Mukesh Kumar and Raminder Kaur*

Glass fiber reinforced rigid polyurethane foam: synthesis and characterization

https://doi.org/10.1515/epoly-2017-0072
Received April 15, 2017; accepted July 4, 2017; previously published online July 27, 2017

Abstract: The present study emphasizes the reinforcement of rigid polyurethane foam (RPUF) by the addition of glass fibers (GFs) for diverse engineering applications. In contrast to the conventional RPUF, the foam developed in this case is castor oil based. The developed reinforced foam was tested for its mechanical properties such as hardness, tensile, flexural and compressive strength and for its morphology. Mechanical properties of the resulted reinforced RPUF were found to be improved with addition of the GF content. The foam density was also observed to be increased with the insertion of GF. The SEM results clearly indicated the decreased cell size in the reinforced RPUF.

Keywords: castor oil; glass fibers; mechanical properties; reinforcement; rigid polyurethane foam.

1 Introduction

Rigid polyurethane foams (RPUFs) are a well-known contender for several light weight engineering and industrial applications due to their low apparent density, excellent dimensional stability and light weight. Because of their closed cell structures, they offer low thermal conductivity along with less moisture permeability. These properties of RPUF make them a very attractive choice as a core material to be used in sandwiched construction panels, thermal insulation of refrigerated vehicles, in ship-building, in false-roofing etc. (1). Due to their unique properties and a very good processing flexibility, RPUFs show the possibility to be used as matrix materials for high strength polymeric composite in combination with different reinforcing materials i.e. both fibers and particulates (2–5). Recent literature studies reported an innovation in the field of resin impregnated fabric bandages that were designed by the knitted fiberglass fabric soaked with a polyurethane resin (6). Glass fibers (GFs) are among the most functional industrial reinforcing agents known today because of their greater surface area to weight ratio (7) and reasonable cost with respect to the advantages offered by them. Their principal advantages are their enhanced insulating properties along with high tensile strength and chemical resistance. Following the present scenario of light weight polymeric composite materials, the present study has been carried out with an aim to reinforce the cellulosic polyurethane material to produce a new composite material with an added advantage of high mechanical strength along with the retention of unique properties of RPUF. The polyol used in the present investigation are castor oil based, which make it more sustainable and quite environment friendly. Prior research carried out by the same research group (8–11) and other researchers (12–14) reported that the petroleum based polyols used for RPUF production, can be successfully replaced by castor oil based polyols by little chemical modification. Cell morphology, density, water absorption, and mechanical properties of prepared glass fiber (GF) reinforced RPUFs have been tested and reported in comparison with that of neat RPUF.

2 Materials and methods

2.1 Raw materials

Castor oil (AR Grade) and 4,4′-diphenylmethanediisocyanate (AR grade) was obtained from Shivathene Linopack ltd. Parwanoo, Himachal Pardesh. Triethylenediamine (TEDA) (99%), Chopped GF (25 μm in diameter), Coupling agent (A-189 gamma-Mercaptopropyltrimethoxysilane) were purchased from Standard Chemicals (ISO 9001:2008 certified), Tilak Bazar, Delhi. Silicon oil (C-63148-62-9) and n-Pentane (C-109-66-0) was obtained from Central Drug House (P) Ltd. 7/28 Vardaan House, Daryaganj, New Delhi – 110022 (India). Glycerol (99.9%) was supplied by Sisco Industries Pvt. Ltd. GF were pre-treated with silane (coupling agent) to attain uniform dispersion of glass-fibre in

***Corresponding author: Raminder Kaur,** Assistant Professor, Department of Polymer Science and Chemical Technology, Delhi Technological, University (Formerly Delhi College of Engineering), Delhi-110042, India, e-mail: rkwaliadtu@gmail.com
Mukesh Kumar: Research Scholar, Department of Applied Chemistry and Polymer Technology, Delhi Technological, University (Formerly Delhi College of Engineering), Delhi-110042, India

Table 1: Formulations used for the sample preparation.[a]

Samples	Glass fiber (wt%)	Mpol	TEDA	C-109-66-0	C-63148-62-9	MDI
GF-00	00	100	2	15	3	110
GF-05	05	100	2	15	3	110
GF-10	10	100	2	15	3	110
GF-15	5	100	2	15	3	110

[a]Samples are based on 100 parts of the polyol by weight (pbw).

PU matrix. All testing was carried out by strictly following ASTM standards.

2.2 Preparation of foams

The formulations used to prepare the foam samples are given in Table 1. Two step method was used to prepare reinforced RPUFs (15). In the first step, castor oil and glycerol were taken in ratio 2:1 (%w/w) and heated up to 185–190°C. The progress of condensation reaction and its stability were confirmed by checking its hydroxyl value. The time required to complete the reaction was nearly 4–5 h (9). In the subsequent step, all materials (Mpol, GFs coated with coupling agent, TEDA, C-109-66-0, C-63148-62-9, MDI) as reported (in Table 1) were added in the reaction kettle and stirred at 2200 rpm for proper mixing. The resulted mixture was spread into a metal mold (200×200×100 mm) and left to stand for 96 h for complete curing. After de-molding, the resulted foam was cut into desired dimensions and tested for its hardness, compressive and tensile strength, cell morphology, density, and water absorption.

3 Results and discussion

3.1 Density

Density is a vital indicator of foam performance in terms of mechanical properties of closed cell foams (16, 17). Density was determined per ASTM D 1622 with sample size of 30×30×30 mm (width×thickness×length). Five samples were tested for density and an average value was reported. It was observed that the insertion of GF enhances foam density as shown in Figure 1. The rigid polyurethane foam without glass fiber (RPUF) posed a smaller cell density with large pore size as compared to that of RPUGF. Probably, the density increased due to the cross linkage of foam cells (18). Highly dense foams are expected to be more rigid which in turn exhibit higher mechanical strength.

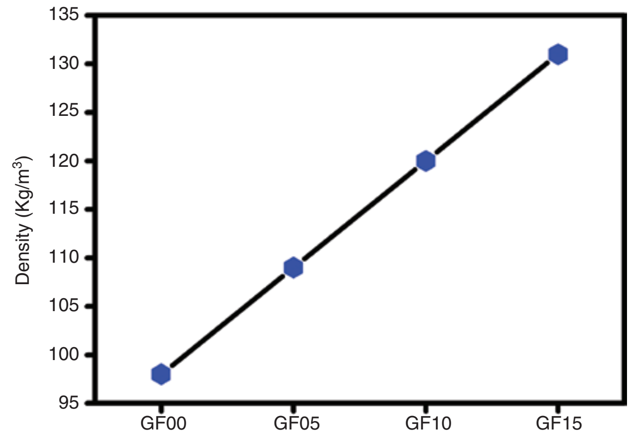

Figure 1: Density of RPUGF vs. glass fiber quantity.

3.2 SEM images

The cell structures of the resulted rigid polyurethane foam with glass fiber (RPUGF) were analyzed by using Hitachi S3700 scanning electron microscope (SEM) using an accelerating voltage of 15 kV. Figure 2 shows the SEM morphology of the resulted reinforced and neat RPUF. It is clearly observed that the shape of the cells is nearly spherical. The cell growth is retarded due to involvement of GFs in the rigid PU that is evident from small sized cell around the GF. This result is quite identical to that was prior reported in literature (16) for the similar studies. RPUF (GF00) exhibited the average pore equal to 171 μm. RPUGF (GF05), (GF10), (GF15) presented the average pore size equal to 158 μm, 121 μm and 104 μm, respectively. The graph of average cell size of RPUGF versus amount glass fiber (GF00, GF05, GF10, and GF15) is as seen in Figure 2. It is clear from the Figures 2 and 3 that the average cell size was decreased as the GF content was increased. The reduced pore size indicated that 3-D structure of foam was more closely packed and consequently resulted in increased density and in turn, increased mechanical strength, as reported in subsequent section.

3.3 Mechanical properties

Mechanical properties of the prepared RPUFs were examined as per the ASTM procedures. Tensile, compressive, and flexural properties of the resulted foams were measured at room temperature using Instron (model no.: 3369)

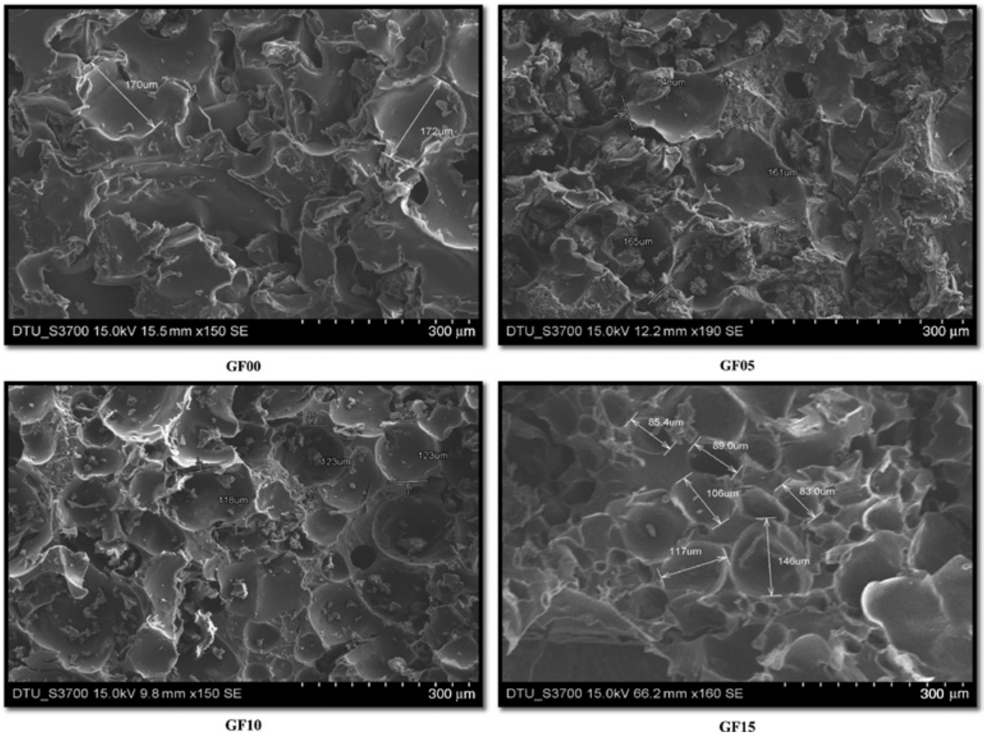

Figure 2: SEM of RPUGF vs. glass fiber quantity.

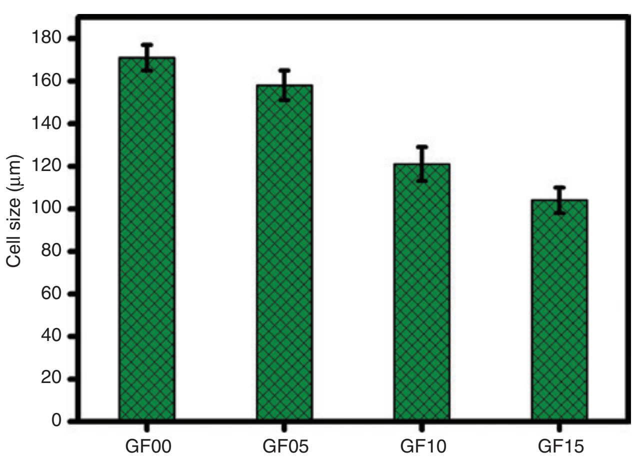

Figure 3: Cell size of RPUGF vs. glass fiber quantity.

universal testing machine as per ASTM D-638, ASTM D-695 and ASTM D 790 method, respectively. Hardness was determined by using ASTM D 2240 method. As expected, all mechanical properties i.e. tensile strength, compressive strength, Flexural strength and hardness (Figure 4) were enhanced significantly and nearly linearly with the insertion of increased GF content. RPUF (GF00) showed the average tensile strength, compressive strength, flexural strength, and average hardness equal to 2.38 MPa, 4.31 MPa, 3.98 MPa and 51 (Shore D), respectively. RPUGF (GF05), (GF10), (GF15) showed the average tensile strength equal to 2.99 MPa, 3.78 MPa, 4.44 MPa, respectively and average compressive strength 5.61 MPa, 6.43 MPa, 7.21 MPa, respectively and average flexural strength 4.76 MPa, 6.12 MPa, 6.98 MPa, respectively and average hardness 67, 91, 114 (Shore D), respectively. Linear (almost) increase of above said properties indicates that the dispersion of the GFs in the PU matrix was good with proper adhesion. SEM images also indicated an average decrease in pore size with increase in GFs reinforcement and supported the idea of densely packed sturdy structure in contrast to that of neat RPUF, which in turn increases the mechanical properties in case on RPUGF.

3.4 Water absorption

The resulted GF reinforced RPUFs were tested for their water adsorption behavior. The test was conducted using distilled water for up to 96 h for all the formulations. The change in weight of the samples were noted down after 24 h, 48 h, 72 h and 96 h. Results of the water absorption study of RPUF and RPUGF are shown in Figure 5. As evident from the Figure 5, a decreasing trend in water absorption was observed with increased GF insertion. RPUF (GF00) showed the average water absorption equal

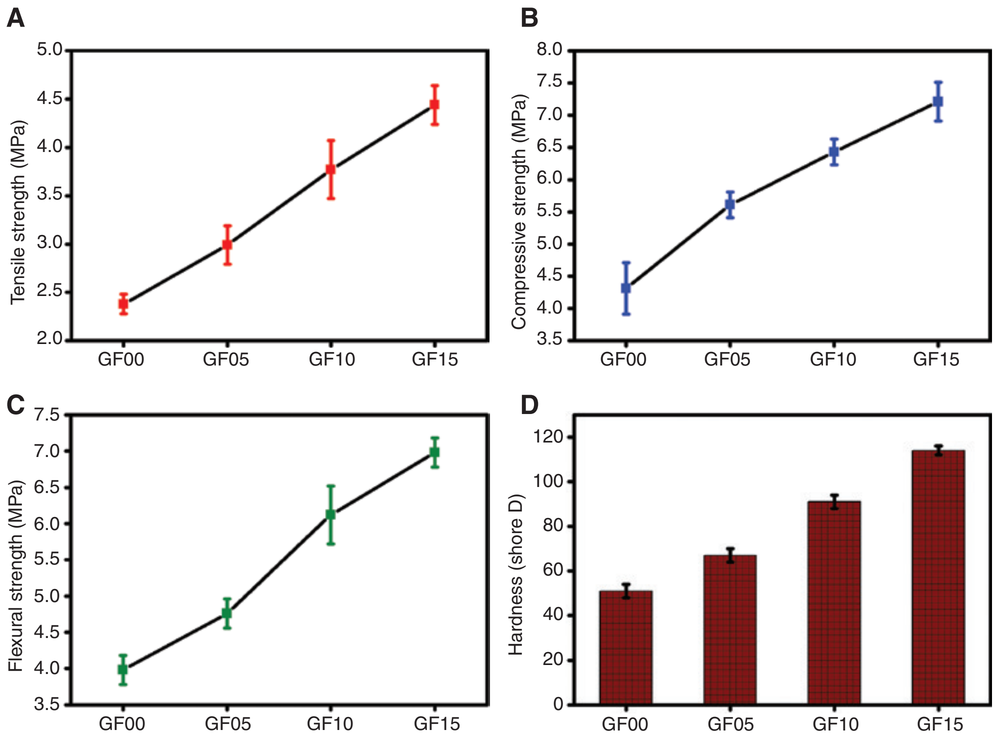

Figure 4: Mechanical properties of RPUGF vs. glass fiber quantity.

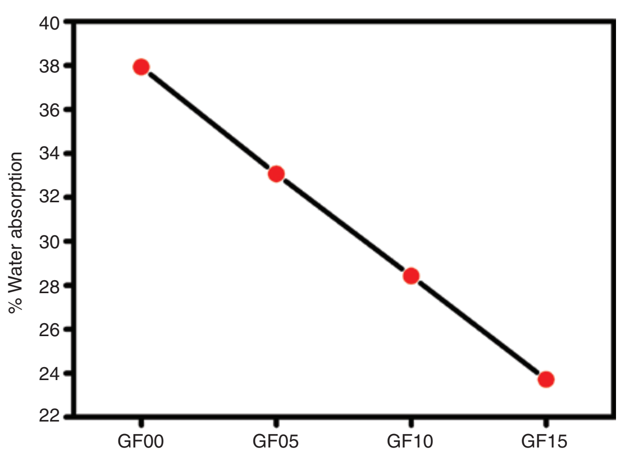

Figure 5: Water absorption of RPUGF vs. glass fiber quantity.

to 37.93% followed by 33.06%, 28.42% and 23.71%, respectively for RPUGF (GF05), (GF10), (GF15). The explanation is simple, as supported by SEM monographs i.e. Figure 2, with incorporation of GF in RPUF, the pore size was decreased, and closely packed cell structure, do not allow the water absorption, as it was in case of simple RPUF. Analogous to other polymer-solvent systems, power law equation (Korsmeyer-Peppas model) was used to study the mechanism of water diffusion in the resulted GF reinforced RPUFs i.e.:

$$M_t / M_\infty = kt^n \quad [1]$$

Where, M_t/M_∞ represents the fraction of solvent (in this case, water) diffused w.r.t. time, t. The constants, k and n, are the characteristics of the polymer-solvent system. In general, for a polymer, $n=0.5$ indicates Fickian diffusion, $n>0.5$ indicates anomalous transport and $n=1$ implies relaxation controlled transport. As the observed values of constant n for all the samples were less than 0.5, it was evident that the kinetics of water absorption followed Fickian diffusion mechanism in all RPUF formulations.

3.5 Conclusion

The higher values of hardness, tensile, flexural and compressive strength, with a relatively linearly increasing trend were observed for RPUGF (GF05, GF10, GF15) than RPUF (GF00). SEM studies had also revealed improved cell morphology with dense packing in RPUGFs. The results for density measurement and water absorption studies supported the idea of more closely packed foam, when reinforced with GF. The resulted castor oil based reinforced GF RPUFs due to their high strength and load bearing capacity are suitable to be used as light weight moldable engineering material for various applications. These RPUGFs may be customized to prerequisite needs, by varying the amount of added reinforcement. In a nutshell, being mechanically strong engineering material with desired characteristics, the resulted RPUGFs also offer an added advantage of being environment friendly being derived from a renewable plant source in contrast to the conventional RPUF. The material developed in the present research, is likely to be engaged in various construction application because of its sizes, shapes, and processing flexibility. Being a light weight, strong material with low thermal conductivity, it could be used as artificial roof or wall panels for various air conditioned assembles by designing it into various thickness.

References

1. Yu YH, Choi I, Nam S, Lee DG. Cryogenic characteristics of chopped glass fiber reinforced polyurethane foam, Compos Struct. 2014;107:476–81.
2. Gama NV, Soares B, Freire CSR, Silva R, Neto CP, Barros-Timmons A, Ferreira A. Bio-based polyurethane foams toward applications beyond thermal insulation. Mater Des. 2015;76:77–85.
3. Lubczak R. Oligoetherols and polyurethane foams with carbazole ring. e-Polymers. 2012;12(1):829–39.
4. Malewska E, Sabanowska A, Polaczek J, Prociak A. Physical and mechanical properties of rigid polyurethane foams modified with polystyrene beads. e-Polymers. 2012;12(1):637–46.
5. Sridaeng D, Jitaree W, Thiampanya P, Chantarasiri N. Preparation of rigid polyurethane foams using low-emission catalysts derived from metal acetates and ethanolamine. e-Polymers. 2016;16(4):265–76.
6. Costa HS, Reis JML, Paim LM, Silva ML, Amorim FC, Perrut VA. Analysis of a glass fibre reinforced polyurethane composite repair system for corroded pipelines at elevated temperatures. Compos Struct. 2014;114:117–23.
7. Reis JML, Chaves FL, Da Costa Mattos HS. Tensile behaviour of glass fibre reinforced polyurethane at different strain rates. Mater Des. 2013;49:192–6.
8. Kumar M, Kaur R. Effect of different formulations of MDI on rigid polyurethane foams based on castor oil. Int J Sci Res Rev. 2013;2(1):29–42.
9. Kaur R, Kumar M. Function of silicon oil in the castor oil based rigid polyurethane foams. J Polym Eng. 2013;33(9):875–80.
10. Malik M, Kaur R. Mechanical and thermal properties of castor oil-based polyurethane adhesive: effect of TiO_2 filler. Adv Polym Technol. 2016, DOI 10.1002/adv.21637.
11. Malik M, Kaur R. Influence of aliphatic and aromatic isocyanates on the properties of polyether-ester polyol based PU adhesive system. Polym Eng Sci. 2017, DOI: 10.1002/pen.24537.
12. Goldblatt LA, Lyon CK. Fat and oil products in urethane polymers. J Am Oil Chem Soc. 1963;40(4):157–61.
13. Guo A, Zhang W, Petrovic ZS. Structure-property relationships in polyurethanes derived from soybean oil. J Mater Sci. 2006;41(15):4914–20.
14. Chian KS, Gan LH. Development of a rigid polyurethane foam from palm oil. J Appl Polym Sci. 1998;68:509–15.
15. Kang SM, Kang MS, Kwon SH, Park H, Kim BK. Effects of chain extender in biodegradable polyurethane foams. J Polym Eng. 2014;34(6):555–9.
16. Kim SH, Park HC, Jeong HM, Kim BK. Glass fiber reinforced rigid polyurethane foams. J Mater Sci. 2010;45(10):2675–80.
17. Palanisamy A, Karuna MSL, Satyavani T, Rohini Kumar DB. Development and characterization of water-blown polyurethane foams from diethanolamides of karanja oil. J Am Oil Chem Soc. 2011;88:(4)541–9.
18. Palanisamy A, Rao BS, Mehazabeen S. Diethanolamides of castor oil as polyols for the development of water-blown polyurethane foam. J Polym Environ. 2011;19(3):698–705.