Influence of filler content and mixing time on the properties and morphology of kenaf/polyurethane foam composites

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Abstract. Kenaf/polyurethane foam composites were prepared at percentage of 2, 4, 6 and 8 wt% of kenaf fiber. Free rising polyurethane foam was prepared at constant (NCO/OH) ratio 1.5:2, while water was used as blowing agent. The mixture was stirred at 400 rpm using mixing times of 20 and 25 seconds. Rise time and hardness of the composites was determined. From the results obtained, rise time and hardness of polyurethane foam composites were reduced at 25s mixing time. However, as kenaf core fiber increase, the rise time decreased and the hardness of the foam composite increased. The Scanning Electron Microscopy (SEM) analysis evidenced the presence of regular cell shape and uniform cell size in the kenaf/polyurethane foam composites. The findings indicate the potential of using kenaf fiber to enhance the properties of the polyurethane foam.

1 Introduction

For over half a century, flexible polyurethane foams has been used in various applications such as footwear, construction [1], cushioning [2], furniture, packaging, bedding and automotive interior [3]. The polyurethane foams are famous with some of its favourable properties like low production cost [4], excellent abrasion resistance and hardness. The main advantage of foams rather than other materials are its light weight, which leads to the production of low density products [5]. These properties results from the complex generation of cellular structure that is made up of a solid and gas phase mixture [6]. Mostly, the basic ingredients to produce polyurethane foam are polyol and polyisocyanate via addition polymerization [7]. Polyurethane foam possesses cellular structure that was created by the expansion of either physical or chemical blowing agent. Usually chemical blowing agent such as water was used because it gives less effect to the environment rather than physical blowing agent such as chlorofluorocarbon (CFC) and hydrofluorocarbon (HCFC) [8]. The blowing agent, i.e. water works by generating carbon dioxide from its reaction with isocyanate and subsequently expand the polyurethane [9].

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Polyurethane foams can be tailored into different cell characteristics, known as closed and open cell structure [10]. Open-cell foams are usually flexible while closed-cell foams are generally more rigid [11]. Recently, researchers have investigated the potential of filler addition into polyurethane foam to improve its physical, mechanical and chemical properties [12][13][14][15][16][17].

In the production of polymer composites, natural fibers were proposed to substitute synthetic fiber as filler material due to its advantages such as reduce cost, less abrasiveness to equipment, lower density and less irritation to skin and respiratory [18]. In addition, they are available in large amounts, renewable and biodegradable [19]. Locally available natural fiber such as kenaf (Hibiscus cannabinus L) can be used as the filler in the polyurethane foam. The kenaf plant consists of a single, straight and branchless stalk. While the stalk is made up of an inner woody core and outer fibrous bark [20], the inner woody core which is the kenaf core fiber comprises of 60% of the stalk's dry weight. Kenaf has been drawing world attention due to its application, such as paper products [21], composites, absorbent and building materials. Realizing on the possibility to exploit and derived products from kenaf, the National Kenaf Research and Development Program has been formed to develop kenaf as a new industrial crop in Malaysia [22]. In addition, kenaf plantations in Malaysia can be harvested three times in a year, which can be considered as the renewable source.

With regards to the development of well-optimized foam composite, filler content and its dispersion quality in polyurethane matrix are of great importance to improve the cellular structure of the resultant foam composites. Cellular structure of polyurethane foam composed of struts, nodes and cell wall [23]. However, fillers can cause various structural effects and lower the mechanical properties of the foam if the dimension of the filler is bigger than the cell’s struts and nodes. In addition, the dispersion degree of the filler also gives significant effect on the properties of the polyurethane foam composites. Therefore, in this study, different mixing time was employed to optimize the fiber dispersion in polyurethane foam. In addition, the effects of filler loadings on the cellular structure and foam composite properties were also investigated. Herein, we report the influence of both mixing time and filler loading on rise time, density, hardness and morphology of the polyurethane foam composites.

2 Experimental

2.1 Materials

Polyethylene Glycol (PEG) and 4, 4-diphenylmethane diisocyanate (MDI) was supplied by Dr. Rahmatullah Holdings Sdn. Bhd. While kenaf (Hibiscus cannabinus L) core fiber was provided by Lembaga Kenaf Tembakau Negara (LKTN). Distilled water was used as blowing agent in this research. Kenaf core was dried in an oven at 80°C overnight to remove its moisture content. Then, the kenaf core was ground and sieved into 63 μm size. The percentage of kenaf fiber was varied from 2% to 8%.

2.2 Preparation of kenaf/polyurethane composite

Kenaf/polyurethane foam composites were prepared by using free rising method. Two different mixing times were employed, which were 20s and 25s. Firstly, PEG was mixed with three drops of water and stirred by using a mechanical stirrer at speed of 400 rpm. Then, kenaf fiber was added and stirred until a homogenous mixture was obtained. Next, MDI was added into the mixture and stirred continuously for 20s and 25s. The mixture was cast into an open mould with dimension of 11.50cm×6cm×6cm, while the rising time of
the polyurethane foam composites was recorded. The foam composites were left to cure at room temperature. Table 1 represents the formulation used to produce polyurethane foam composites.

**Table 1.** Formulation for polyurethane foam filled with kenaf fiber based on ratio 1.5:2.

| Amount of kenaf fiber (%) | MDI (g) | PEG (g) | Water (Drops) | Mixing time (Sec) |
|--------------------------|---------|---------|----------------|-------------------|
| 0                        | 37.5    | 50      | 3              | 20                |
| 2                        | 37.5    | 50      | 3              | 20                |
| 4                        | 37.5    | 50      | 3              | 20                |
| 6                        | 37.5    | 50      | 3              | 20                |
| 8                        | 37.5    | 50      | 3              | 20                |

2.3 Hardness Test

Hardness test on soft foam was conducted based on ASTM D2240 by using SHORE A Durometer. This test measures the penetration of a specific indentor into polyurethane foam under specific conditions of force and time. The measurement was taken from five spots of the specimen.

2.4 Scanning electron microscopy study

The model used is JEOL JSM 6460 Scanning Electron Microscope (SEM). The samples were cut into 0.5cm X 0.5cm X 0.5cm. Then, the samples were mounted on an aluminium stub by using double-sided tape and then coated with a very thin layer of platinum by using Auto Fined Coater to attain observation of the samples. The samples were analyzed under 50 and 300 X magnifications.

3 Results and discussion

Fig. 1 shows the effects of filler loading and mixing time on the rising time of polyurethane foam. Based on the result, the rising time of polyurethane foams becomes shorter as the amount of kenaf fibers increases. This may due to the higher amount of lignin content in kenaf fiber rather than other natural fiber. Lignin was responsible to provide free OH groups to react with the isocyanate and consequently increase the rising rate. Furthermore, addition of kenaf fiber in the polyurethane foam resulted in faster cell nucleation and leading to more uniform cell sizes within the foam [3]. Besides that, rising time of the polyurethane foam was also affected by mixing time used in the preparation of the foam composites. The longer the mixing time, the shorter the rising time taken by the polyurethane foam because the filler dispersion was improved throughout the polyurethane foam matrix. In fact, at 25 seconds mixing time, the foam already started to rise in the mold.
Hardness is defined as the resistance to indentation [24]. Fig. 2 represents the effect of filler loading and mixing time on the hardness of polyurethane foam composites. Based on the results, hardness of polyurethane foam composites with addition of filler show 134% increments at 20s mixing time, while only 110.53% increments at 25s mixing time due to randomly cell size formation for higher gas releases in foaming process. Random cell size in foam composites will lower the hardness properties of the composites. From the result obtained, hardness of the polyurethane foam shows increased in trend as filler was added into it. As the amount of filler loading in the polyurethane foam increases, the foam cell size and cell structure become smaller which offer more resistance to compression. Furthermore, the addition of micro-sized fillers can increase the hardness of the foam composites due to the higher total surface area for a given particle loading. This can contribute to efficient stress transfer mechanism in the polyurethane foam structure [25].
SEM analysis was carried out to investigate the morphology of pure polyurethane foam and polyurethane foam composites and simultaneously support the findings of hardness and density tests. Micrograph in Fig. 4 shows that thicker struts were formed on the cell walls of pure polyurethane foam. This is due to bigger cell size formed that take large surface areas of cell walls obtained [26]. It can be seen that the estimated cell size diameter of pure polyurethane foam is bigger than others which is about 1867µm. Based on the results obtained in Fig.4 (A) and (B), foam with bigger cell size shows lower hardness. However, the hardness can be improved with the addition of kenaf fiber which is able to act as nucleating agents in the composites. In addition, uniform cell size within the foam can be formed with the present of negligible nucleation energy and the presence of preexisting microvoids [27]. Fig.4 (B), (C) and (D) proved that the foam cell size become smaller and more uniform with the addition of filler in the polyurethane foam.

Fig. 3 : SEM micrograph of (A) pure and (B) polyurethane foam with 2% kenaf fiber (C) polyurethane foam with 4% kenaf fiber and (D) polyurethane foam with 6% kenaf fiber at (50X) mag at 20 sec mixing time.

4 Conclusion

In this work the effects of incorporation of kenaf fiber in polyurethane foam composites with different mixing time were investigated on rise time, hardness and morphological studies. From the studies, it show that polyurethane foam with shorter rising time have faster curing time. In addition and hardness of polyurethane foam increased as the amount of filler in the foam composites increased. Furthermore, the SEM micrographs showed polyurethane foam with regular and uniform cell size were obtained as the amount of kenaf
fiber increases. As a conclusion, kenaf fiber plays a crucial role in determining the properties of the polyurethane foam.

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References

[1] H.M Nakhoda, Dahman Y. Polym Bull 73(7):2039–2055. (2016)
[2] M. A Azmi, MFC Yusoff, H.Z Abdullah, M.I Idris. Int J of Integ Eng 4(1):11–15. (2012)
[3] GK Latinwo, DS Arbitike, AA Susu, SA Karee. Nature and Sci 8(6):23-26. (2010)
[4] AB Frances, MVN Banon. Mater Sci and Eng 64:1–6. (2014)
[5] ZM Ariff, NAA Rahim, LC Low. In Proceeding of polymer processing society 24th Annual Meeting, Italy. (2008)
[6] P Kekicheff, D Mouhamadou, G Dalongeville, C Gauthier, T Roland. Macromol Symp 369:56–66. (2016)
[7] P Li, Y Tao, QS Shi. Bioresources. 9(2):2681–2688. (2014)
[8] M Modesti, V Adfuani, F Simioni. Polym Eng and Sci 40(9): 2046–2057. (2000)
[9] KH Cheo, DS Lee, WJ Seo, WN Kim. Polym J 36(5):368–373. (2004)
[10] C Webber, M Nar, N Dsouza. Polym Eng and Sci:1–13. (2014)
[11] E Aram, S Mehdipour-ataei. Inter J of Polym Mater 65 (7): 358-375. (2016)
[12] Y.M Daud, K Hussin, AF Osman, CMR Ghazali, MM Al Bakri Abdullah, AV Sandu, Materiale Plastice, 54 (3), pp. 543-545(2017)
[13] Y.M Daud, K Hussin, AF Osman, CMR Ghazali, MM Al Bakri Abdullah, Key Engineering Materials, 673, pp. 55-63(2016).
[14] F.F Zainal, K Hussin, A Rahmat, M.M.A.B Abdullah, S.R Shamsudin, AIP Conference Proceedings, 1756, art. no. 040001(2016)
[15] N.S Azhar, D.M., F.F Zainal,., M.M.A.B Abdullah, AIP Conference Proceedings, 2129, (2019)
[16] M.A.A Hashim, M.M.A.B Abdullah, A.V Sandu, A Pusakas, Y.M Daud, F.F Zainal, M.A Faris, Hasri, Hartati. IOP Conference Series: Materials Science and Engineering 572 (1) (2019).
[17] Y Mat Daud, A Fazlina Osman, F Farhana Zainal, M Firdaus Abu Hashim, H.M Si, H.S Si, N Soo Li, SJ Arzuria Adnan,. IOP Conference Series: Materials Science and Engineering, 551 (1) (2019)
[18] S Shibata, Y Cao, I Fukumoto. Polym testing 25:142-148. (2006)
[19] S Ochi. Mechanics of Mater: 40, 446–452. (2008)
[20] MR Ishak, Z Leam, SM Sapuan, AMM Edeerozey, IS Othman. Mater Sci and Eng: 1–6. (2010)
[21] R Shmulsiky, PD Jones. Wiley Blackwell, UK. (2011)
[22] HPSA Khalil, NL Suraya. Bioresources 6 (2): 1122–1135. (2011)
[23] V Yakushin, L Belkova, I Sevastyanova. In ECCM15-15TH European Conference On Composite Materials (pp. 1–8). Venice, Italy. (2012)
[24] M Thirumal, D Khastgir, KNSingha, BS Manjunath, & Y.P. Naik,. Applied polym sci: 108, 1810-1817. (2007)
[25] J Njuguna, F Silva, S Sachs In: Lin T (ed) Production, properties and functional applications, UK. pp. 401-434. (2011)
[26] CW Shan, MI Idris, MI Ghazali. Applied Physics and Mathematics: 2(2). (2012)
[27] I Javni, K Song, J Lin, ZS Petrovi. J of Cellular Plastic: 358-372. (2011)