Rubber waste as potential filler for polymer composites: Material characterisation

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ABSTRACT – Rubber waste is difficult to degrade due to its highly cross-linked structure that can lead to pollution and spreading of diseases. Rubber waste is very elastic and possess high durability behaviour which potentially can provide enhancement towards the composite properties. In this work, rubber waste was obtained from rubber glove waste and went through cryogenic grinding to produce crumbs. The crumbs were later analysed by using physical, microscopy and thermal characterisation methods. The sizes of the rubber crumbs were ranging from 300 µm to 2 mm and the microscopy observation showed the rubber crumbs has regular shapes and smooth surfaces. Thermo-gravimetric results revealed rubber crumbs degrade in three stages and obvious mass loss occurred between 250 ºC to 400 ºC due to degradation of the main natural rubber element; poly-cis-1,4-isoprene. In comparison with the fresh rubber, thermal behaviour of waste rubber crumbs insignificantly changed as compared to fresh rubber crumb. Thus, on the basis of properties obtained from this work, the rubber waste crumbs acquired from rubber waste glove potentially can be used as a filler for the polymer composites as an alternative to recycle the waste material.

1. INTRODUCTION

Environmental concern has been a never-ending discussion among environmentalist, researchers and scientists. To ensure survivability of mankind and life being in the future, numerous, and extensive efforts by all relevant parties have been conducted in order to materialise this greener environment campaign [1]. Researchers have conducted numerous studies that involved rubber waste in the composites composition, such as polymer-based composites and ceramic-based composites. From the literature, it was reported that rubber waste went through crushing, grinding, macerating or pulverising processes in order to obtained smaller sizes of rubber article prior added into the composite matrices such as thermoset, thermoplastic or elastomer matrix. Smaller sizes of rubber waste can be in the form of crumbs, particles, granulates, powder or dust which were categorised by its sizes [2, 3]. The characteristics of rubber crumbs, particles, granulates, powder or dust can be analysed by using physical and thermal methods [4]. Physical characteristics of these rubbers include the size distribution, shape, and surface characteristics. The thermal degradation characteristic of the rubber crumbs can be determined by thermal analysis.

From the literatures, the size of rubber crumbs being incorporated into a composite is in the range from 75 µm to 500 mm [2, 5] while the shapes can be varied from irregular, regular to spherical shape and their surface can be rough or smooth [3, 4]. The cryogenic grinding process is a method of using liquid nitrogen or other materials or techniques that are able to freeze the rubber articles below its glass transition temperature (T_g). Natural rubber is the main component of the rubber glove has T_g of -70 ºC. Rubber changes from elastic to brittle behave "glass-like" property thus it is able to be ground or crushed to reduce size. The cryogenic grinding also preserves rubber from heat degradation and maintains its unique properties [3, 6]. Behaviour of rubber crumbs towards heat can be identified by thermal analysis techniques. Thermo-gravimetric analysis (TGA) is the common method used for this purpose [7, 8]. It is important to conduct thermal analysis study as the oxidative and thermal degradation of the rubber crumbs are very much influenced by its suitability for the desired application, especially its impact on the products' performance and shelf life [9].

2. RESEARCH METHODOLOGY

Rubber waste used for this work was the rubber gloves from laboratories used. The gloves were washed, rinsed, and dried in a dry and airy environment. The gloves were soaked in liquid nitrogen until frozen and the frozen gloves were crushed by using an electrical powered rotating sharp metal blade to produce rubber crumbs. The rubber crumbs were subjected to several tests to study its potential as reinforcement material in polymer composites such as determination of the crumbs size, shapes, surface characteristics and thermal analysis.

The size of rubber crumbs was determined by a sieve shaker. The crumbs were sieved by using mesh sizes of 300 microns, 450 microns, 600 microns, 850 microns and 2 mm. The shape and surface morphology of the rubber crumbs was analysed by using JSM-6010Plus/LV Scanning Electron Microscope (SEM) from JOEL.

For thermal analysis, samples of fresh and waste rubber crumbs were analysed using TGA. The purpose of analysing both rubber crumbs were to detect if there were any significant differences or changes occurred between these two rubbers. The analysis was conducted by using TGA Q500 TA Instruments thermal analyser. Samples of 5-10mg were heated from 30 °C - 950 °C at a nitrogen flow of 20 mL/ min at a heating rate of 10 °C/min.

3. RESULTS AND DISCUSSIONS

3.1 The size, shape and surface of rubber crumbs

To produce composites with good physical and mechanical properties is by enhancing compatibilisation between filler and the matrix. Good compatibilisation improves the filler-matrix adhesion hence, resulting in better physical and mechanical properties of the composite. Smaller filler sizes are one of the key elements in providing better matrix-filler adhesion. Reduced filler size will increase specific surface area of filler thus allowing more area for adhesion [10]. The reduced size of filler can be obtained by cryogenic grinding as it is capable of producing the finer size of rubber crumbs up to 75 µm [11]. Grinding rubber below its T_g changed elastic behaviour of rubber to brittle which ensured effective grinding in producing smaller size of rubber crumbs. It was a challenge to produce finer rubber crumbs through ambient grinding as because glove is highly elastic article and tends to stuck at the grinder blade. Rubber glove was specially manufactured to have very high elongation and high strength in order to minimise glove rupture and tear during use [12]. Thus, effort of conducting cryogenic grinding on the rubber glove waste in this study is proven relevant. Figure 3.1 shows the SEM image of the rubber crumbs obtained from the cryogenic grinding. It can be observed that the rubber crumbs size ranging from 300 µm to 2 mm.

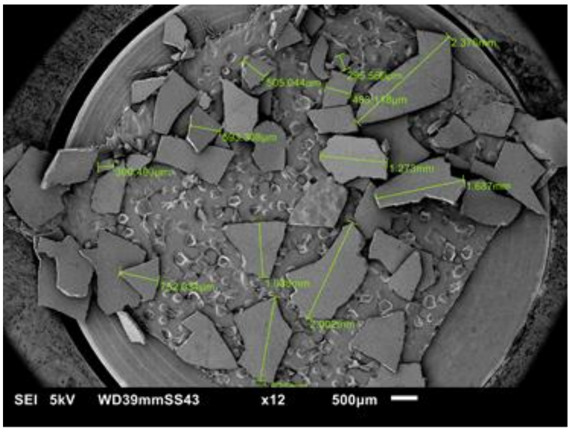

Figure 3.1 SEM image of rubber crumbs.

Figure 3.1 also revealed the shape of the crumbs, as it was regular in shape and sharp-angular edges and its fracture surface is smooth and clean cut. Smooth fracture surface and sharp-angular edges showed rubber experienced brittle fracture as it embrittled below glass transition temperature during cryogenic grinding process [3, 4, 10, 11, 13, 14]. Although many findings mentioned that regular and smooth surface of filler may not be producing stronger adhesion with matrix as compared to irregular and rougher surface crumbs, it can be overcome by modifying the surface of the fillers or the crumbs with compatibiliser [13–15].

3.2 Thermal properties

The thermal analysis for the rubber crumbs is to determine its thermal degradation in order to understand the heat resistance and thermal stability of the crumbs. Therefore, product damage or deterioration during manufacturing and application can be prevented. The thermo-gravimetric curves of weight loss comparison for both fresh and waste rubber crumbs are shown in Figure 3.2.

Three main steps were observed for both samples of rubber crumbs [8] which represent rubber crumbs degrade in 3 stage. The first weight loss occurred between 250 ºC to 400 ºC due to degradation of organic components present in rubber as the main rubber elements. They are poly-cis-1, 4-isoprene, protein, and other minor substances present in the glove's formulation. The degradation of these substances continued from the temperature 400 ºC to 700 ºC [8, 13]. The final steps between 700 ºC to 950 ºC were attributed by mass loss happened due to the decomposition of ashes and carbonaceous residue either from the earlier thermo-oxidation process of organic substances or elements that already present in the rubber [8, 13]. The thermo-gravimetric curve of waste rubber shows insignificant change as compared to fresh rubber hence proven that waste rubber that remains its elastomeric properties.

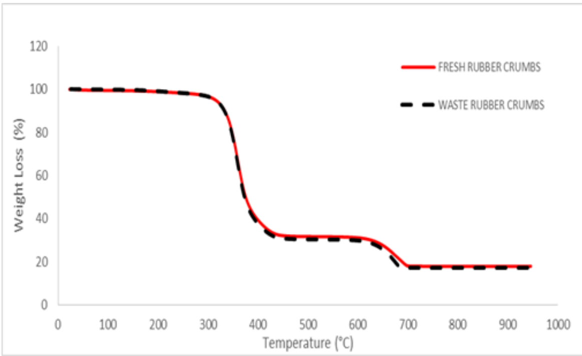

Figure 3.2 Thermo-gravimetric curves of fresh rubber crumbs and waste rubber crumbs.

4. SUMMARY

Physical and thermal characterisations of waste rubber glove crumbs help in identifying the potential of rubber crumbs to be incorporated in the polymer composites. Cryogenic grinding is able to produce a smaller size of rubber crumbs that offers higher surface area that could enhance filler-matrix adhesion of the composites. Crumbs sizes obtained from cryogenic grinding were ranging from 300 µm to 2 mm. Cryogenic grinding produced regular shape and smooth surface of rubber crumbs. On the thermal properties of the rubber crumbs, both waste and fresh crumbs start to degrade at 250 ºC and noticeable weight loss continues until the temperature is 400 ºC. The weight loss, is mainly due to the decomposition of poly-cis-1,4-isoprene, the natural rubber main element. This similar thermal behaviour of both waste and fresh rubber shows insignificant chance in waste rubber behaviour. With the unique and good characteristics of waste rubber glove crumbs, it has a huge potential as filler for the polymer composite.

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