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THERMAL AND RHEOLOGICAL BEHAVIOR OF RECYCLED RUBBER/NATURAL RUBBER BLENDS IN RECYCLE TIRE PROCESS

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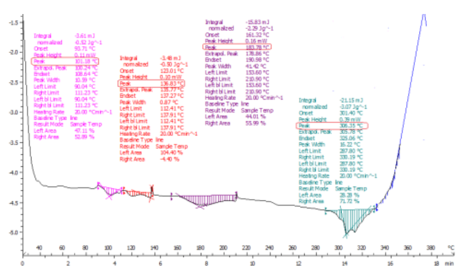
Graphical abstract



Abstract

The usage of recycled rubber in tire production is not common. This paper mainly focuses on feasibility of recycled tire to be used in production, particularly on thermal and rheological behavior of the blended recycled rubber and natural rubber. The investigation has been conducted on the blend of recycled rubber (RR) and natural rubber to determine the suitable composition of RR and SMR (Standard Malaysian Rubber) for the manufacturing of tire thread. RR which was taken from the thread of lorry tires was blended with two natural rubber types; SMR-L and SMR-10 at different mass ratio. The thermal characteristic was studied using Differential Scanning Calorimetry (DSC) while Capillary rheometer and Mooney viscometer was used to study the rheology behavior of the blends. It was found that SMR-10 has increased the thermal stability of the blend as opposed to SMR-L. Both natural rubber blends show similar relationship between shear viscosity and shear rates but SMR-10/RR blends exhibit higher viscosity than SMR-L/RR blends based on Mooney viscosity analysis.

Keywords: Recycle rubber, blending process, rheological measurement, waste management

1.0 INTRODUCTION

Rubber-based products have a wide range of application; from the rubber band, shoes that we wear and also the automobile parts. Rubber, which is a type of polymer has been used in many applications, either in its own or combined with other materials. The utilization of rubber is revolutionizing because of its special properties. Rubber can be divided into natural rubber and synthetic rubber. There are more than 100 000 types of articles where rubber is used as a raw material [1]. Since 1920, automobile had been the largest consumer in rubber industry. In terms of finished product, it has contributed large amount of waste materials. In Malaysia, a study on waste tire shows that 8.2 million or approximately 57391 tons of waste tire were generated annually [2]. A lot of things can be benefited from the waste rubber products. Therefore, many researchers had done studies on waste tire rubber to form into a new product. Among them was the research on the new compound using recycled rubber by Sekhar Research Innovations (SRI) [3]. The compound, called SRI compound were formulated from recycled tires and waste rubber for making new tires, rethreading tires or manufacturing automotive parts. Scaffaro *et al*. conducted a research on the prepared blend based on recycled polyethylene and ground tire rubber (GTR). The results showed that the compound exhibit fairly good properties in term of mechanical and rheological analysis with a relatively low concentration of GTR and proper thermal conditions [4]. The accumulation and disposal of polymer wastes such as the product of plastics, rubbers and synthetic rubbers has become a global issue. Polymer waste with crosslink structure is difficult to recycle of which they are neither fusible nor soluble. Critical degradation method is needed to reshape the polymer waste with this crosslink structure under the extreme temperature and pressure [5]. This has contributed to the large accumulation of polymer waste especially waste from tire.In this study, an investigation was done to find suitable composition of recycled rubber (RR) and natural rubber for the tire manufacturing in an effort to reuse the RR as well as addressing the global issue. XRD, differential scanning analysis (DSC) and rheological properties analysis were employed to determine the appropriate composition of the rubber blend. From here, the rubber blending processing method was established and characterized.

2.0 EXPERIMENTAL

Samples used for this study were recycled rubber (RR) and two grades of natural rubber (NR) from Standard Malaysian Rubber (SMR) quality such as SMR-L and SMR-10. RR was salvaged from the thread of lorry tire where the fibre and wire mesh had been discarded. X-ray Diffraction (XRD) analysis was done on the RR samples to determine its element using XRD RigakuUltima IV. The X-ray Diffraction graph depicting the diffraction pattern for RR is presented in result and discussion section.Samples blends of (i) RR with SMR-L and (ii) RR with SMR-10 were prepared using two-roll mill. Each samples weighed 400 grams at various mass ratio of RR and NR; i.e 100/0, 70/30, 50/50, 30/70 and 0/100 and the blending process took about 5 minutes. The finished samples were left to cool at room temperature. Differential Scanning Calorimetry (DSC) measurements were performed using Mettler Toledo DSC 1. The blended samples weighed between 7 to 8 mg were placed in an aluminum crucible with pierced lid before analysed. The running temperature was set at 350 °C at a scan rate of 10°C/min. Rheology analysis was then carried out using RH2000 Rosand Capillary Rheometer. The blend or RR/SMR was cut into smaller specimen for easily loading it into the capillary rheometer's barrel. Specimen was preheated at 60°C for 1 minute prior to the 8 stages shear rates procedure. The running temperature was set at 100°C. Further rheology analysis was done using Mooney Viscometer. It is noted that the Mooney Viscometer rotor was preheated before the sample was tested.

3.0 RESULTS AND DISCUSSION

Figure 1 shows the X-Ray Diffraction pattern for the RR specimens. From the reference of International Center for Diffraction Data (ICDD), the peaks of intensity in Figure 1 representing the phase for Calcite, Magnesian (Ca, Mg)CO3. The XRD analysis can only determine the element that exists in the compound. According to Sekhar [3], scrap tire has gone through vulcanization process and it is almost impossible to trace its composition at this stage. This confirms the XRD results at 2-theta degrees range from 30 degrees to 95 degrees, wherein only the Calcite, Magnesian; (Ca, Mg)CO3 elements were identified.

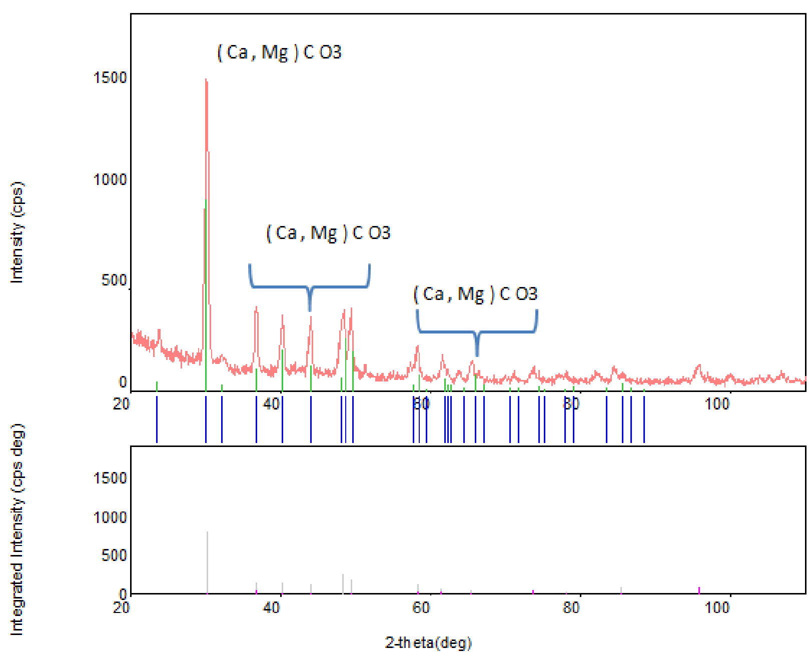


Figure 1 XRD analysis of Recycle Rubber (RR) original material

DSC was conducted to study the behavior of SMR/RR blends as they are heated. DSC is able to determine endothermic and exothermic characteristic of the blends [9]. The melting temperature of the blend can be determined from this analysis. Figure 2 shows the DSC analysis of RR samples without adding the neutral rubber component (SMR-10 / SMR-L). Four peaks were detected in a blend that is at 101.18 °C, 136.83 °C, 178.86 °C and 306.35 °C which indicates different melting temperature for possibly four different components in RR. Comparison of melting temperatures of different mixes of RR and SMR (10 & L) is shown in Table 1. Despite of unavailability of data for SMR10/RR(70/30) and SML/RR (50/50), the data suggest that when SMR10 was used in the blend, the melting temperature of the mix increased linearly with the increase amount of SMR10. This phenomena maybe caused by the increased of thermal stability of the blend with the incorporation of SMR10 material. On the contrary, by increasing the content of SMR-L to the blend will decrease the melting temperature accordingly. This observation suggests that the interfacial adhesion between the blend components decreased with increased SMR-L content.

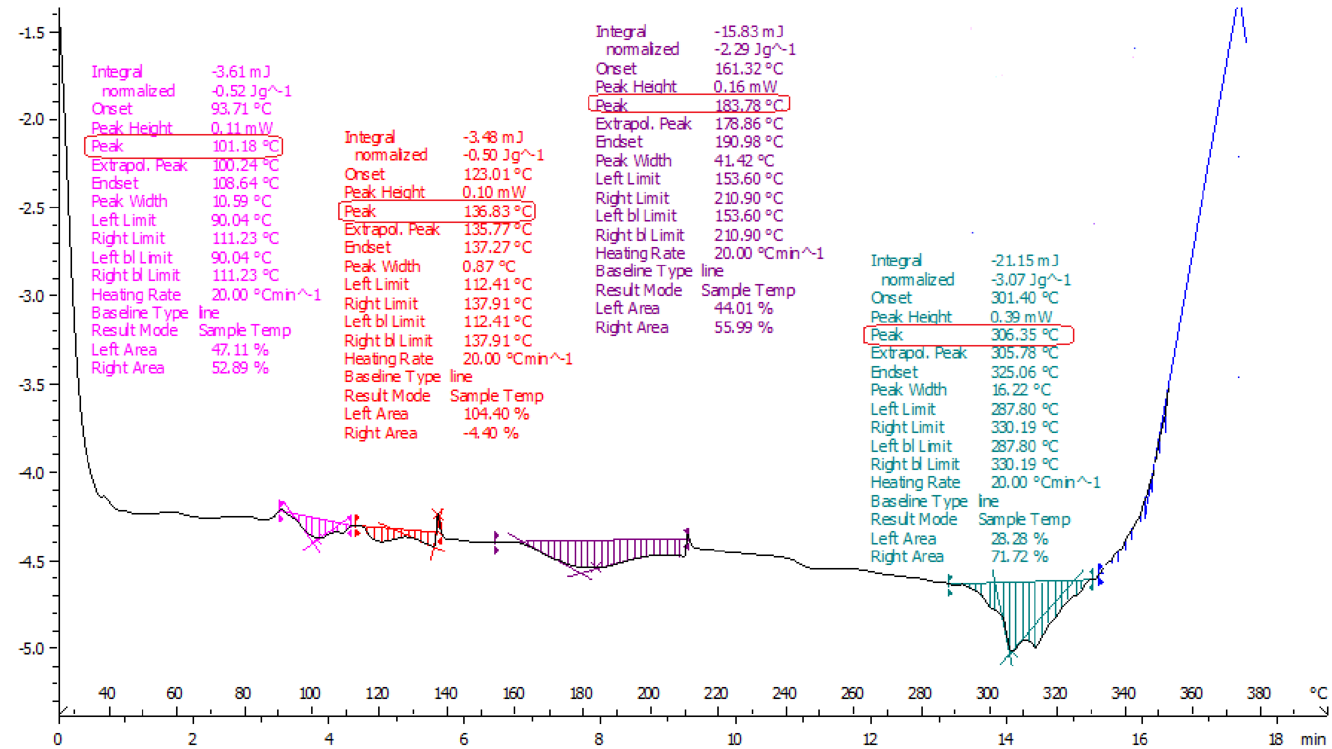


Figure 2 DSC Thermograph for 100% RR

Table 1 DCS Melting Point Data of SMR-10 and SMR-L/RR Blend [a]

RR Content	SMR-10	SMR-L	Melt Temp (ºC)
0	100	-	302.19
30	70	-	-
50	50	-	305.70
70	30	-	276.20
0	-	100	341.00
30	-	70	207,00
50	-	50	-
70	-	30	302.00

Figure 3(a) shows the relationship of shear viscosity and shear rate for SMR10/RR blends. The differences in the plot indicate by adding the natural rubber; SMR10 to the blend it alters the viscosity of the RR. The shear viscosity of the unmodified RR at low shear rate is higher compared to SMR10/RR blends. All blends of SMR10/RR exhibit pseudoplastic behavior as the viscosity of the blends decrease with increasing shear rates.

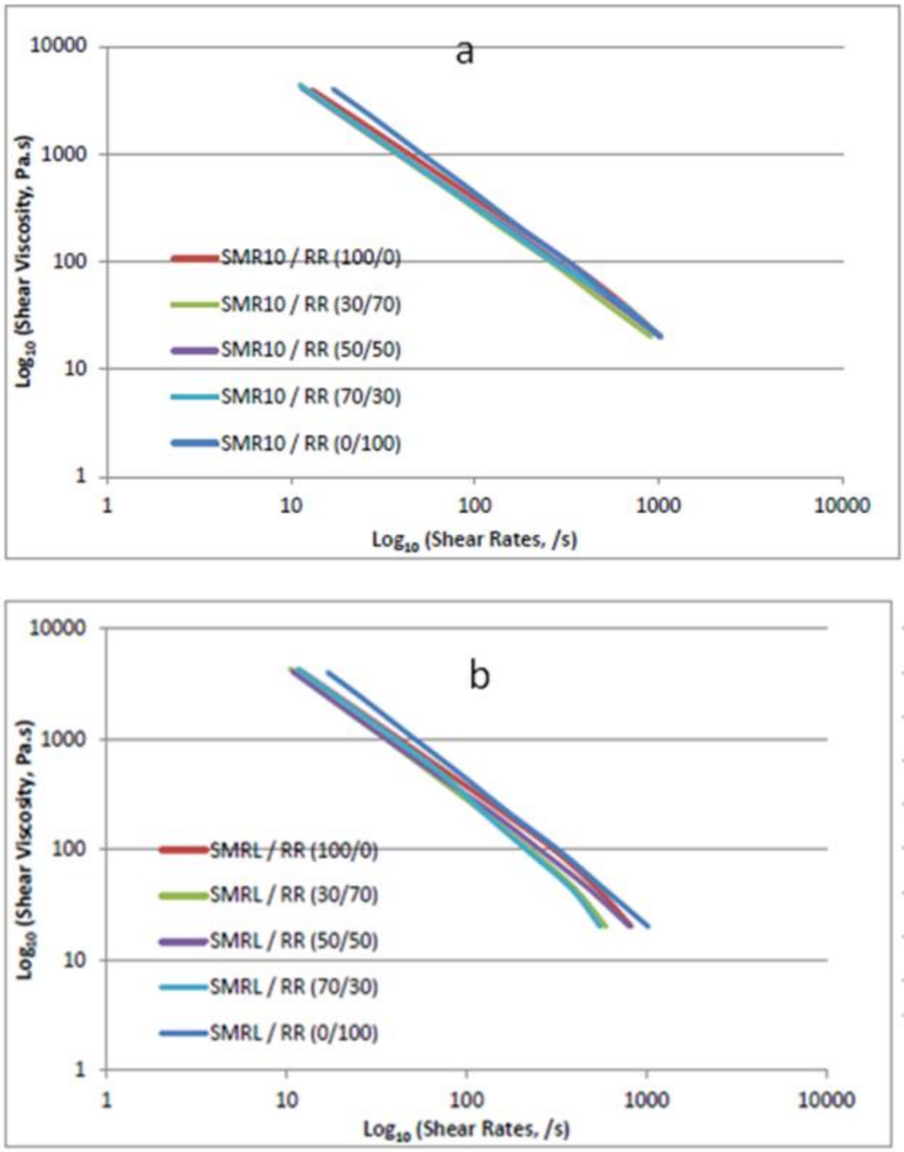


Figure 3 Relationship between Shear Viscosity and Shear Rate of RR/SMR blends

Figure 3(b) shows the relationship of shear viscosity and shear rate for SMRL/RR blends. The pattern of shear viscosity is almost similar to the SMR10/RR blends. The unmodified RR blends has higher viscosity than other SMRL/RR blends. This character is materialized as a result of the crosslinking structure via the vulcanization process of the RR. In which it was also observed that the viscosity of natural rubber was lower than RR [4]. This shows that the elements in the RR are still of the crosslinked structure although curing process was not applied in this blend. All blends of SMRL/RR also show pseudoplastic behaviour because their viscosity decreases as the shear rates increases.The shear viscosity of both blends, i.e. SMR10/RR and SMRL/RR show almost the same value.

Table 2 shows the power law index, n at the shear rate of 20/s. Power law index, n indicates either a polymer is Newtonian, shear thinning (pseudoplastic) or shear thickening (dilatant) in nature [12]. The value of n for all blends was less than 1, i.e. n<1, thus indicates that they are non-Newtonian fluid. According to R. S. Subramanian, n for pseudoplastic polymer is between 0.3 to 0.5 but, it is also possible for other values than that [13].

Table 2 Power Law Index, n at shear rate of 20/s [a]

Blend of SMRL/RR	Power Law index, n	Blend of SMR10/RR	Power Law index, n
0/100	0.27	0/100	0.27
30/70	0.39	30/70	0.21
50/50	0.28	50/50	0.19
70/30	0.45	70/30	0.15
100/0	0.37	100/0	0.26

Figure 4 shows the Mooney viscosity of SMR-L/RR blend and SMR-10/RR blend. As the mass by weight ratio of natural rubber increases, the viscosity increases accordingly. The viscosity of SMR10/RR blend is higher than SMRL/RR blend for all mass by weight ratio. This is different from what was obtained from Sombatsompop and Kumnuantip [14]. What they observed was increased of viscosities with the increased of RR content to the natural rubber of their blends. This indicates that different rubber content exhibit different viscosity properties.

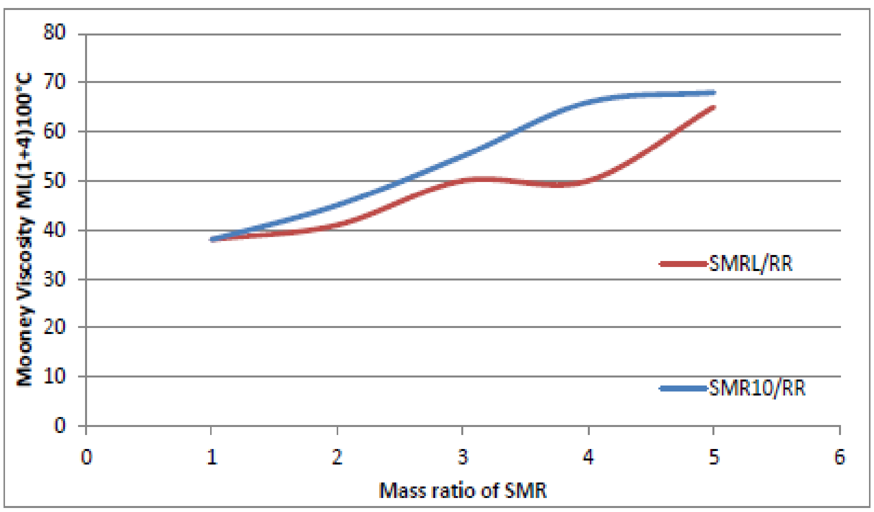


Figure 4 Mooney Viscosity of the RR/SMR blend

4.0 CONCLUSION

The blend of SMRL/RR and SMR10/RR had been produced. Investigation outcomes showed that RR and SMR can be blended together to produce a new product. DSC analysis showed that the incorporation of SMR10 to SMR/RR blends increased its thermal stability and the interfacial adhesion between the molecules of the blends. The incorporation of SMRL on the other hand, produced an inverted result. Both blends show pseudoplastic behaviour as shown by the relationship between the shear viscosity and shear rates of the blends. From Mooney Viscosity analysis, the blend of SMR10/RR exhibit higher viscosity than the blend of SMRL/RR. In overall, the blends of SMR10/RR exhibit better properties than the blend of SMRL/RR. It increased the thermal stability of the blends with better rheological properties. However, mechanical testing such as tensile test are required to further analyse the ability of the SMR10 as one of the ingredient in tyre threading production.

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