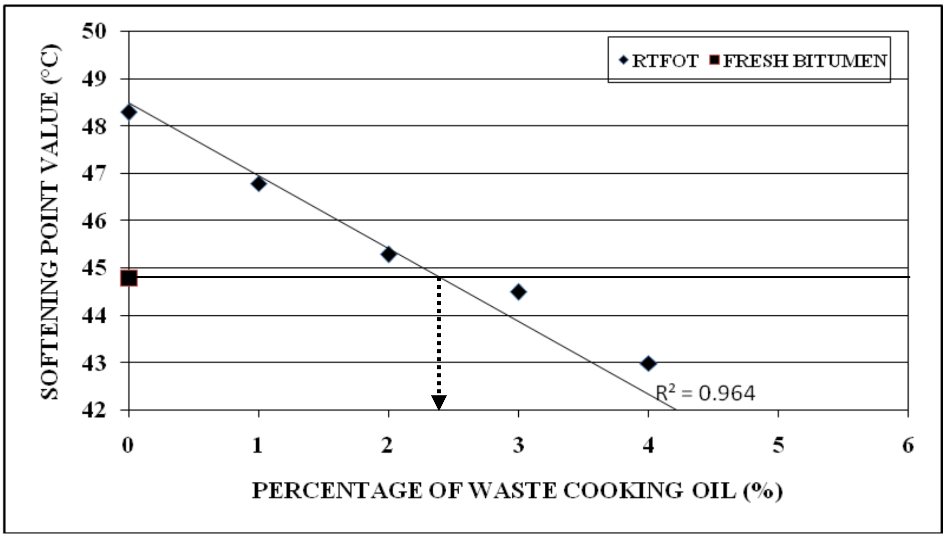

Figure 4 Comparison graph of softening point Temperature, (°C) against percentage of waste cooking oil, (%) for before (Fresh Bitumen) and after RTFOT aged binder

As illustrated from the graph above, when the four group of aged bitumen is increased with the penetration value, the softening point value is decreased by added of various percentage of waste cooking oil. For aged bitumen without waste cooking oil for pen-grade 30/40, the softening point is 54°C but for pen-grade 40/50, the aged bitumen melted at 50°C meanwhile for pen-grade 50/60 and pen-grade 60/70 is 49°C. Instead, the higher percentage of waste cooking oil added into the aged bitumen group, the lower softening point temperature is obtained. For example, aged bitumen penetration of grade 60/70 and 50/60, addition approximately of 1% waste cooking oil seems alike the original softening value, 46°C. The rejuvenated bitumen was achieved for RTFOT ageing method when 2.4% waste cooking oil is added (see figure 4).

As can be seen in the figure 3 and 4, the softening point value is diminishing gradually. With the increasing of aging time, the penetration value is decreased but softening point temperature is increased due to oxidation reactions happened and more asphaltenese micelles appeared. Increasing of asphaltenese content with high molecular weight was produced harder bitumen. The chemical reaction and mixture of waste cooking oil was rejuvenating the diverse groups of aged bitumen.

3.3 Significance of waste cooking oil on the viscosity

This test is significantly to ensure that the binders are sufficiently fluid when being pumped and mixed at the hot mix plants. For Superpave binder specification purpose, the rotational viscosity test is to be run at standard temperature, 135 °C to ensure proper workability during mixing and placement.

The effectiveness of the mixing of asphalt cement and aggregate, and the effectiveness of the placement and compaction of the hot asphalt mix are affected greatly by the viscosity of the asphalt. The result of viscosity towards the elevated temperature for two ageing method which is propeller mixer reported in figure 5, 6, 7, 8 and RTFOT displayed in figure 9 as the following below. In this study, elevated temperature of 90°C, 110°C, 130°C, 135°C, 150°C and 170°C is concerned. Viscosity of rejuvenated bitumen is attained when a certain volume of waste cooking oil is well blended into it.

As example, figure 5 illustrated relationship between six elevated temperature versus viscosity with various percentage of waste cooking oil (i.e. 1% to 5% by weight if bitumen binder) to aged bitumen penetration grade of 30/40. The rejuvenated bitumen is compared to original bitumen pen-grade 80/100. From the curve shown, rejuvenated bitumen of aged bitumen pen-grade 30/40 is occurred in between of 4% and 5% waste cooking oil mixed. Viscosity after RTFOT showed addition of 3% of waste cooking oil change the ageing properties as similar as original bitumen (see figure 9). According to Sengoz and Isikyakar (2008), the increase in viscosity is not favorable because the bitumen with high viscosity levels require higher mixing, laying and compaction temperatures which results in too much energy consumption.

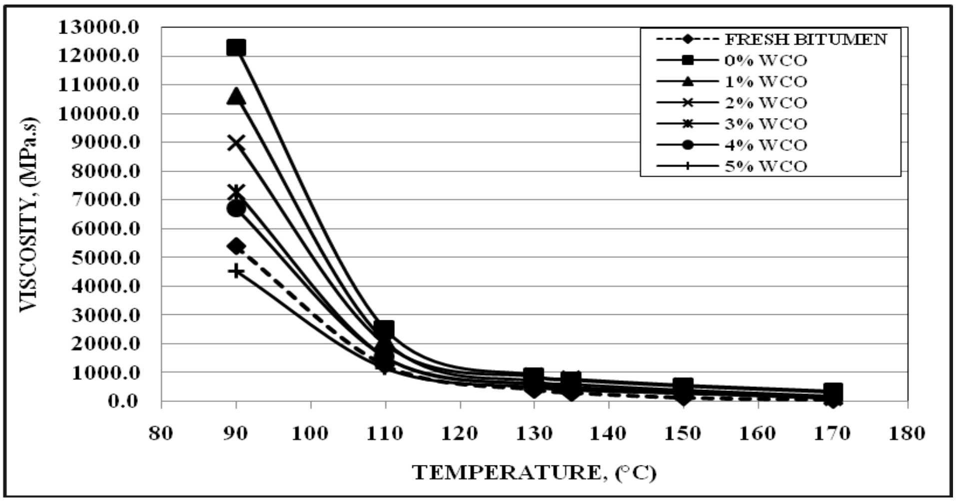

Figure 5 Viscosity (MPa) curves for fresh bitumen and various percentage of waste cooking oil added to aged bitumen grade 30/40

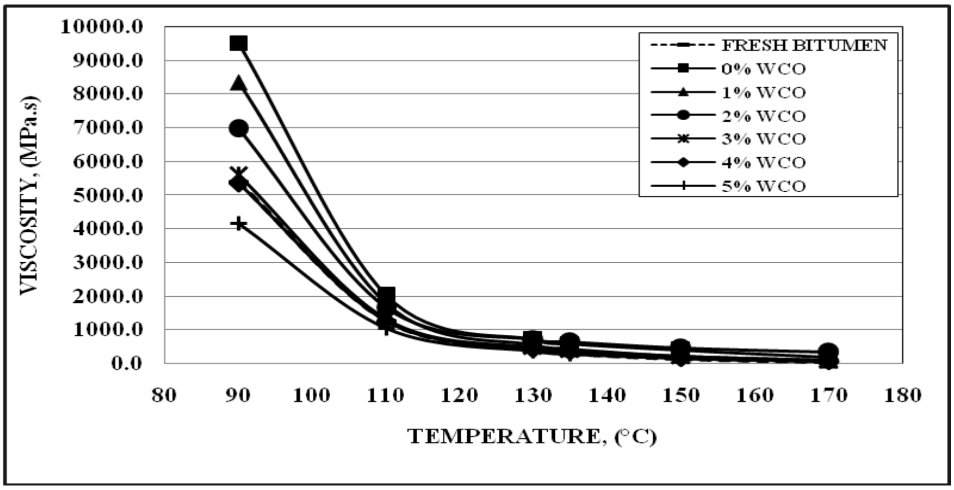

Figure 6 Viscosity (MPa) curves for fresh bitumen and various percentage of waste cooking oil added to aged bitumen grade 40/50

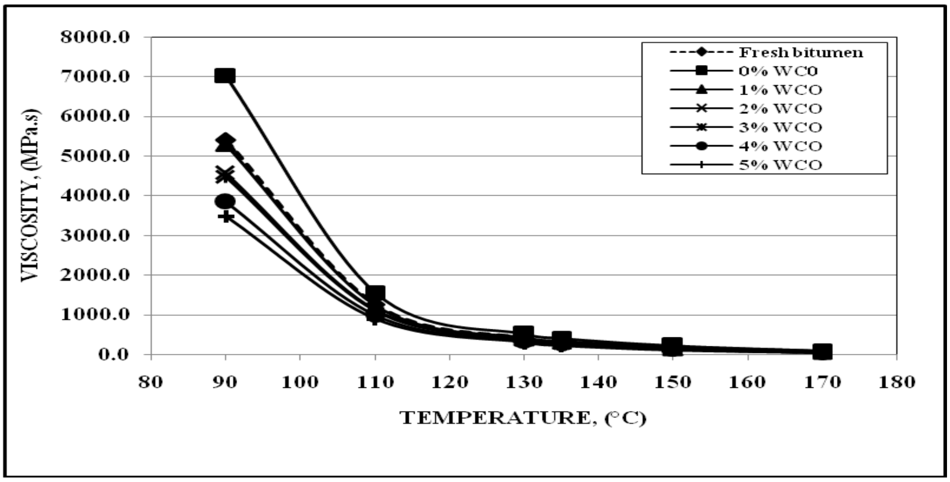

Figure 7 Viscosity (MPa) curves for fresh bitumen and various percentage of waste cooking oil added to aged bitumen grade 50/60

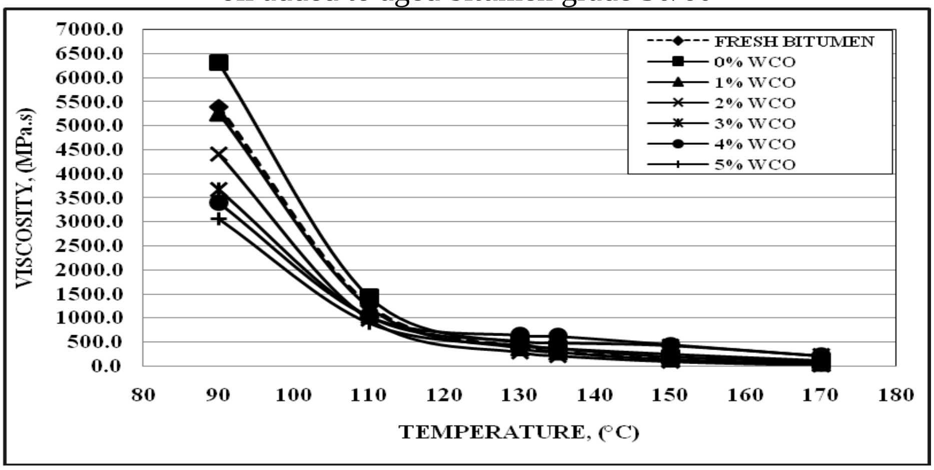

Figure 8 Viscosity (MPa) curves for fresh bitumen and various percentage of waste cooking oil added to aged bitumen grade 60/70

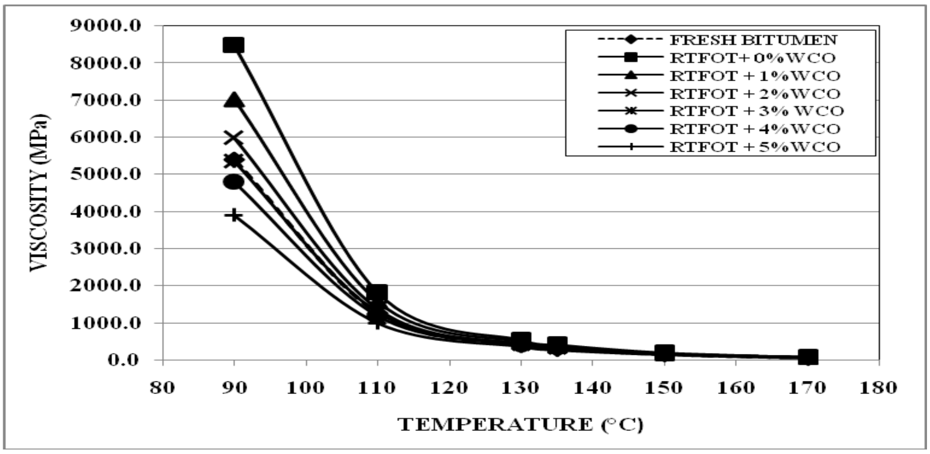

Figure 9 Viscosity (MPa) curves for before (fresh bitumen) and after RTFOT aged binder added to various percentage of waste cooking oil

As to the Brookfield viscosity is increasing from 90°C to 170°C, the results clearly showed the decreasing in viscosity due to increasing waste cooking oil contents. From the Brookfield viscosity test, it was obviously an additional proved that waste cooking oil may be used as an alternative waste material that used as rejuvenating agent for reclaimed asphalt pavement apart of softening point test and penetration test. Obviously, via viscosity versus temperature curve, accelerated ageing process using RTFOT is defined to be efficient method.

3.4 Significance of waste cooking oil on the rheological properties

When testing bitumen with the DSR tester according to the Superpave specification, the sample is sandwiched between a fixed-base plate and an oscillating spindle plate. The stress–strain pattern is recorded. The angular frequency, which is varied in many other types of test, is fixed at 10 rad s^{-1} in the Superpave specification, which can be attributed to the loading time within a pavement where vehicles travel at 90 km/h. Basically the purpose of this test is to determine the properties of bitumen at high and intermediate temperature. Common rheological parameters involved in this test are complex shear modulus (G*), loss modulus (G”), storage modulus (G’) and phase angle (δ) and also considered in this research.

The rheological properties of four penetration classification aged bitumen with five different percentage of added waste cooking oil are compared to original bitumen (80/100) as illustrated in figure 10, 11, 12 and 13. On the contrary, figure 14 displayed the rheological properties before and after RTFOT. Behaviour of asphalt binders can be showed by plotting master curves of the complex modulus vs. temperature. Figure 10 plot G* vs. temperature (i.e. 30°C-80°C) at 10 rad/s for aged bitumen pen-grade 30/40 added to various waste cooking oil content and fresh bitumen. The well blended approximately of 4% to 5% waste cooking oil does rejuvenate the complex shear modulus of the 30/40 aged bitumen pen-grade as equivalent to complex shear modulus of original bitumen. As the temperature increases, the modulus decreases significantly. Aged bitumen pen-grade 30/40, 40/50, 50/60 and 60/70 as shown in figure 10, 11, 12 and 13 respectively, without adding waste cooking oil was attained the stiffest over the entire range of temperatures, but after adding waste cooking oil from 1% to 5%, the aged bitumen binder become soft due to decreasing of modulus value. Figure 14 below showed rejuvenated bitumen after RTFOT is obtained once mixing waste cooking oil about 2%.

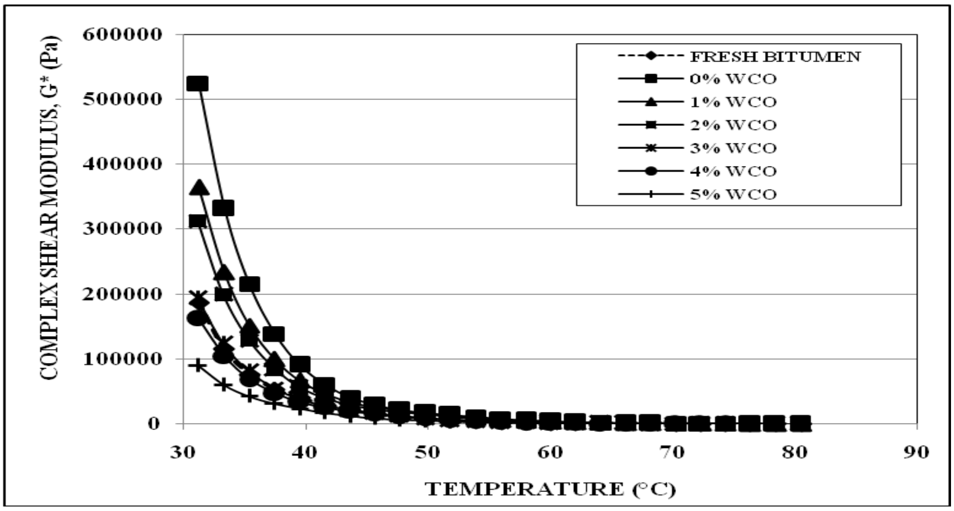

Figure 10 Complex shear modulus, G* (Pa) curves for fresh bitumen and various percentage of waste cooking oil added to aged bitumen grade 30/40

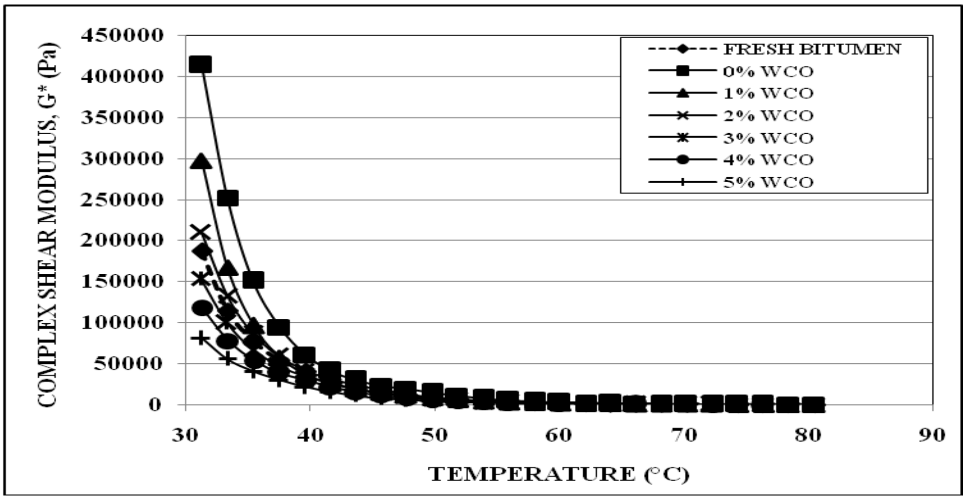

Figure 11 Complex shear modulus, G* (Pa) curves for fresh bitumen and various percentage of waste cooking oil added to aged bitumen grade 40/50

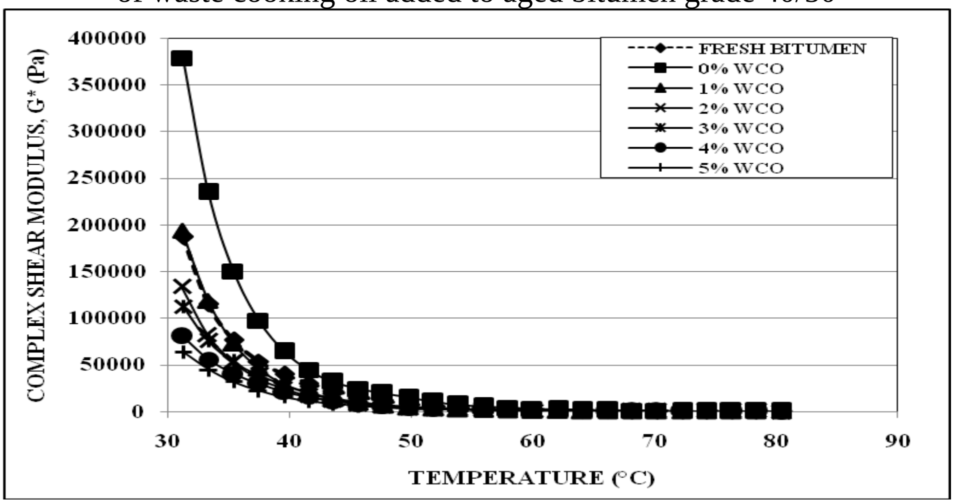

Figure 12 Complex shear modulus, G* (Pa) curves for fresh bitumen and various percentage of waste cooking oil added to aged bitumen grade 50/60

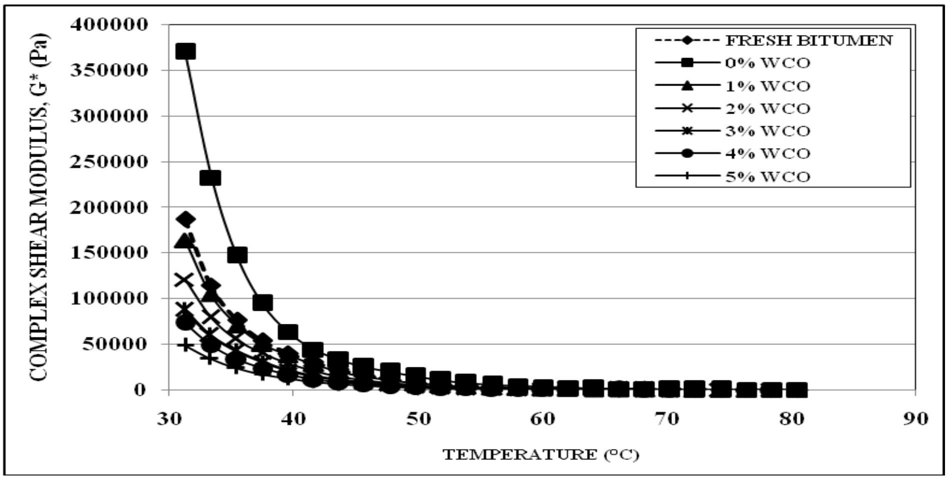

Figure 13 Complex shear modulus, G* (Pa) curves for fresh bitumen and various percentage of waste cooking oil added to aged bitumen grade 60/70

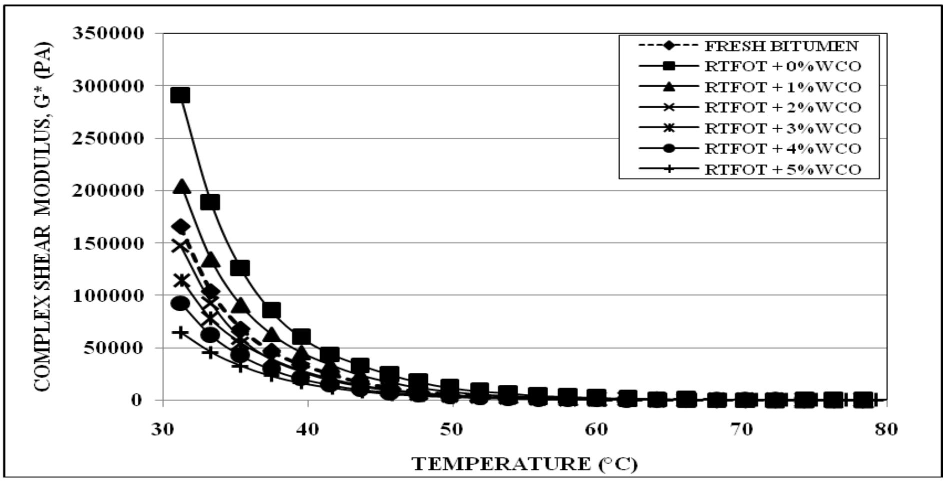

Figure 14 Complex shear modulus, G* (Pa) curves for before (fresh bitumen) and after RTFOT aged binder added to various percentage of waste cooking oil

Phase angle, δ (°) is the phase difference between the stress and strain in an oscillatory deformation and is a measure of the viscoelastic character of the material. If δ is equals to 90°, then the binder can be considered purely viscous in nature and when the δ is equal to 0° would represent an ideal elastic solid. The ability of the binders to store deformational energy at high temperatures and to dissipate deformational energy through flow at low temperatures is called elasticity and flexibility, respectively. As can be seen from the figure 15, 16, 17, 18 and 19, at temperature of 65°C and above, the phase angle of each case were approached 90° which is considered purely viscous. In this case, the stored energy per cycle of deformation becomes negligible compared to that dissipated as heat. The rejuvenated bitumen curve for every condition (see figure 15 to 19) showed the identical pattern as the virgin bitumen when an optimum amount of waste cooking oil is determined. This initial finding would provides further detailed study of using waste cooking oil as rejuvenator for aged bitumen and reclaimed asphalt pavement simultaneously.

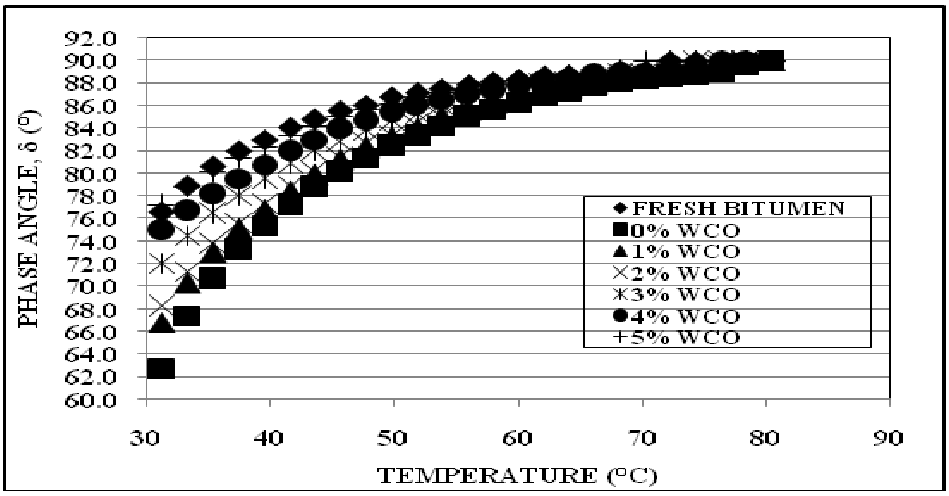

Figure 15 Phase angle, δ (°) curves for fresh bitumen and various percentage of waste cooking oil added to aged bitumen grade 30/40

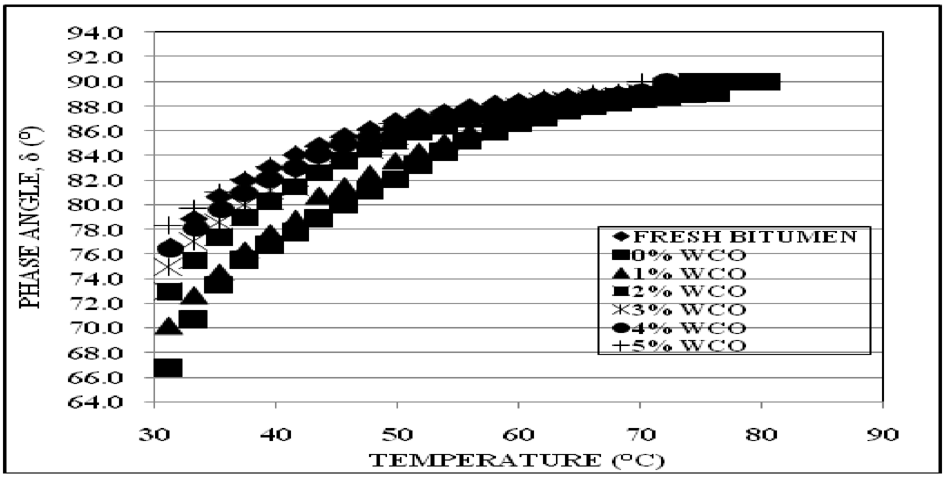

Figure 16 Phase angle, δ (°) curves for fresh bitumen and various percentage of waste cooking oil added to aged bitumen grade 40/50

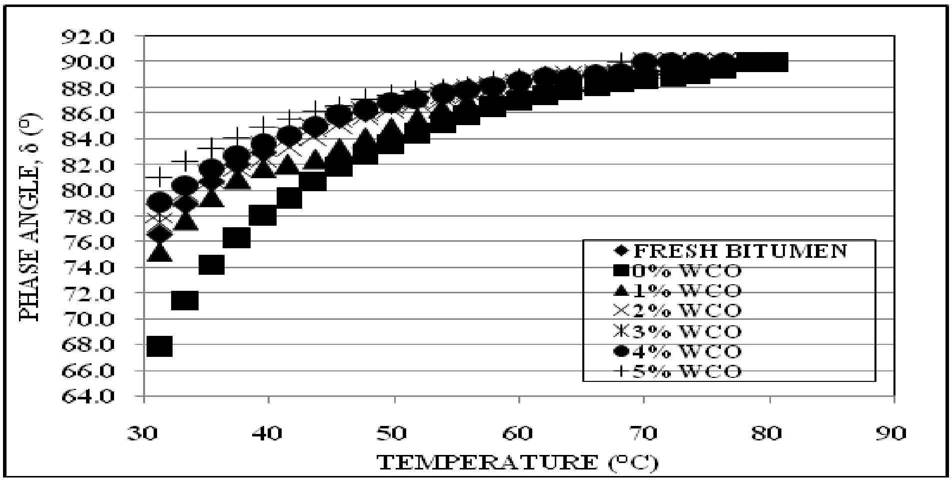

Figure 17 Phase angle, δ (°) curves for fresh bitumen and various percentage of waste cooking oil added to aged bitumen grade 50/60

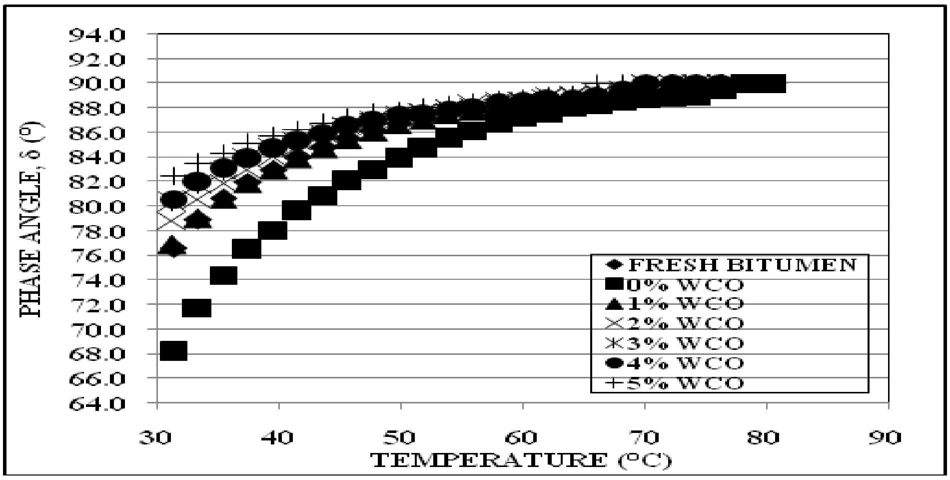

Figure 18 Phase angle, δ (°) curves for fresh bitumen and various percentage of waste cooking oil added to aged bitumen grade 60/70

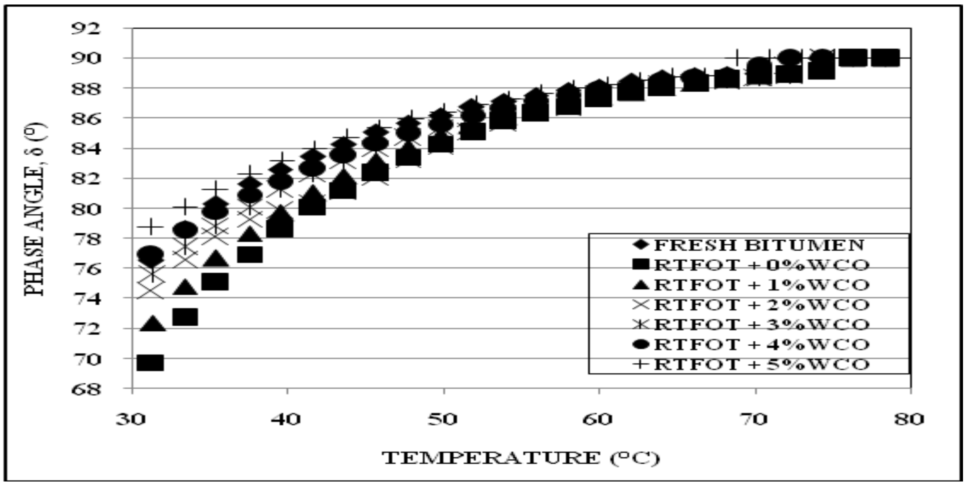

Figure 19 Phase angle, δ (°) curves for before (fresh bitumen) and after RTFOT aged binder added to various percentage of waste cooking oil

4. CONCLUSION

Based on the results of the laboratory investigation, the following conclusions can be drawn.

1. Waste cooking oil (waste material) is found to be a suitable rejuvenating agent for aged bitumen in bituminous pavements.
2. From the entire graph observed, RTFOT is one of the efficient accelerated ageing processes.
3. By using waste cooking oil as bitumen rejuvenator in recycled asphalt pavements, it significantly can be the alternative waste material in addition to recycled paper, glass, aluminum, plastic bottle, crumb rubber etc that contributes to the reduction in environmental degradation.
4. In addition, recycling asphalt pavements reduces the use of virgin materials (natural rocks, bitumen from petroleum).

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