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Physical properties and energy absorption characteristic of open cell ENR/RR foam

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ABSTRACT - Impact absorber foam materials were produced from epoxidised natural rubber/reclaimed rubber (ENR/RR) with the addition of sodium bicarbonate (SBC) as blowing agent. The physical properties of ENR/RR foams were studied, and the results showed a significant influence of the physical properties of base matrix against the pore structure. The physical properties are governed by the relative density and water absorption. From the experimental values, ENR/RR with the ratio 90/10 yielded the rubber foam with the highest relative density of 0.85 as well as lowest water absorption rate of 2.48. These foam cell characteristics resulted in superior energy absorption behaviour. Sample with optimum pore size of ~0.36 mm shows the highest energy absorption up to 0.65 joules compared to others.

1. INTRODUCTION

There is growing interest for rubber materials in industrial and commercial applications. One of the major demands is rubber foam which is also known as cellular, sponge or expanded rubber [1,2]. Rubber foam is widely applied for footwear, stereo earphones, speaker surrounds, goggles, orthopedic soft goods, carpet anti-skid cushioning, cycle seats, etc. which are commonly require good cushioning, excellence shock absorption, elasticity and resistance to fatigue properties. All these properties are attainable from rubber materials due to their high tear and tensile strength, high abrasion resistance and durability [2]. Reclaimed rubber (RR) is one initiative for reducing the environmental problem and at the same time to produce significant properties product with lower cost.

A substance that produces a cellular structure in a polymer mass is defined as a blowing agent [3]. Chemical blowing agents for polymer are available in a wide range of formulations depending on the polymer processing temperature and the decomposition temperature of the blowing agent. Referring to Yamsaengsung et al. [4] and Karak [5], the gas release temperature of blowing agent should match the processing temperature of the polymers for optimum foaming. Several finding suggested *N,N'*-diniteosopentam (H) [6], sodium bicarbonate (SBC), 4,4'oxybis(benzenesulfonylhydrazide) (OBSH) [4], azodicarbonamide (AZD) [4], zinc carbonate ($ZnCO_3$), etc as a foaming agent.

In this present work, the best ratio of ENR/RR for the optimum pores structure and physical properties of rubber foam was studied, followed by the evaluation of shock absorption efficiencies of rubber foam in respect to pores dimension, was performed by applying drop impact test methodologies. This finding was further supported by the optical microscopy (OM) observation.

2. METHODOLOGY

2.1 Materials and Sample Preparation

For the preparation of ENR/RR foam, epoxidised natural rubber (ENR) and reclaimed rubber (RR) were used with a gas-producing chemical of sodium bicarbonate (SBC). The semi-EV system was used that consisted of 100 phr (part per hundred rubber) ENR/RR, 4 phr zinc oxide, 2 phr stearic acid, 2.5 phr tetramethyl thiuram disulfide (TMTD), 1 phr benzothiazyl-2-cyclohexyl-sulfenamide (CBS) and 1.0 phr sulfur. All the materials were used as received. The compounding was performed on a Rheomix OS, Haake internal mixer at temperature of 60°C and rotor speed of 60 rpm, and the mixing time was 1 min. A fixed amount of 4 phr of sodium bicarbonate was loaded at the end of the compounding process but before the addition of sulfur. Varied ratios of ENR/RR were used for the preparation of ENR/RR compounds; 100/0, 90/10, 70/30, 50/50, 30/70, 0/100. A heat transfer foaming technique was used for the vulcanization and foaming process. This two-stage process involved 1 min of compression molding at a temperature of 100 °C for pre-vulcanization and was followed by simultaneous curing and foaming in an air-circulating oven for 30 min at temperature of 150 °C.

2.2 Sample Characterization

Relative density: The relative density of the foam was measured in accordance to ASTM D-1056 by using Eq. (1) as given below:

$$\text{Relative density} = \frac{\text{Foam density (g/cm}^3\text{)}}{\text{Solid density (g/cm}^3\text{)}} \qquad (1)$$

Water absorption, Wabs: Water absorption test was conducted in accordance to ASTM C-1083 to determine amount of water absorbed under specified conditions. The 20x20x10mm samples were dried in an oven for period of 3hrs and temperature of 60°C and then placed in a desiccator to cool. Immediately upon cooling the specimens are weighed. The material is then emerged in 450ml water at 23°C for 24 hours. Specimens are removed, blotted dry with a lint free cloth, and then weighed. Water absorption rate was calculated based on following Eq. 2:

$$\text{Wabs} = \text{Final weight} - \text{Initial weight} \quad (2)$$

Impact absorbance drop test: The impact or dynamic stress test was performed, where a 0.14 kg mass sphere ball impactor was dropped from a height of 540 mm onto the 30x30 mm samples. The height of the first rebound was measured and the energy absorption (in unit of joule, J) was calculated as Eq. 3:

$$\text{Potential energy}, E = \text{Mass x Gravity acceleration x Rebound height} \quad (3)$$

Foam pore morphology: The optical microscope (OM) was used to investigate the pore structure of ENR/RR foam. The average cell size was determined.

3. RESULTS AND DISCUSSION

Figure 1a shows the decrease of relative density of rubber foam with the increase of RR content. Higher RR content with lower tendency for new crosslinking provides loose sites for the carbon dioxide (CO_2) gases to stretch the pore wall created by sodium bicarbonate in the ENR/RR mixture. The expansion of the pore walls results in a relatively larger pore size and thus produces foam with lower relative density. The amount of solid phase per unit volume is reduced, and thus less crosslinking is presence.

Figure 1b depicts the increase of water absorption rate of foam with the increase of RR content. Higher content of RR allowing the foam to expand more and consequently producing a foam with large unfilled space. Thus, more water is absorbed into the unsaturated part of the foam.

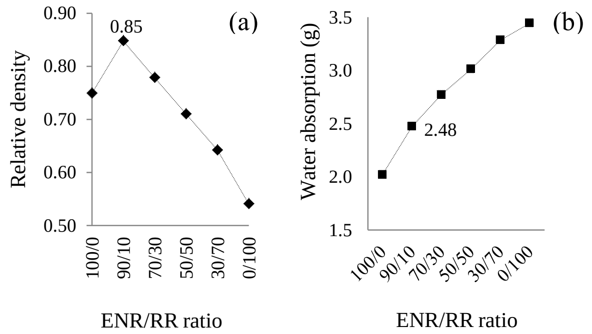

Figure 1 Plot of (a) Relative density and (b) Water absorption for different ENR/RR ratio

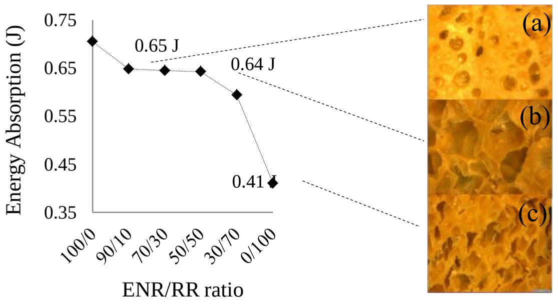

Figure 2 Impact energy absorption variation and the micrographs of pore structure for varied ENR/RR ratio

The efficiency of impact absorption of the rubber foam is a compromise between the ENR/RR ratio and the foam structure. The resultant value of impact absorption is inversely proportional to the pore size. From the graph plot and optical micrographs in Figure 2, sample with 90/10 ENR/RR ratio contribute to the highest impact absorption value with the smallest pores dimension compared to other samples (not considering the reference sample of ENR/RR 100/0 and 0/100). An optimum pores size capable of absorbing highest energy whereas larger pore's structure in a particular sample is believed to exhibit higher plasticity.

4. CONCLUSION

The experimental result indicates the effective ratio of ENR/RR affects the physical and energy absorption properties of the rubber foam. As the RR content increases, there are more loose sites for pore enlargements by CO_2 gas per unit volume. This results in a foam with relatively lower density and higher water absorption rate due to the decrease of crosslink density. In drop ball testing, samples which absorbs more energy after impact caused the ball to bounce at a lower height after impact. The test revealed that samples with optimum pore size is applicable for an efficient energy absorption. This is in a good agreement with morphological characteristics of the foam structure. Sample with higher pore unit/volume and at an optimum diameter are essential for energy absorption. As the conclusion, it is revealed that higher fresh rubber content (ENR) has better tendency to produce a foam with higher pore density, lower pore sizes and consequently exhibit higher energy absorption than a mixture with higher reclaimed rubber (RR) content.

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