Mechanical Properties of Lightweight Composite: Polyurethane Reinforced with Kenaf Core Particles

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Abstract— **The objective of this paper was to study the effects of pulverized kenaf core particles on the mechanical properties (compressive and impact), density and as well as the pore size of polyurethane composite and to compare the compressive stress of the polyurethane with expanded polystyrene foam (EPS). The composite was prepared by mixing of polyols with different kenaf particle sizes such as <125 µm, 125-300 µm and >300 µm and for each different size of kenaf particles, different kenaf core particles loadings were also prepared; 5 wt%, 10 wt% and 15 wt% before mixing with diphenylmethane 4,4'-Diisocyanate . The samples were cut into standard samples shape for compressive and impact testing. The density and pore size of each sample was analyzed. Based on the result , the kenaf particles size of >300 µm at 15 wt% particles loadings exhibited the best compressive stress while for 10 wt% particle loading for all kenaf core particles size class, the compressive stress decreased. The additions of the kenaf core particles increased the pore size of the polyurethane hence make the decreased in the density. Moreover the polyurethane with >300 µm pulverized kenaf core particles sizes with 10 wt% and 15 wt% particles loadings possessed the highest impact strength while the impact strength decreased as the percent loadings increased for <125 µm kenaf core particles size. As conclusion, the expanded polystyrene foam (EPS) has lower density with higher compressive stress compared to polyurethane reinforced with kenaf core particles.**

Keywords—Kenaf,Polyurethane,Compressive,Impact and Pore Size.

INTRODUCTION

Nowadays natural –fiber reinforced polymers were being used instead of synthetic fiber such as carbon and glass fiber. These natural fiber have the advantages such as renewability, biodegradability, reduction in weight and cost.(Yousuf Ali El-Shekeil, Salit, Abdan, & Zainudin, 2011). Moreover natural fiber based composite have received splendid attention by researchers around the world especially in production of lightweight composite and have a great mechanical strength.

(A.S Singha et al,2008) have investigate the influence on fiber size that is Hibiscus Sabdariffa in polymer urea formaldehyde.3 samples of different fiber size that was particle, short fibre and long fiber. It was also stated in his study that static mechanical properties of fiber reinforced composite depend on the nature of the polymers matrix, distribution, and orientation of the reinforcing fibers and also the nature of the fiber-matrix interfaces. It was observed that particle reinforcement, the compressive stress was better than the short and long fiber.

Polyurethane was made up from 2 components which were isocyanates and polyols (Y. A. El-Shekeil, Sapuan, Abdan, & Zainudin, 2012). In polymer industry, the properties of the new composite were mainly affected by the interfacial bonding between fibers and matrix which in this case was kenaf and polyurethanes. Moreover there was one difficulties in utilization of composite due to hydrophilic nature of natural fibers vs. hydrophobic nature of most polymers which caused lack of adhesion (Y. A. El-Shekeil, Sapuan, Abdan, & Zainudin,Al-Shuja, 2012). The benefit of polyurethane used in this research was the hydrophilic properties of the polyurethane.

In the composite of the polyurethanes, the kenaf core did not replace the polyurethane but mostly filled the void space which initially filled with air and those increased the density and reduced the porosity of the polyurethane respectively. Moreover, the increased of kenaf core fiber loadings has improved the bending strength of the polyurethane (Batouli, Zhu, Nar, & D'Souza, 2014).

(Mosiewicki, Dell'Arciprete, Aranguren, & Marcovich, 2009) have studied on the compressive stress of polyurethanes from castor oil based polyols reinforced with wood flour showed that the compressive stress decreased as wood flour content increased.

In contrast, a non uniform distribution of the filler elements could lead into embrittlement effects due to areas of high stress concentration can be induced and cause failure of the sample at random location. (Mosiewicki, Dell'Arciprete, Aranguren, & Marcovich, 2009). In addition (Saint-Michel, Chazeau, & Cavaillé, 2016) have shown that filler addition in the composite could cause the cell walls to become brittle and rupture. Moreover, the reinforcement level of the composite depends on the interaction between the filler and the polymer matrix as stated in this research.

In this paper, pulverized kenaf core particles will be used as the reinforcing agent and polyurethane as the matrix. Kenaf plant or Hibiscus cannabinus is economically cheap, resistant to insect damage and require fewer pesticides (Elsaid, Dawood, Seracino, & Bobko, 2016). In Malaysia, Kenaf has commercially be planted since 2000 after its potential in many industry and have replaced the cultivation of tobacco in 2006 (Zainuddin.BeritaHarian,2015).

In this project, Jabatan Kerja Raya Malaysia (JKR) has been approached by Kefi (M) Sdn Bhd to explore all possible application of kenaf in road construction projects. One of the major problems they have endure was the used of polystyrene foam (EPS) in the soil embankments. EPS has much vulnerability such as non-biodegradability issues and easily dissolve by liquid petroleum hydrocarbons.

In order to overcome those problems and to find a new composite for the replacement of EPS, polyurethane reinforced with pulverized kenaf core particles will be choose as the study material especially on the compressive stress.

I. METHODOLOGY

A. *Materials*

Pulverized kenaf core particles was obtained from KEFI (Malaysia) Sdn Bhd and polyurethane was composited by using E-135 polyols given by MPOB Malaysia and diphenylmethane 4,4'-Diisocyanate purchased from Chemo lab Supplies Malaysia. In this project, polyurethane was used as polymer while kenaf core particles as the filler or reinforcement material. Triethylamine was used as a catalyst, polyethylene glycol as surfactant and pentane as the blowing agent.

B. *Fiber Preparation*

Pulverized kenaf core particles was sieved using an auto shaker into 3 different sizes (<125 μm, 125-300 μm and 300-425 μm) by using mesh 125 μm and 300 μm.

C. *Composite Preparation*

Diphenylmethane 4,4'-Diisocyanate and polyols (both in liquid) were mixed in ratio 1:1. Firstly, polyols was added with 1 drop of triethylamine (catalyst), 1 drop of polyethylene glycol (surfactant) and 1 drop of pentane (blowing agent). The mixture was stirred for 15 seconds before 5 wt% of kenaf core particles with size <125 μm was mixed in the solution. The solution was also stirred for 15 seconds and then diphenylmethane 4,4'-Diisocyanate was added in the solution. The solution was stirred until become cream-look (cream time) and the solution began to expand to form polyurethane. The cure time was 3 days to make the polyurethane become fully rigid.

Moreover, samples with different kenaf core particles loadings such as 5 wt%, 10 wt%, and 15 wt% with different kenaf core particles size (<125 μm, 125-300 μm and >300 μm) were also prepared for the compressive stress test and impact test as shown in Table 1

Table 1. Pulverized kenaf core size and loadings percentage loadings of kenaf in polyurethanes

Particles size of pulverized kenaf core (μm)	Percent kenaf particles loadings (wt %)
<125 μm	5%
	10%
	15%
125-300 μm	5%
	10%
	15%
>300 μm	5%
	10%
	15%

D. *Mold Preparation*

Mold was fabricated into cuboids shape by using hard aluminium sheet with the dimension of 6cm x 6cm x 3cm.

E. *Mechanical Characterization*

Compressive tests were conducted using Instron 3382 machine, according to ASTM D 1621 or ISO 844. Samples for compressive tests were cut into cuboids shape using a small size saw with dimensions of 5 cm x 5 cm x 2.5 cm as shown in Figure 2 (a). The samples were tested with crosshead speed of 2.5 mm/min (Figure 2(b)). The compressive stress of the polyurethane reinforced with different kenaf core particles loadings and size were compared to the compressive stress of expanded polystyrene (EPS) foam at 1% strain. The data of the EPS were given from Jabatan Kerja Raya (JKR).

Izod impact testing was measured by using Izod/Charpy Impact Tester according to ASTM D-256.Five samples were cut into 6.3 cm x 1.3 cm x 0.3 mm dimension as shown in figure 1

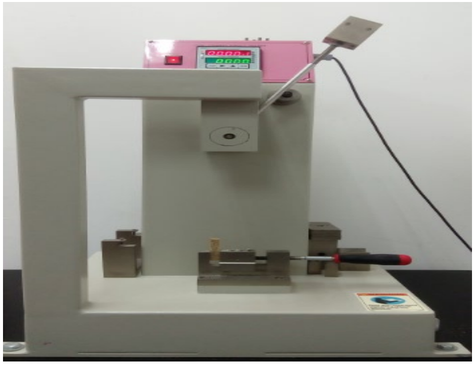


Figure 1. Izod impact testing machine

The density of the polyurethane samples was calculated by using ISO 845 standard. The weight of the samples were weighted by using electronic balance and in order for density calculation the weight-value of each samples were divided by the total volume-value of the samples to get the value of density of each samples.

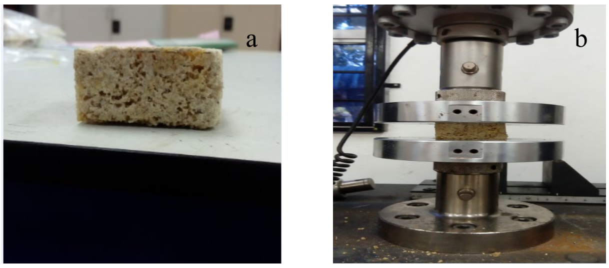
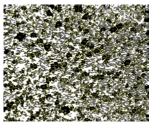


Figure 2. (a) The cuboid shape of the polyurethane samples (b) The polyurethane sample was compressed in compression test machine.

F. *Pore size analysis*

The pore size analysis for every different type of samples was analyzed by using Image J –software analysis. 2 dimensional of macro picture were taken for every specimens before being analyzed by using image J analysis software as shown in Figure 3.

II. RESULTS ANI



Pore size analysis was taken at area 4 cm x 4 cm for all prepared polyurethane samples.

Figure 3. The macro-picture of polyurethanes reinforced with kenaf core particles

A. The Effect of particles loadings and particles size of pulverized kenaf core fiber on the compressive stress of the polyurethane

Figure 4 show that for all size range of pulverized kenaf core particles that was filled in the polyurethane, the compressive stress decreased from 63 kPa to 10 kPa, 107 kPa to 8 kPa and 143 kPa to 82 kPa for 5 wt% to 10 wt% kenaf core particles loadings at particles size <125µm, 125-300µm, >300 µm respectively. The compressive stress increased back from 10 kPa to 262 kPa, 8 kPa to 191 kPa and 82 kPa to 269 kPa from 10 wt% to 15 wt% at each particles size range respectively.

For <125µm of kenaf particles size, 15 wt% particle content sample showed the highest compressive stress and the stress decreased significantly when the particles content was at 10 wt%. The compressive stress increased when the particles content decreased to 5 wt% but the stress was less than the 15 wt% particles content sample. The compressive stress for sample without kenaf was at 130 kPa and it has higher stress compared to 10 wt% and 5 wt% particles loadings. The reason was smaller size particles will result in good dispersion between the fiber particles to matrix interfacial bonding due to smaller size fibers have larger surface area for the polyurethane to react with the fiber (El-Shekeil et al., 2011). Moreover, the increased of the fiber particles content with smaller size tend to make the fibers particles sufficiently wetted by the polyurethane and cause good dispersion of fiber (El-Shekeil et al., 2012).

Furthermore, for 125-300µm kenaf particles size, the 15 wt% particles loadings possessed the highest compressive stress compared to 5 wt%, 10 wt% particles loadings and sample without kenaf. Pickering, 2008 stated that below a critical aspect ratio the wood fiber behaved as filler rather than the reinforcement and this explained that for every 10 wt% of pulverized kenaf core particles loadings, the compressive stress was lower compared to other percent loadings of particles. For >300µm kenaf particles size class, the result trend was the same as <125µm particles size and have the highest stress when compared to other particles size for 15 wt% particles loadings.

The reasons was for 15 wt% particles size of >300 µm, the interfacial bonding between the matrix (polyurethane) and the pulverized kenaf core particles was better than other class of particles size. El-shekeil stated that larger pulverized kenaf core particles size contributed to more to absorption of energy.

The compressive stress of polyurethane with kenaf particles of 5 wt% of <125µm and 10 wt% of all particles size class, were lower than the expanded polystyrene foam (EPS) but the density were higher than the EPS. The reason was because the difference in density of pure polyurethane and EPS without any reinforcement was slightly higher between these two types of composite. The pure polyurethane have compressive stress at 130 kPa with density at 553 kg/m^3 and the EPS with highest density of 30 kg/m^3 have compressive stress at 90 kPa at 1 % deformation. The difference percent between the densities was at 95% but the difference percent of the compressive stress was only at 30%. This shows that the EPS have splendid mechanical strength at low density.

The comparison shows that the EPS tend to have lower density and higher compressive stress .This can be seen that for 10 wt% particles loadings for all different particles size class and 5 wt% particles loadings for <125 µm particles size class tend to have about similar compressive stress with the expanded polystyrene foam but possessed a higher density.

B. The Effect of particles loadings and particles size of pulverized kenaf core fiber on the density of the polyurethane.

Based from Table 2, the table show that the density of all the polyurethane reinforced with kenaf core particles for different size and percentage loadings were lower than the sample without kenaf. This was due to when the kenaf core particles was introduced to the polyurethane; the pore sizes were increased and tend to make more void space in the polyurethane. Hence the density decreased due to the increased size of the pore in the polyurethane. Based from Figure 7, it can be shown that the average pore size diameter tend to increase when the addition of kenaf core particles to the polyurethane. Antunes et al., 2011 studied that the addition of esparto wool as the reinforment agent tends to make the density of the polyurethane lower and reduced the compressive stress.

The density of the polyurethane reinforced with kenaf core particles showed an increment only for particles size of 125µm-300 µm when the percent loading increased. This happens due to that the kenaf core particles has density about 280 kg/m^3 at this size (Nar, Webber and Anne D'Souza, 2017) compared to pure polyurethane which was at 553 kg/m^3**.** The increased of addition of kenaf core particles tend to increase the density of the polyurethane.

It can be seen that from Table 2 and Figure 7, the interrelationships between the pore size and the density of the polyurethane varied for every different class of particles size that been used. Supposedly when the pore size decreased, the density of the polyurethane should be increased due to the compaction and tight packing of polyurethane matrix and less number of pore which contain the air. In this experimental result, the addition of kenaf core particles tend to produce irregular and less uniform foam size and this explained why the density varied with the size of the pore. This also can has been shown by (Mohd Soberi, Rahman and Zainuddin, 2017) that study on the effect of kenaf fiber on the morphology of rigid polyurethane. Moreover, in this study the pore size analysis was only being done on the surface not entirely on the bulk of polyurethane reinforced with the kenaf core.

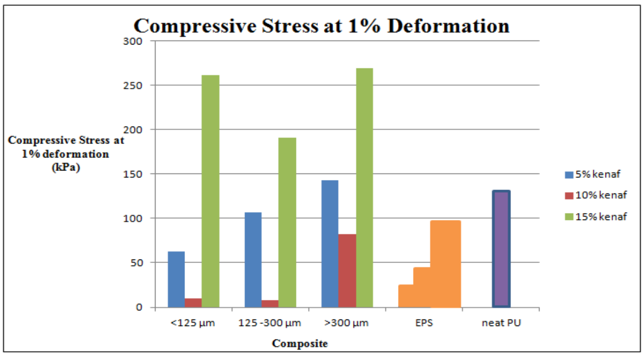


Figure 4 .Compressive stress at 1% deformation of PU with different kenaf core particles loadings and sizes compared to compressive stress of different density of EPS.

Based from Table 2, the percent difference between the highest density of the EPS and the polyurethane without kenaf was about 93 % .Moreover Seo, Cho and Hong, 2005 showed that in their research that the density of the EPS was slightly lower than the polyurethane without kenaf. The percent difference between those two different composite in density was about 91.3 % .Basically the addition of the kenaf core tend to reduce the density of the polyurethane and increased the compressive stress only for particles size >300 µm.

Varying the percent of the kenaf core particles loadings and size, the density of the polyurethane could be affected due to different of pore size. Bledzki, Zhang and Chate, 2001 studied that different types of filler or reinforcing agent tend to produce different density of the polyurethane. Furthermore, Subramaniyan et al., 2013 showed that the effect on increasing the filler content of kenaf particles and recycled tires rubber particles produce varies density of polyurethane.

tend to reduce the pore diameter while for >300 µm particle size, increasing the percent loadings tend to increase the pore diameter.

The polyurethane reinforced with 5 wt% particles kenaf core loadings showed about the same pore sizes for different particles size compared to 10 wt% which showed variation of pore size. Findings by (Nar, Webber and Anne D'Souza, 2014) stated that 10 wt% kenaf core particles tend to make non-uniform of foam cells with lower mechanical properties as compared to 5 wt% and 15 wt% particles loadings. The viscosity of the polyurethane during the mixing and stirring process before the curing time also influenced the variation of pore size formation. This was why from Figure 5, the irregular shape and formation of few larger pore size were due to the bubbles present in the premix mixture of the polyurethane.

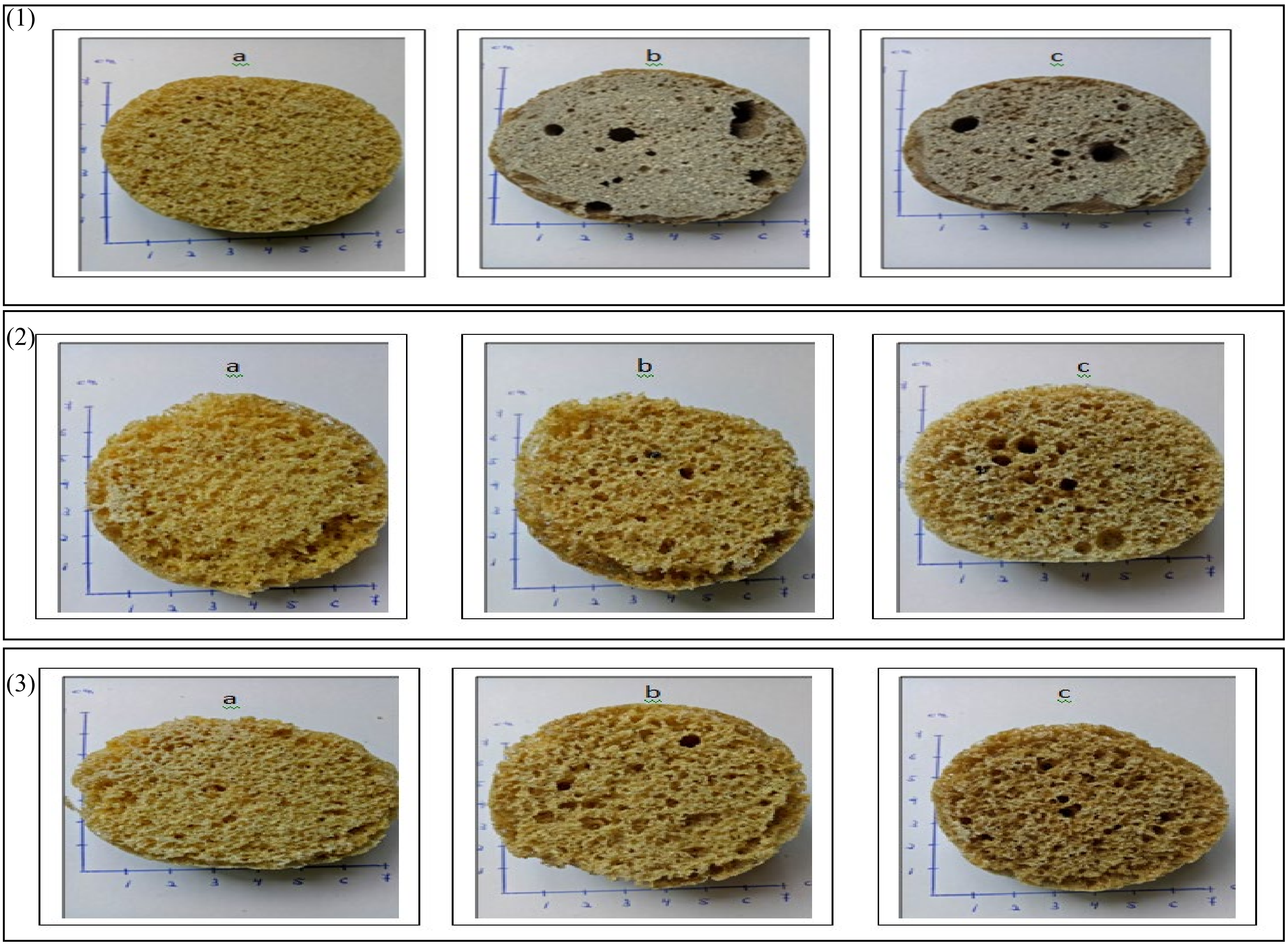


Figure 5 .The images of pore size for different particles size (1) <125 µm (2) 125 -300 µm (3) >300 µm and particles loading (a) 5 wt% (b) 10 wt% (c) 15 wt%

C. The Effect of particles loadings and particles size of pulverized kenaf core fiber on the pore size of the polyurethane

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Figure 7 demonstrate that the average pore diameter was increased due to the addition of kenaf core particles as the filler or reinforcing agent in the polyurethane compared to the sample of polyurethane without kenaf. The highest average pore diameter was at 125-300 µm particles size with 10 wt% loadings. It can be seen that at <125 µm particles size, increasing the percent loadings

make the premix polyurethane before curing time to have higher viscosity. Moreover, the higher viscosity of the polyurethane when mixed with kenaf core particles during the stirring process tends to trap more air in the composite and resulted with formation of non-uniform and larger pore size. The higher viscosity of the polyurethane during stirring process caused non homogenous distribution of fibers particles during the stirring process. (El-Shekeil et al., 2011)

Furthermore, the viscosity of the premix of the polyurethane was influenced by the addition of difference kenaf core particles size and percent loadings. The viscosity also tend to effect the formation of varies size of air bubble entrapped in the polyurethane during the expansion of the polyurethane foam. Nar, Webber and Anne D'Souza, 2014 also stated in their research that there was a difference in the void space of the polyurethane between free expansion and constraint during foaming process of the polyurethane reinforced with kenaf core particles.

Table 2. The density of the polyurethane with kenaf, EPS and polyurethane without kenaf.

Composite	Density (kg/m^3)
PU_<125 µm ,5 wt%	341.12
PU_<125 µm ,10 wt%	282.24
PU_<125 µm ,15 wt%	333.28
PU-125-300 µm,5 wt%	280.08
PU_125-300 µm,10 wt%	321.44
PU_125-300 µm,15 wt%	477.92
PU_>300 µm,5 wt%	462.88
PU_>300 µm,10 wt%	261.92
PU_>300 µm,15 wt%	475.04
EPS 1	15
EPS 2	20
EPS 3	25
EPS 4	30
PU without kenaf	553.11

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Based from figure 4 and figure 7, polyurethane with >300µm kenaf core particles size for 15 wt% particles loadings possessed the highest compressive stress at 1% deformation with an average pore size of 0.049 mm. However, polyurethane with 125-300 µm particles size for 10 wt% particles loadings have highest average pore size but lower compressive stress. Consequently, the compressive stress was majorly influenced by the irregular cell structure which will attribute to poor load transfer hence lower the compressive stress as stated in Mohd Soberi, Rahman and Zainuddin, 2017 that study on the morphological and compressive stress of polyurethane reinforced with kenaf core particles.

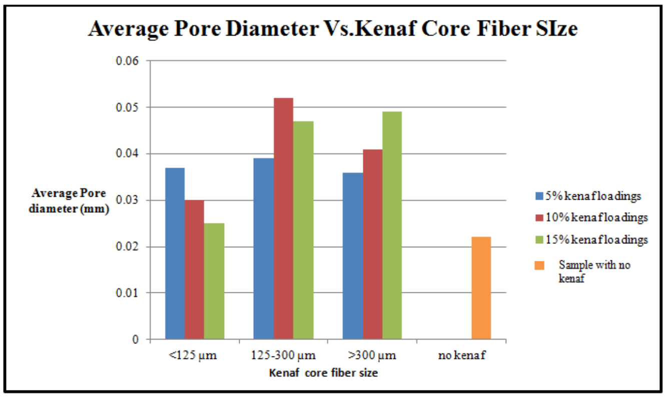

Figure 7. Average Pore Diameter for different kenaf core particles size and percent loadings in the polyurethane.

D. The Effect of particles loadings and particles size of pulverized kenaf core fiber on the impact strength of the polyurethane.

Figure 8 show that the variation of energy absorbed by the different tested samples. The impact strength increased as the kenaf core particles size increased only for the 10 wt% particles loadings in the polyurethane while the 5 wt% loadings the impact strength was the highest for <125 µm particles size. Based from the figure also, it can be showed that >300 µm particles size with 10 wt% and 15 wt% particles loadings possessed the highest impact strength.

Based from El-Shekeil et al., 2011, it was stated that in his research larger particle size of pulverized kenaf fiber contributed more to absorption of energy. It was clear that, the maximum impact energy for 125-300 µm particle size in the polyurethane was at 10 wt% kenaf core particles and the impact strength decreased as the percent loading of the particles increased. Moreover for particles size <125 µm the impact strength decreased as the percent loadings increased because not all the kenaf particles was fully wetted by the premix polyurethanes and agglomeration of kenaf particles fiber occurred which result in low mechanical strength as stated by Tawakkal, Cran and Bigger, 2014.

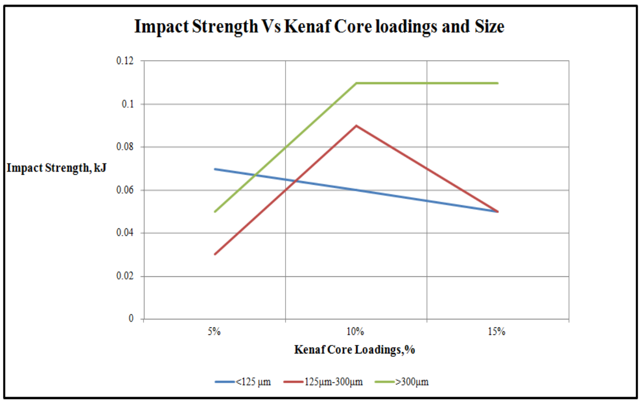

Figure 8. Impact strength for different particles fiber size and percent loadings in the polyurethane.

III. CONCLUSION

Varying particles of pulverized kenaf core loadings and sizes resulted in different mechanical and physical properties of the polyurethane. The specific following conclusion can be drawn from this study.

1. The EPS have lower density with higher compressive stress compared to polyurethane reinforced with kenaf core particles.
2. The highest compressive stress was the polyurethane reinforced with kenaf core particles size at >300 µm with 15 wt% particles loadings at 1% deformation.
3. The addition of the kenaf core particles show slight increased in the compressive stress at 1 % deformation of the polyurethane but only for 15 wt% kenaf core particles loading for all size class.
4. The addition of the kenaf core show slight decreased in the compressive stress at 1 % deformation of the polyurethane but only for 10 wt% kenaf core particles loading for all particles size class.
5. The highest impact strength was polyurethane reinforced with kenaf core particles size at >300 µm with 10 wt% and 15 wt% kenaf core particles loadings.
6. The impact strength decrease as the percent loadings of kenaf core particles increased from 5 wt% to 15 wt% for <125 µm particles size.
7. The additions of the kenaf core particles to the polyurethane increased the pore size of the polyurethane hence resulted in the decreased in the density.

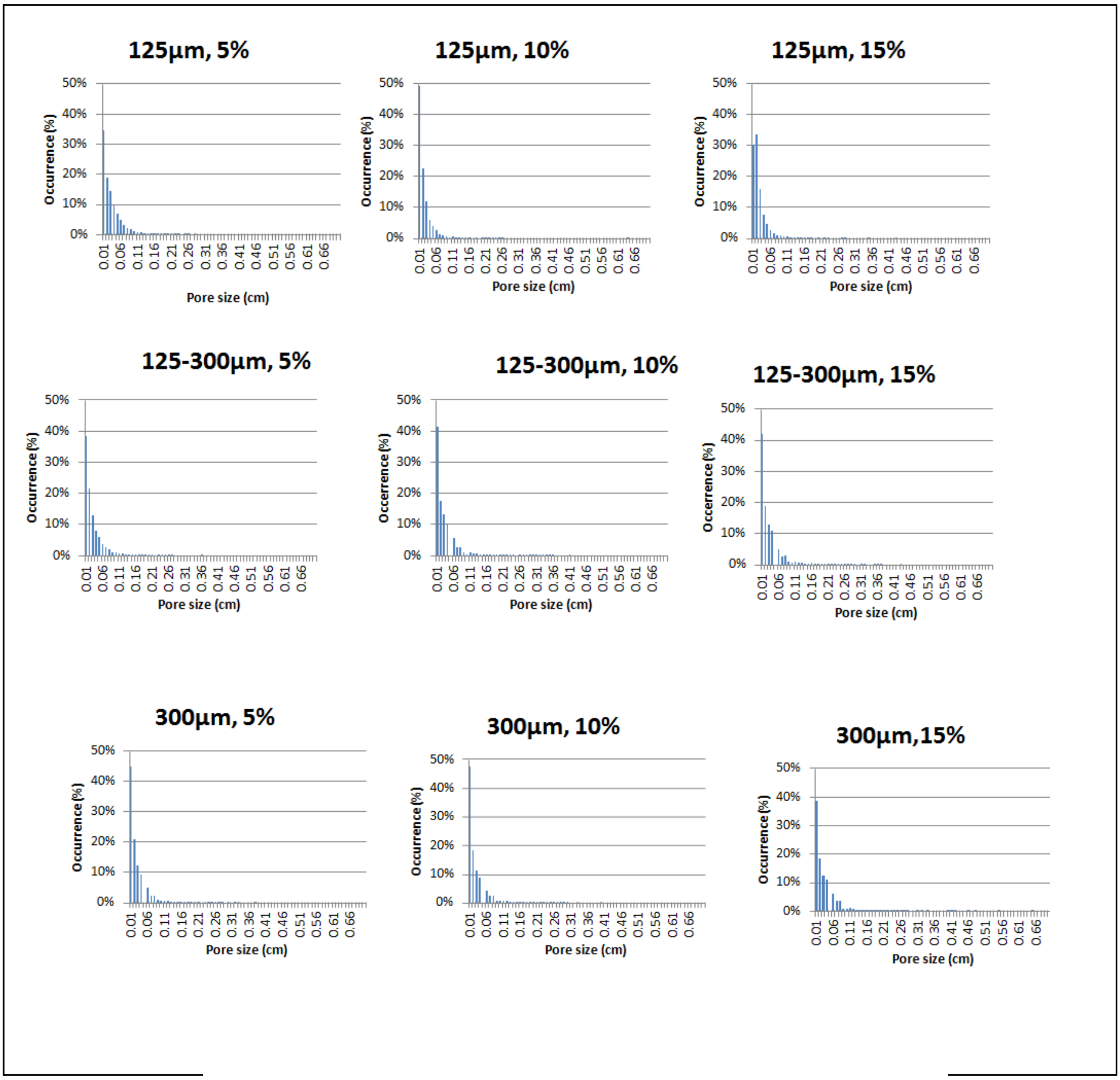

Figure 9. The pore distribution of polyurethane sample reinforced with kenaf core particles at different particles loadings (wt %) and size (µm).

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References

[1] El-Shekeil, Y.A., Sapuan, S.M., Abdan, K. and Zainudin, E.S. (2012) 'Influence of fiber content on the mechanical and thermal properties of Kenaf fiber reinforced thermoplastic polyurethane composites', *Materials & Design*, 40, pp. 299–303. doi: 10.1016/j.matdes.2012.04.003.

[2] Elsaid, A, Dawood, M., Seracino, R., & Bobko,C. (2016).Mechanical properties of kenaf fiber reinforced concrete. *Construction and Building Materials,25*(4),19912001.doi:10.1016/j.conbuildmat.2010.11.052

[3] Zainuddinbhkb, O. M. Z. Potensi kenaf komoditi eksport baharu Negara. Retrieved November 25, 2016, from http://www.bharian.com.my/node/41911.

[4] A.S.Singha and Vijay Kumar Thakur, "Mechanical properties of natural fiber reinforced polymer composites", Bull. Mater. Sci., Vol. 31, No. 5, pp. 791–799 , October 2008.

[5] El-Shekeil, Y.A., Sapuan, S.M., Abdan, K. and Zainudin, E.S. (2012) 'Influence of fiber content on the mechanical and thermal properties of Kenaf fiber reinforced thermoplastic polyurethane composites', *Materials & Design*, 40, pp. 299–303. doi: 10.1016/j.matdes.2012.04.003.

[6] El-Shekeil, Y. A., Salit, M. S., Abdan, K., & Zainudin, E. S. (2011). Development of a new kenaf Bast fibre reinforced thermoplastic polyurethane composite. *6*(4). . Doi:http//dx..org/10.15376/biores.6.4.4662-4672

[7] Mosiewicki, M. A., Dell'Arciprete, G. A., Aranguren, M. I., & Marcovich, N. E. (2009). Polyurethane foams obtained from castor oil-based Polyol and filled with wood flour. *Journal of Composite Materials*, *43*(25), 3057–3072. doi:10.1177/0021998309345342

[8] Antunes, M., Cano, Á., Haurie, L. and Velasco, J. (2011). Esparto wool as reinforcement in hybrid polyurethane composite foams. *Industrial Crops and Products*, 34(3), pp.1641-1648.

[9] Nar, M., Webber, C. and Anne D'Souza, N. (2014). Rigid polyurethane and kenaf core composite foams. *Polymer Engineering & Science*, 55(1), pp.132-144.

[10] Mohd Soberi, N., Rahman, R. and Zainuddin, F. (2017). Effect of Kenaf Fiber on Morphology and Mechanical Properties of Rigid Polyurethane Foam Composite. *Materials Science Forum*, 888, pp.188-192.

[11] Seo, K., Cho, C. and Hong, S. (2005). Evaluation of the Shock Absorption Properties of Rigid Polyurethane and Polystyrene Foam Used in a Small Transport Package. *Packaging, Transport, Storage & Security of Radioactive Material*, 16(2), pp.145-150.

[12] Bledzki, A., Zhang, W. and Chate, A. (2001). Natural-fibre-reinforced polyurethane microfoams. *Composites Science and Technology*, 61(16), pp.2405-2411.

[13] Subramaniyan, S., Mahzan, S., Ghazali, M., Ismon, M. and Zaidi, A. (2013). Mechanical Behavior of Polyurethane Composite Foams from Kenaf Fiber and Recycled Tire Rubber Particles. *Applied Mechanics and Materials*, 315, pp.861-866.

[14] Tawakkal, I., Cran, M. and Bigger, S. (2014). Effect of kenaf fibre loading and thymol concentration on the mechanical and thermal properties of PLA/kenaf/thymol composites. *Industrial Crops and Products*, 61, pp.74-83.

[15] Pickering,,K., & Kim Louise Pickering, M. *Properties and Performance of Natural Fibre Composite*.(CRC Press 2008)