



Effect of Different Filler Materials on the Bonding Compounds of the Polyurethane Foam: FTIR Perspective

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Abstract. The use of lightweight materials has become one of the choices in automotive, structural, and aerospace applications today, as it can improve fuel efficiency and the manufacturing process itself. Polyurethane Foam is one of the materials with low density, good material strength, and can be applied in various fields. Its ability to react and form a solid structure in the applied medium is an added value in the manufacturing process. Lightweight materials like Polyurethane foam, however, have weaknesses in terms of strength when compared to metals or other solid materials. Mixing Polyurethane foam with reinforcing materials is one way to increase the material's resistance to applied forces. The reinforcing materials include graphite powder, PLA powder, and glass powder. The compound bonds formed from these three types of mixtures have different intensity levels obtained in FT-IR testing. The compound bond in graphite powder shows that the 2% mixture has the highest intensity, then the PLA mixture at 3%, and the glass powder shows the highest intensity at the 5% mixture. The high or low intensity of compound absorption in FT-IR testing can affect the mechanical strength of the material according to the mixture used.

Keywords: Polyurethane, Polimer, Micro filler, Composite, FT-IR.

1 INTRODUCTION

Materials that have low weight are one way to increase efficiency in the manufacturing process and its application in industry. One of them is the use of lightweight materials in the automotive world, aircraft, and systems in building structures. The use of solid and heavy materials is slowly being abandoned because of the considerable expenditure compared to the results obtained in terms of energy expended and maintenance which is quite complicated. Then came the composite technology that mixes several materials to obtain new properties that support the strength of the material itself. One material that has low weight and good strength is polyurethane foam, because this material is resistant to conductivity, temperature differences and rust. Polyurethane foam is formed from a mixture of two liquids including polyol and isocyanate which utilizes a polyurethanization reaction to develop

the material into a solid. Providing filler material during the polyurethane foam formation process can increase the durability of the material in terms of what is needed.

Based on the results of previous research on PU foam with graphite material as filler conducted by Alvin Dio et al [1]. The results show that the provision of graphite filler as a composite mixture can change the pore size and structure of PU foam, thus affecting the durability of the material. Pore size can be modified in such a way as to find graphite mixture efficiency and its effect on mechanical strength. Then the research conducted by Katalin Litauszki et. et. al [2] show that the provision of PLA as a filler in foam can affect the size of pores and density in solid foam material, more PLA content given the effect of enlarging pores, so the resistance of the material is getting lower. It has been reported by Siegmann A. et al. [3] that the addition of glass material increases the durability of the material, as the number of glass material mixture levels increases, the higher the durability value of the specimen, followed by a higher specimen weight.

This research, shows that utilizing micro fillers as reinforcement in the PU foam manufacturing process can also increase the durability of the material in any aspect according to the nature of the filler material used. The use of graphite, glass, and PLA has different characteristics and material properties, combined with PU foam which is known as a lightweight material. The appropriate level can increase the durability value, but also the use of filler levels that are not in accordance with the dosage can make PU foam specimens worse for material durability. This research identifies compound bonds in FT-IR testing of the type of filler used and combines the results with previous research which shows that differences in compound bonds can affect the mechanical ability of the material.

2 METHOD

This research utilizes Polyurethane foam material, which will be reacted along with a mixture of reinforcing materials, namely graphite powder, PLA powder, and glass powder. The combination of reinforcing materials is carried out in the unreacted PU foam liquid using mechanical mixing for one hour. Material characterization testing is then performed using the FT-IR IRXross testing machine.

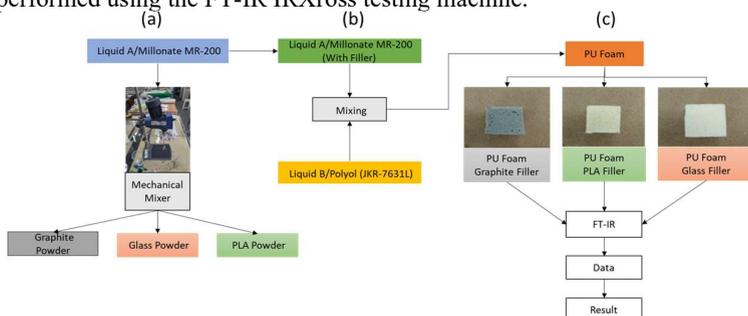


Fig. 1. Research Flow. (a) Mixing Filler, (b) Mixing PU foam, (c) PU Foam Testing Material.

In Figure 1, point (a) explains the process of combining liquid A, also known as Isocyanate, which acts as an elastic polymer, with reinforcing materials including graphite powder, PLA powder, and glass powder. These are mixed using mechanical mixing for one hour. Point (b) describes the Isocyanate material that has been mixed with reinforcing materials and is then further mixed with liquid B, commonly known as Polyol, to create the polyurethanization reaction that is useful for the formation of solid PU foam. Point (c) explains the PU foam specimens that have been created and left to rest for 24 hours, after which they are cut and ready for FT-IR testing to observe the differences that occur with each material used.

3 MATERIALS PREPARATION

In this study, two materials were used, liquid A (Millionate MR-200), which is a polyisocyanate commonly used to make rigid polyurethane foam systems, and liquid B (Polyol (JKR-7631L)), which is a polyether containing water, catalysts, and silicone surfactants. Mixing these two materials, liquid A and B, will react to form a rigid PU foam. All polyurethane materials are produced by PT Justus Kimiaraya Indonesia. Table 1 shows the properties of the PU foam filler powder used in this study. Mixing filler powder using a dose of 1-5% of the total weight of making PU foam weighing 40 grams for each type of filler.

Table 1. Specification of Material.

<i>Material</i>	<i>Specification</i>	<i>Value</i>	<i>Unit</i>
<i>Glass Powder</i>	Purity	<98	%
	Mesh	200	micron
	Appearance	-	Clear
<i>PLA Powder</i>	Purity	<98	%
	Mesh	200	micron
	Appearance	-	White
<i>Graphite Powder</i>	Purity	<98	%
	Mesh	200	micron
	Moisture	0.5 max	%
	Appearance	-	Black Color
Polyurethane (Liquid A Isosyanate and B Polyol)	Type	-	Liquid
	Appearance	-	Brown- Clear
	Viscosity	150-250	-

The PU foam-making process involves mixing two types of liquids in a ratio of 4:1, then using a mechanical mixer to mix the two materials, stirring for 30 seconds. The results of the mixing are then placed in a plastic cup of the same size (15 cm high) which will have a significant development reaction and fill the volume of the media container. PU system that consists of 2 different materials are mixed to form reactions. The first reaction occurs between isocyanate and polyol, resulting in the formation of polyurethane. The second reaction involves the reaction between water and isocyanate, producing polyurea and CO² gas as chemical blowing agents [1].

Table 2. Reaction Formula on PU Foam [4].

<i>Reaction stages</i>	<i>Material</i>	<i>Formula</i>
<i>Polyurethane formation</i>	Isocyanate alcohol	R-NCO + HO-R1
	Amine Carbon dioxide	R-NH2 + CO2↑+22 kcal/mole
<i>Gas production reaction (Step I)</i>		
<i>Gas production reaction (Step II)</i>	Amine Isocyanate	R-NH2 + R-NCO

The reaction formed from the mixing of two liquids, namely isocyanate and polyol, results in a polyurethanization reaction that expands. Solid PU foam is formed, and the mixture of PU foam with reinforcing materials is left to rest for a day, and the material is then tested using the FT-IR IRXross machine to observe the compound bonds that occur.

Table 3. Expansion and variable specimen research [4].

Filler Powder (micron)	Specimen Expansion	After Cutting	Specimen Variable
Graphite			<ul style="list-style-type: none"> • 1% Graphite filler • 2% Graphite Filler • 3% Graphite Filler • 4% Graphite Filler • 5% Graphite Filler
PLA			<ul style="list-style-type: none"> • 1% PLA filler • 2% PLA Filler • 3% PLA Filler • 4% PLA Filler • 5% PLA Filler
Glass			<ul style="list-style-type: none"> • 1% Glass filler • 2% Glass Filler • 3% Glass Filler • 4% Glass Filler • 5% Glass Filler

4 RESULTS AND DISCUSSIONS

The produced PU foam has been treated with the addition of reinforcing powders, tested for its compound bonds using FT-IR. The results of the characteristic testing on this material are then compared with the results of mechanical testing from several references on PU foam materials with the addition of reinforcing powders.

4.1 FT-IR Result

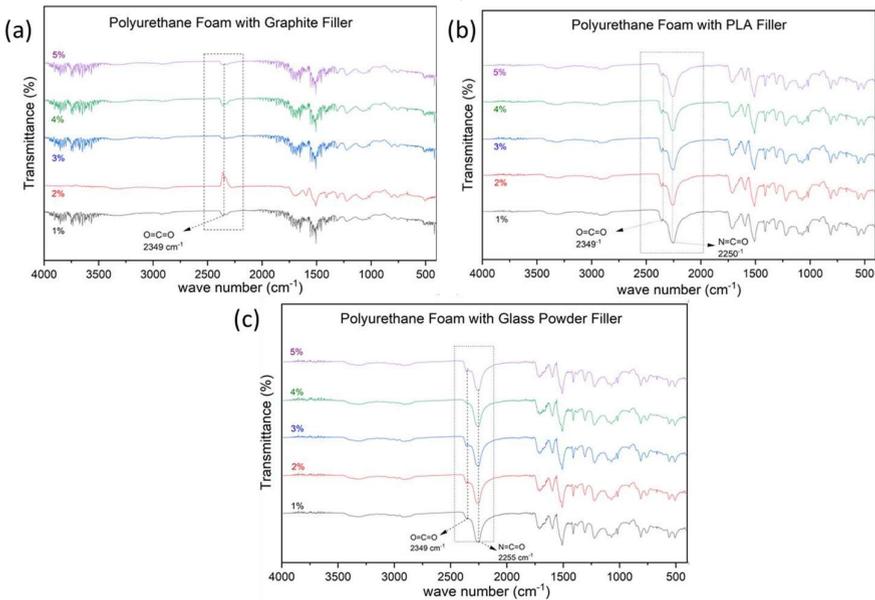


Fig. 2. FT-IR Result.(a) FT-IR Graph on PU foam with graphite filler, (b) FT-IR Graph on PU foam with PLA filler, (c) FT-IR Graph on PU foam with glass filler.

The graph shown in Fig 1 point (a), is the result of testing PU foam with filler in the form of graphite powder. The highlight is the O=C=O bond which is a carbon dioxide bond, the difference is seen in each specimen with each level from 1-5% filler mixture. At 1% filler mixture which is at peak 2349 cm^{-1} shows the presence of carbon dioxide bonds which when compared to the others show similarities, the difference is the magnitude of the transmittance absorption intensity value shown in the figure. The highest intensity value is shown at a mixture level of 2%, when compared to other mixture levels. as the filler mixture level increases, it is inversely proportional to the transmittance absorption intensity value obtained. The decrease began to be seen at a mixture percentage of 3 to 5%. It can be concluded that in graphite filler, the most optimal value of filler mixture is at 2% level, indicated by the difference in transmittance absorption intensity values.

The graph shown in Fig 1 point (b), is the result of testing PU foam with filler in the form of PLA powder. It can be seen from the compound bonds seen in the graph,

namely the $N = C = O$ bond at peak number 2250-1 which is an isocyanate compound bond, in this peak when compared between 1% - 5% mixing ratio, there is no difference, but the difference is seen in peak number 2349-1 $O = C = O$ which is a carbon dioxide compound bond, as the increase in the level of PLA powder mixture as a filler actually makes the intensity of this compound bond lower, and the highest intensity value is found at 3% PLA content. The decrease in intensity began to occur at 4-5% mixture.

In Fig 1 point (c) FT-IR is the result of FT-IR testing using glass powder as a filler shows different results when compared to fillers derived from organic materials, namely graphite and PLA. The graph shown in Fig. 3 shows the opposite, the more glass powder content used, the higher the transmittance intensity produced. The bonding of the carbon dioxide $O=C=O$ compound is getting higher as glass powder is added to the filler at a ratio of 1-5% of the mixture. In a mixture of 1-5%, the highest value is at 5%. When compared with research conducted by Siegmann et al and research by Nuryanta et al [3], [5], the more glass powder content given, the more resistance value the material has, but with the disadvantage that the weight of the specimen also increases, in contrast to the graphite filler or PLA mixture. In mixtures originating from organic materials tend to have a maximum limit until they decrease at certain levels.

Comparing the relationship between the height of compound bonds in the reinforced PU foam material in this study with the mechanical test results:

Table 4. The highest compound bond absorption

Specimen PU foam with filler	The highest compound bond absorption (1-5% mixing ratio)	Explanation
PU foam graphite filler	(2%)	The optimal ratio of mixing
PU foam PLA filler	(3%)	The optimal ratio of mixing
PU foam glass powder	(5%)	The optimal ratio of mixing

In Table 4, it can be seen that the highest compound bond absorption occurs when graphite is used as a reinforcement at a mixing ratio of 2%, and this can be compared with the mechanical testing results from the study conducted by Nugroho et al [1]. It is found that adding graphite above 2% can lead to a decrease in the mechanical capability of the PU foam with graphite filler as the graphite content increases. For PU foam with PLA filler, the highest compound bond absorption value is obtained at a 3% ratio. Adding PLA content above 3% in the 1-5% range can impact the mechanical strength. The results of the FT-IR test can be compared to the research conducted by Chaigneau et al [6]. In the FT-IR testing of PU foam specimens with glass powder as a reinforcement, the highest compound absorption value is obtained at a 5% mixing ratio. Within the mixing ratio range of 1-5%, the highest value is obtained with an increased amount of glass powder added. According to the study conducted by Lugas et al,[7] it is shown that adding glass powder content affects the mechanical strength of the material but is proportional to the increase in specimen weight.[8], [9].

5 CONCLUSION

The addition of graphite powder as a reinforcement shows the highest efficiency at a 2% ratio within the mixing range of 1-5%. Similarly, for PU foam with PLA as reinforcement, the optimal mixing ratio is 3%. Both of these materials exhibit the highest compound bond absorption at specific content levels. As the reinforcement content in PU foam increases, the ability to absorb compound bonds decreases, and this is related to the material strength, as indicated by previous mechanical testing data. However, the results differ when using glass powder as a reinforcement. With higher glass powder content, the intensity of compound bond absorption also increases. The degree of compound bond absorption influences the mechanical strength of the material, especially in the context of this study, which focuses on testing PU foam.

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References

1. A. D. Nugroho *et al.*, "Excellent Hybrid Polyurethane-Graphite Filler Micro Powder as a Lightweight Structure," *Journal of Composites Science*, vol. 7, no. 10, p. 433, Oct. 2023, doi: 10.3390/jcs7100433.
2. K. Litauszki and Á. Kmetty, "Investigation of the damping properties of polylactic acid-based syntactic foam structures," *Polym Test*, vol. 103, Nov. 2021, doi: 10.1016/j.polymertesting.2021.107347.
3. A. Siegmann, S. Kenig, D. Alperstein, and M. Narkis, "Mechanical Behavior of Reinforced Polyurethane Foams Mechanical Behavior of Reinforced Polyurethane Foams Table 1. Tensile and Compressive Mechanical Properties of Glass-Reinforced Foams Compressive Modulus Fiber E, (wt.%) (glcm3) (kg/cm³) P(-C"IOO/)," 1983.
4. J. Wang, H. Wang, and G. Geng, "Flame-retardant superhydrophobic coating derived from fly ash on polymeric foam for efficient oil/corrosive water and emulsion separation," *J Colloid Interface Sci*, vol. 525, pp. 11–20, Sep. 2018, doi: 10.1016/j.jcis.2018.04.069.
5. M. I. Nuryanta, J. Sentanuhady, and M. A. Muflikhun, "Moisture absorption behavior of hybrid composite laminates consist of natural and glass fiber," *Mater Today Proc*, vol. 66, pp. 2924–2928, Jan. 2022, doi: 10.1016/j.matpr.2022.06.559.
6. L. Chaigneau, A. Perrot, D. Brezulier, J. F. Coulon, F. Chevre, and R. Lebullenger, "Bioresorbable polylactic acid (PLA) and bioactive glasses (BG) composite: Influence of gold coated of BG powder on mechanical properties and chemical reactivity," *J Mech Behav Biomed Mater*, vol. 138, Feb. 2023, doi: 10.1016/j.jmbbm.2022.105571.
7. L. G. Aryaswara, M. Kusni, D. Wijanarko, and M. A. Muflikhun, "Advanced properties and failure characteristics of hybrid GFRP-matrix thin laminates modified by micro glass powder filler for hard structure applications," *Journal of Engineering Research*, Aug. 2023, doi: 10.1016/j.jer.2023.08.022.
8. M. A. Muflikhun, "The Progressive Development Of Multifunctional Composite Materials In Different Applications," *Angkasa: Jurnal Ilmiah Bidang Teknologi*, vol. 12, no. 2, Oct. 2020, doi: 10.28989/angkasa.v12i2.673.
9. M. A. Muflikhun and T. Yokozeki, "Experimental and numerical analysis of CFRP-SPCC hybrid laminates for automotive and structural applications with cost analysis assessment," *Compos Struct*, vol. 263, May 2021, doi: 10.1016/j.compstruct.2021.113707.

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