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An experimental study of tensile properties and vibration absorption characteristic of ground tire rubber (GTR)/HDPE waste: Effect of temperature and heating time.

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Abstract. HDPE is type plastic that is often found as after use containers in a large number, is disposed of as waste that pollutes the environment. Likewise with rubber waste which is also often found in landfills such as used tires. This research utilizes HDPE waste and used tires which are then combined as a test sample for mechanical testing and vibration test. 30% of rubber powder and 70% of HDPE powder were mixed and put into metal molds and then pressured at 8.5 Mpa. The size of rubber powder and HDPE have the same size that is equal to mesh 45. The samples in pressurized molds are heated to 140oC and 180oC with variation in heating time are 10 minutes, 15 minutes, and 20 minutes, respectively. After that, tensile testing and vibration testing are carried out on the sample. Microstructure observations were carried out using LSM (laser scanning microscope). For vibration testing, the sample is used as a damper material placed between the electric motor and the supporting plate. The results showed that increasing the heating temperature tends to decrease the tensile strength but increased the strain at the break slightly. Finally, the vibration test shows a decrease in vibration displacement with the use of HDPE/GTR as damper material. The lowest value of peak to peak of vibration amplitude obtained in 180oC heating temperature and 10 minutes of heating time.

Keywords: GTR/HDPE, tensile, vibration, damper.

1. Introduction

Currently, the environmental issue is dominated by a large amount of waste from the polymeric material. Plastic waste and rubber have become serious problems for the environment (1). This is inseparable from the high demand for these two types of material. The automotive sector, which is one of the sectors with high growth rates, has contributed a large amount of plastic and rubber waste. For example the use of HDPE plastic as vehicle oil packaging bottles and rubber which are dominated as vehicle tires. HDPE plastic is one type of plastic with the largest contribution to the problem of plastic waste. According to APBI that tire production in 2018 in Indonesia reached 84 + 69 million units (2). Also as we know, as much as two-thirds of the total use of rubber in vehicles is fully used as tires (3). Natural rubber is still topped in terms of use, which is 40%, followed by styrene-butadiene rubber (SBR), butyl rubber (IIR), and ethylene-propylene-diene (EPDM)



monomer rubber (3). Based on this fact, of course, in the end, these two types of material will become a burden on the environment.

To overcome this problem, several alternative efforts have been made including reusing or recycling these two types of material. The reuse of this waste, especially tire waste can be intended for some uses such as retreading, energy needs, and to make composite materials. These efforts are needed to change the mindset that the waste is not considered as a hazardous material anymore but as a more environmentally friendly material (4). The initial step taken to use rubber waste is to reduce and resemble the size or in other words, change it to powder form with a size in the range of 0.25 mm - 2.5 mm by grinding or abrasion (4). The grinding process is the most carried out process for this purpose (5-7). If the size of the processed powder is below 1 mm, it is called Ground Tire Rubber (GTR).

A combination of polymer-based materials both thermoplastic and thermosetting with GTR has been done. This combination can be used as a new type of material for various purposes. Thermoplastic is the type of polymer most often combined with rubber waste powder and several thermosetting polymers are also found (8). However, this combination has constraints. The main obstacle in reusing rubber waste especially used tires is because of its complex structure (5, 9) and tire composition which consists of several types of materials such as steel wire, silica, carbon black, fibers made of nylon polyester and cellulose (4). So to be combined with other types of polymers will cause difficulties and make the combination strength is low. This is referred to as low compatibility.

In terms of fixing the problem, the most widely used approach is by using agent compatibility (modifier). Various types of compatibility agents have been used such as styrene grafted styrene-butadiene rubber copolymer (PS-g-SBR) (10), non-polar elastomer (11), Polyethylene grafted with maleic anhydride (12) and rice husk (13). In general, the presence of compatibility agents or modifiers is to improve the interfacial adhesion between GTR and its polymer matrix. Some researchers using a compatibility agent to improve the mechanical properties of the combination. Formela et al [11] investigated LDPE/GTR composites using non-polar elastomers as agent compatibility. The presence of non-polar elastomers provides strong interfacial interactions thereby increasing its mechanical properties. Interfacial interaction behavior is caused by a combination of nonpolar elastomeric compatibility with polyethylene and also with GTR. The 50% content of LPDE provides the best mechanical strength [11]. Elnaz et al [12] applied a method namely dynamic-vulcanization and reactive-compatibilization, the results showed an increase in torque plateau compared to the RR / HDPE with the traditional method. The dynamic-vulcanization method shows better results than the reactively-compatibilized method, it can be seen from the higher elastic modulus value. The dynamic-vulcanization method provides an improved distribution of the RR phase, an also increase in blend viscosity and thermal resistance. Ziyad et al [14] conducted a study on the rheological properties of HDPE / Recycled tire rubber with the result that the crosslinked structure of the tire and differences in chemical composition between HDPE and GTR made it difficult for both constituents to have a good interfacial adhesive without any agent compatibility. The combination of HDPE and GTR shows that the elastomeric phase is dispersed in HDPE where the function of HDPE is dominant as a load carrier. However, another reason was given by Sienkiewicz et al [15] that the difference in manufacturing properties between HDPE and GTR makes it another difficulty to combine this type of material.

Several studies that combine GTR and PE polymers have been carried out [16-20]. The aims are to find the best combination of PE and GTR for various applications. However, a paper about the vibrational behavior of HDPE/GTR material has still limited, The present study aims to examine tensile properties and the vibrational behavior of HDPE/GTR materials with different heating temperatures and heating times without using modifiers or agent compatibility.

2. Methods and materials

Waste plastic bottles made from HDPE and rubber waste obtained from truck tires is first washed and cleaned. After cleaning the plastic and rubber waste was grinding manually to produce powder as shown in Figure 1. HDPE powder and rubber powder are then filtered using a mesh-sized sieve 45 to get uniform powder sizes which are around 0.35 mm.



Figure 1. a) Rubber particle (GTR), b) HDPE after grinding, c) HDPE and GTR particle after mixing.

HDPE and GTR powder were mixed with a composition of 30% GTR and 70% HDPE by weight using a mixer for 1 minute to make it homogeneous. The mixture of HDPE-GTR powder was put into a cylindrical metal mold with a diameter of 12 mm and a length of 150 mm. The mold was then pressed until it reached a pressure of 8.5 Mpa using the WAW-600D Servo Hydraulic Universal Testing Machine. After the pressure reaches 8.5 Mpa, the mold is clamped and then heated in a furnace with the variation of heating temperature was 140 °C and 180 °C and heating time was set up to 10 minutes, 15 minutes, and 20 minutes then the sample was cooled to room temperature. After that, samples are removed from the mold (see fig 2a) and then cut using a cutter to the dimensions of the ASTM D638-V (Figure 2b). The tensile test was carried out on a testing machine with tensile speed was set at 1 mm min⁻¹. The sample code can be seen in the following table 1.

Tabel 1. Sample code of the specimen

Sampel Code	Heating Temperature °C	Heating time (minutes)	Number of sample
S140/10	140	10	5
S140/15	140	15	5
S140/20	140	20	5
S180/10	180	10	5
S180/15	180	15	5
S180/20	180	20	5

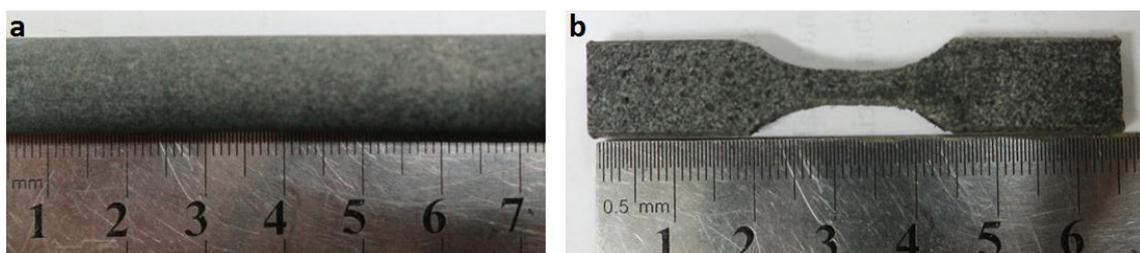


Figure 2. a) HDPE/GTR Blended sample after compaction and heating, b) Tensile test specimen

For of vibration characteristics testing, the sample was cut to the size of 45 mm x 8 mm x 6 mm and then used as a damper material placed between the electric motor and the supporting steel plate as shown in Figure 3.



Figure 3. Set up installation for vibration test

The 9-volt dc motor with exciter was used as a source of vibration. Damping behavior was measured using a Vibexpert II device with a transducer placed on the supported steel plate. The rotational speed of DC Motor was set to 3140 rpm, Vibration starts to be measured after 1 minute after the steady-state condition was reached. The time to measure vibration was set for 2 seconds. For microstructure, observations were carried out using a 3D Measuring Laser Microscope OLS4100.

3. Result and discussion

Figure 4 shows the correlation between heating time and heating temperature to the tensile strength of the combination HDPE/GTR sample. The result shows that tensile strength value is in the range (3.57 Mpa – 6.36 Mpa). The value obtained is similar in the range also obtained by Morrin et al [21] with heating time for 20-30 minutes at a temperature of 200 °C pressure of 8.6 MPa which is 3.5 - 6.5 MPa. Furthermore, Ramin et al (22) also obtained tensile strength values in the range of 2-8 MPa for LDPE / RNR material by a rotational molding process and stated that this process led to good consolidation and adhesion of the constituents [22]. Meanwhile K. Formela et al with a mixture of LDPE / GTR 50%: 50% get tensile stress of 4.20 MPa (11).

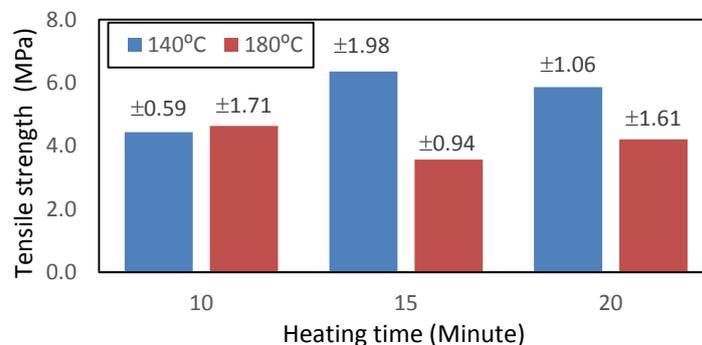


Figure 4. Correlation between heating time and heating temperature to the tensile strength

Figure 4 also shows that at the 10 minute heating time does not seem to have any noticeable effect on the tensile strength. The difference looks quite large at the 15 minutes and 20 minutes,

while the heating temperature at 140°C has greater tensile strength than the heating temperature at 180°C. Therefore, the S140/15 sample provides the greatest tensile strength value (6.36 Mpa) and the S180 / 15 sample gives the lowest tensile strength (3.67 Mpa). The decrease in tensile strength with the increasing heating temperature can be attributed to a decrease of crosslink bonds in GTR during heating [22]. This suggests that at a higher heating temperature more crosslinks will disappear and as a result, the lower tensile strength occurs. It has been recognized that due to differences in heat absorption behavior of HDPE and GTR make difficulties to combine these two types of materials, especially at the higher processing temperature. The differences in the behavior of HDPE and GTR in receiving heat play an important role in the final structure. Nevertheless, the interface adhesive also depends on the degree of compatibility as has been well established in several studies [16, 18, 20].

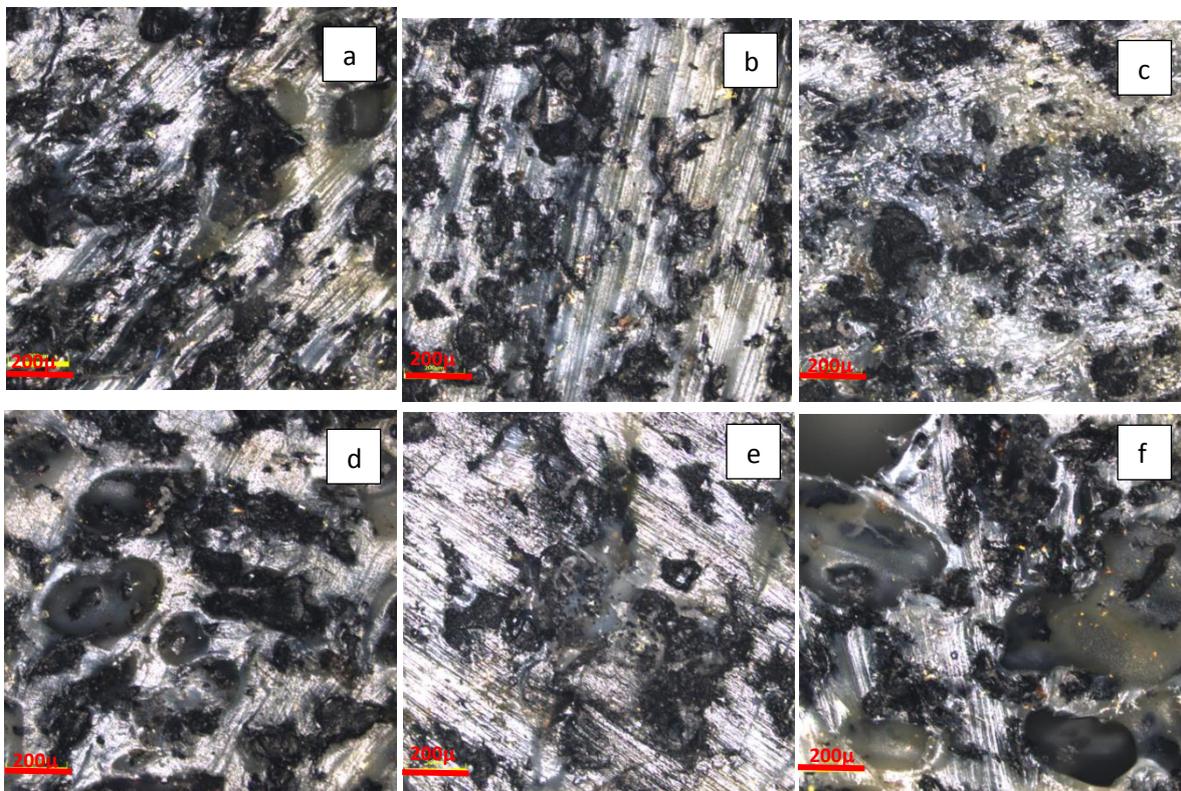


Figure 5. Microstructure of HDPE/GTR blend; a. S140/10; b. S140/15; c. S140/20; d. S180/10; e. 180/15 and f. S180/20

From the examination of the microstructure reveals information on the interface between HDPE-GTR. Images from a laser optical microscope show that there are three different regions namely white HDPE, GTR which is black and pores or voids indicated by areas that look blurry. The GTR area is dispersed in the HDPE matrix. The microstructure image shows a clear gap between the two phases between HDPE and GTR. The weak interfacial adhesive can be confirmed by the formation of a clear gap boundary between two phases [11], so this combination cannot distribute the load perfectly. As shown in Figure 5, micrograph of pores with relatively larger sizes is seen to occur at a higher temperature. Ramin Shaker and Denis Rodrigue [22] stated that there is a relationship between heating time and heating temperature with the presence of bubbles and defects on GTR/PE blended. Higher temperature and time, a higher number of bubbles, and damage. In addition, porosity is also caused by the contraction of the GTR main chain which

becomes shorter during the heating period, so that the presence of voids surrounding the rubber particles causes an imperfect interface between the particles and the matrix. However, without the presence of the compatibility agent, the interfacial adhesive does not strong enough.

Figure 6 shows the relationship between heating time and heating temperature to fracture strain. The strain at break increases almost linearly with increasing heating time and heating temperature. The increase in strain at the break of the sample might be due to the increase in flexibility of the GTR after the heating process. As previous explanation, higher heating temperatures could damage the crosslink bonds and also create defects and the number of bubbles causing GTR to become more flexible. However, the low fracture strain value of blended material is caused by a highly crystalline structure of HDPE and only contain 30% of GTR. This condition makes the HDPE/GTR sample is still far from to recognize as thermoplastic elastomer material where the fracture strain for the material is greater than 100%. This suggests that the heating process did not improve the fracture strain due to a nonuniform structure and the presence of void or defect.

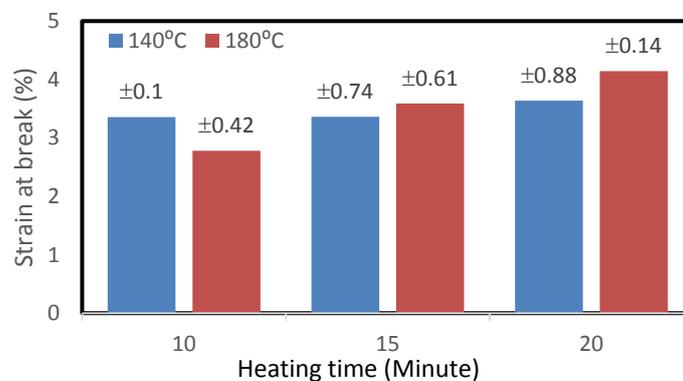


Figure 6. Effect of heating temperature and heating time on strain at break GTR/HDPE

To find out the vibrational behavior of the sample, a 9 volt motor with an exciter is used as a source of vibration. The transducer of the Vibexpert II device is attached to the supporting steel plate to measure the vibrations. The Vibexpert tool records vibrations that occur on the supporting plate for two seconds and is shown in Figure 7a and Figure 7b. The results show a decrease in vibration displacement with the use of HDPE / GTR as damper material. It is noticed that at the same heating temperature the vibration displacement tends to increases as the heating time increases. The ability of energy dissipation is related to the viscoelastic behavior and degree of connectivity of many interface areas in a structure [24] where both of these are influenced by heating temperature and heating time. Howarth et al stated that the vibration characteristics are influenced by the characteristics of the damper such as the thickness of the damper, the structure, and the composition of the damper material [24]. Damping behavior is also influenced by the shape of the irregularity of the rubber particles, and pore irregularity [25]. This attenuation can also be derived from the contribution of the interfacial friction between matrix and rubber particles [26.]. In addition, the pores arising from the dispersion of rubber particles can play a role in damping capacity behavior [27]. Overall, the difference in decreased vibration behavior with variations in heating time and the heating temperature is entirely due to differences in the structure of HDPE/GTR.

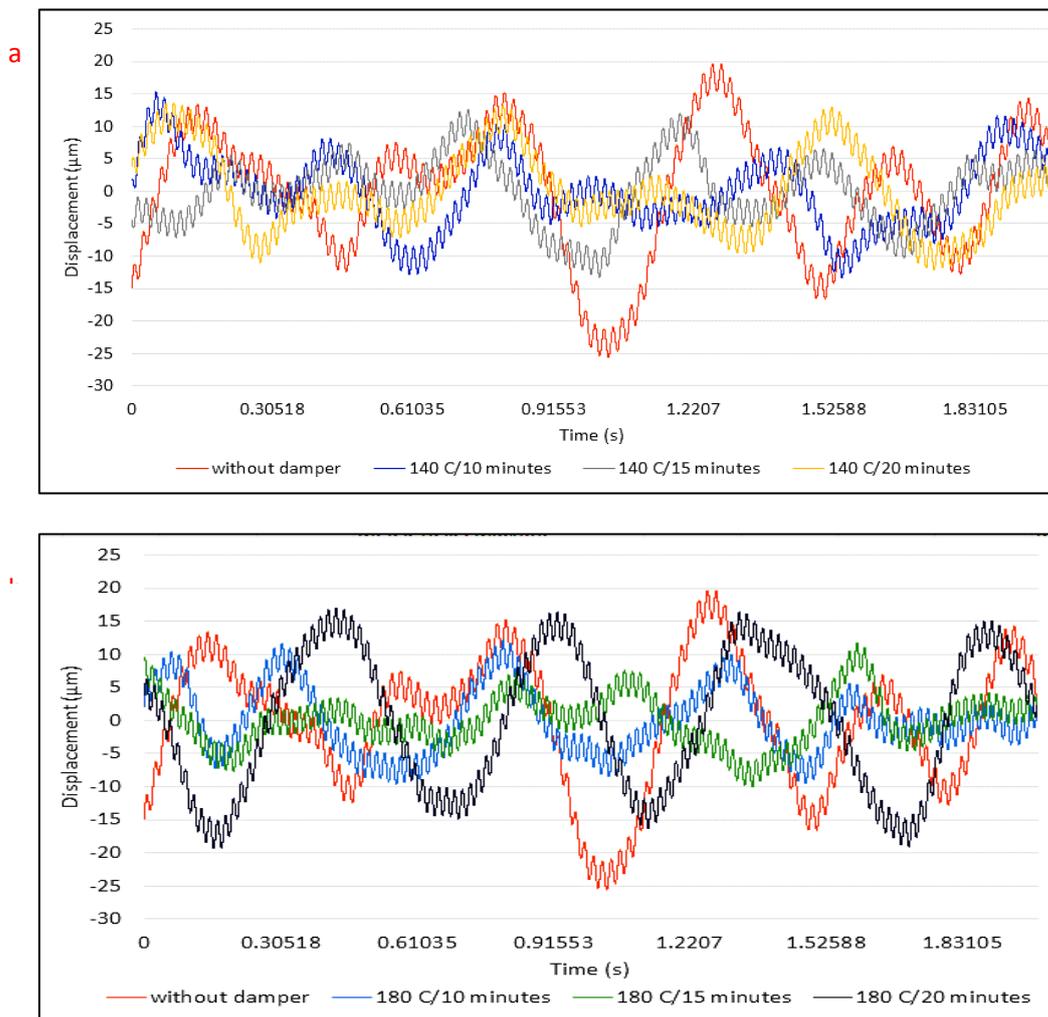


Figure 7. Profile of vibration displacement: a) sample S140, b) sample S180.

Table 2. Peak to peak value of GTR/HDPE blended sample.

Overall value	With HDPE/GTR Damper						Without Damper
	S140/10	S140/15	S140/20	S180/10	S180/15	S180/20	
Min. Amplitudo (µm)	-12.72	-14.61	-14.78	-12.01	-12.5	-17.75	-22.87
Max. Amplitudo (µm)	13.64	15.86	13.67	11.62	12.14	15.93	19.51
Peak to peak (µm)	26.36	30.47	28.47	23.71	24.65	33.68	42.38

Peak to peak values is presented in the table 2, the value of peak to peak without a damper was obtained at 42.38 µm. The results indicate that the use of the HDPE/GTR as damping material between the motor and supporting steel plate has succeeded in reducing the peak to peak value. The lowest peak to peak values obtained in the sample S180/10 and the highest value obtained in S180/20. Peak to peak value is the distances obtained from the maximum and minimum amplitude

on the vibration cycle. A high value of peak to peak means that there is poor vibration damping. The vibration damping capacity is related to the performance of material to absorb vibrational energy. In the case without a damper, vibration energy is not dissipated by the structure but transmitted directly to the structure. Damping ability depends on the amount of dissipation energy absorbed [24]. The test sample uses 30% GTR as a filler, with the presence of GTR particles to reduce vibration. It has been stated by Zhao et al [25] that the addition of recycled rubber crumbs increases damping properties. the presence of rubber powder as a filler in the composite matrix will function as a damper for incident energy [28].

Figure 8 shows the amplitude value using the frequency domain for each sample. In the fig.8a, the difference in amplitude values is significant at a frequency of 16 Hz in the condition of the absence of a damper, which produces the largest amplitude value. In the sample with a heating temperature of 140 (S140) shows the amplitude value is not much different at each frequency. Then, the amplitude is close to zero at a frequency of 512 Hz and above. On the other hand at 16 Hz, for S180 (figure 8b) produces a relatively large amplitude difference with the variation of heating time, however for the next frequency shows that the amplitude is to be the same.

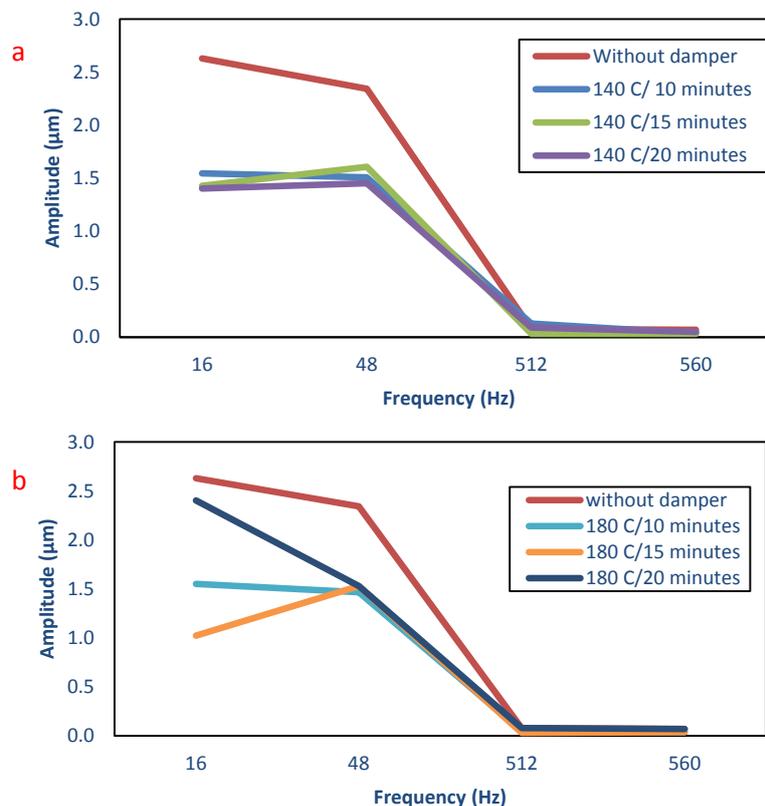


Figure 8. The amplitude value using the frequency domain for: a) Sample S140, b) Sample S180

These results indicate that the difference in vibration characteristics is only found at low frequencies, especially for S180. This can be concluded that for samples with a heating temperature of 180°C shows the difference in absorption vibrational energy, it is noticed that the heating time greatly affects the morphology of the GTR/HDPE structure. Based on the observation of the microstructure of the S180 sample, it shows relatively larger pores than the S140, a greater degree of structural irregularity occurs at a heating temperature of 180 which is probably the cause. Based on the observation of the microstructure of the S180 sample (Figure 5), it shows relatively larger pores than the S140, the structural irregularity occurs at a heating temperature of

180 which is probably the cause. Damping ability varies depending on the amount of energy dissipation absorbed, the amount of energy dissipation obtained by the material by converting it into molecular motion, and the friction mechanism between the constituents of the material [24].

4. Conclusion

In this research, GTR/HDPE was processed via a hot compression process using constant pressure with different heating temperatures and heating time. and the results showed that the tensile strength of the GTR/HDPE blended sample is higher for the sample S140 than S180. Sample with the higher heating temperature and heating time show larger value for strain at break. From microstructure, observation shows a lot of void by increasing heating time and temperature. Poor of adhesion due to the formation of bubbles/void around GTR particle causing low tensile strength. Application of GTR/HDPE as damper material has successfully to reduce vibration that can be seen from peak to peak value which is 42.28 mm (without damper) to 23.71 mm (S180/10) and also from vibration displacement profile.

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