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Effect of Recycle Carbon Fiber Powder (RCFP) and Fabric Reinforcement (FR) on The Flexural Properties of Polyurethane

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Abstract

Polyurethane's versatility is limited by its weak flexural strength. This study explores methods to address this limitation. Recycled carbon fiber powder (RCFP) was investigated as a reinforcing agent. The research found that incorporating recycled carbon fiber particles (RCFP), particularly finer particles (100 mesh), significantly enhanced flexural strength and modulus. This improvement is attributed to RCFP effectively filling voids in the polyurethane, increasing its density and resistance to bending loads. While a higher content strengthens the material, it can also lead to excessive stiffness and a decrease in flexural strength. Polyester fabric reinforcement (FR) emerged as another effective method, with five layers increasing flexural strength to 2.1 MPa. FR also introduces flexibility, potentially reducing the risk of catastrophic failure under impact or bending. Additionally, FR improves the composite's compressive, shear, and tensile strength. The study highlights the importance of optimizing both RCFP size and content to achieve the desired mechanical properties. Future research could explore the combined effects of RCFP and FR for even greater improvements. This research paves the way for the development of stronger and more sustainable polyurethane composites using recycled materials.

Keywords: Recycled Carbon Fiber Powder; Fabric Reinforcement; Flexural Properties; Polyurethane

Introduction

Polyurethane is a versatile polymer that has a wide range of applications in various industries [1]. From insulation to furniture, polyurethane is used to produce durable and high-performance products. The versatility of polyurethane stems from its unique properties, such as its ease of shaping, resistance to wear, and excellent thermal insulation ability. In addition, polyurethane is known for its exceptional adhesive properties, allowing it to bond well with different materials such as concrete, wood, and metal.

However, this polymer has a weakness in terms of its mechanical strength. Seydibeyoğlu, Misra [2] showed that the flexural strength of polyurethane is only 3.03 MPa. Another study by Ganjar (2024) indicated that polyurethane has a flexural strength of up to 0.95 MPa So various efforts are needed to improve the flexural strength of polyurethane so that it can be used in applications without considering its weaknesses. Various studies have been conducted in the literature to improve the mechanical strength of polyurethane Adding reinforcing powders has been used to enhance the mechanical strength of polyurethane [3, 4]. The addition of 10% glass powder has proven to increase the hardness of polymer composites [5]. In addition, adding aluminum powder has been shown to increase the mechanical strength of polyurethane [6]. Li, Guo [7] also addressed the weakness in mechanical strength by incorporating carbon powder into urethanes which has proven effective at increasing their maximum strength [7, 8].

Carbon powder, such as graphite or black carbon, has good mechanical properties and conductivity. Currently, carbon powder is widely used in pyrolysis production [9]. The use of carbon powder as a composite material is also becoming more popular as a reinforcement. However, the use of carbon powder as a reinforcement requires high cost. This restricts its usage. In addition, the use of carbon powder as reinforcement does not support environmental sustainability. Therefore, using recycled carbon fiber powder from the milling process of carbon fiber composites is a solution for utilizing carbon powder as polyurethane reinforcement. In this article, polyurethane is reinforced with recycled carbon fiber powder to strengthen PU [10]. This issue emphasizes environmental awareness to encourage RCFP utilization in reinforcing polyurethane materials [11]. Besides environmental factors, the use of RCFP is considered cost-effective making it suitable for large-scale applications. However, various factors impact other characteristics when using powders on polyurethanes. Powder size and content have significant influence on its characteristics. In some cases, the use of reinforcing powder added to polyurethane does not increase the mechanical strength significantly. Marhoon [12] who used carbon black powder only increased the flexural strength to 0.93 MPa. In addition, the use of Carbon Nano Tube (CNT) increases the tensile strength of polyurethane to 1.42 MPa.

Therefore, it is necessary to add reinforcement to increase the flexural strength of polyurethane. Polyurethane that undergoes bending loads will break because it lacks support to withstand the load. Therefore, additional strategies are required to enhance flexural strength by structural strengthening to ensure more uniform and efficient load distribution. This research will add reinforcing fabric (FR) to polyurethane to increase its ability to withstand the load it receives. The reinforcing fabric provides additional structural support through interlocking mechanisms and matrix reinforcement, effectively increasing resistance to bending deformation. This combination of carbon powder and reinforcing fabric not only enhances the mechanical properties of polyurethane but also creates new possibilities for using composite materials in infrastructure and construction projects that demand high resistance to dynamic and static loads. The use of reinforcing fabric can also provide flexibility in adjusting the mechanical properties of the composite according to the requirements of specific applications. Polyester fabric is chosen for its increased resistance to corrosion and environmental factors. This research aims to observe load propagation in polyurethane reinforced with recycled carbon powder and reinforcing fabric.

Materials and Methods

Materials

Apparatus Recycled Carbon Fiber Powder (RCFP) is powder from recycled carbon fiber that has gone through a mechanical pollination process. RCFP is obtained through a carbon fiber composite grinding process. The grinding results are sifted and separated based on powder size. Sieving using 20 Mesh, 60 Mesh and 100 Mesh sieves. Polyurethane material is processed with the components Polyurethane A/Millionate MR-200 (polyisocyanate) and Polyurethane B/JKR-7631L (polyether). These components are printed in a 1:1 ratio. Fabric Reinforcement (FR) is a fabric with holes with a size of 20 mesh. The fabric is made of Polyester with a density of 0.03 g/cm2 and a tensile strength of 82 N. The thickness of the fabric is 0.9 mm and is resistant up to 70oC. All material components are molded and produce polyurethane material as shown in Figure 1. The amount of each component PU, RCFP, FR, and powder size are described in table 1.

Materials	*Polyurethane (%)*	*RCFP (%)*	*Particle Size (Mesh)*	*Fabric Reinforcement*
1	100	0	0	0
2	96	4	100	0
3	92	8	100	0
4	88	12	100	0
5	88	12	20	0
6	88	12	60	0
7	88	12	100	0
8	88	12	100	1
9	88	12	100	2
10	88	12	100	3
11	88	12	100	4
12	88	12	100	5

Table 1: Material Manufacturing Parameters.

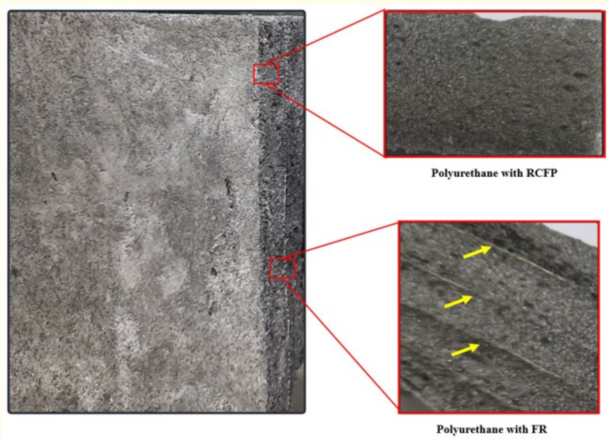

Figure 1: Material of Polyurethane with RCFP and FR.

Manufacture Process

Mold of polyurethane material is carried out using the closed mold method [13]. This printing method makes it possible to increase the density of the material. Polyurethane molds use a closed method. The molding process utilizes variations in particle size, particle content, and the incorporation of reinforcing fabric. The polyurethane manufacturing process is illustrated in Figure 2. The first mold is printing Polyurethane A/Millionate MR-200 (polyisocyanate) and Polyurethane B/JKR-7631L (polyether). The second mold added RCFP to the polyurethane mold with volume fractions of 4%, 8%, and 12%. Then, the third step involves adding RCFP with different powder sizes of 20 mesh, 60 mesh, and 100 mesh. The final step is adding fabric reinforcement as polyurethane reinforcement. FR reinforcement is applied to polyurethane in 1, 2, 3, 4, and 5 layers.

Particle Size of RCFP		
20 Mesh	60 Mesh	100 Mesh
1 mm - 0,84 mm	0,85 mm - 0,25 mm	0,26 mm - 0,15 mm

Table 2. Particle Size of RCFP.

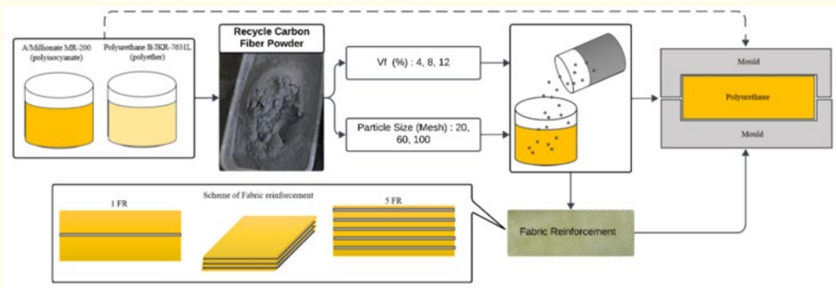

Figure 2: Material Manufacturing Procces.

Material Testing

Polyurethane density is measured according to ASTM D792. Measurements were taken using samples that measured 10 x 10 x 10 mm (length x width x thickness), with a total of 10 pieces in each print. Samples were cut from PU foam after being humidity conditioned at 23°C and 50% RH for 24 hours. Density is calculated using:

$$\rho : \frac{m}{V}$$

where m represents the measured mass (g) of each specimen and V represents the volume (cm^3) obtained by multiplying the length, width, and thickness of the specimen.

Flexural testing utilizes a Universal Testing Machine (UTM) with a capacity of 1000 kg. The test follows the ASTM D790 testing standard. The test results calculated the flexural strength and flexural modulus of the specimen. Calculations using the formula:

$$\sigma_a = \frac{3PL}{2bd^2}$$

$$E = \frac{L^3 m}{4bd^3}$$

where: σ_a: flexural strength (MPa); E: Flexural Modulus (MPa); P: load (N); L: span length (mm); b: width (mm); d: thickness (mm); m: deflection slope (N.mm).

Results and Discussion

Density of Polyurethane

The results of the density test indicated that there was an impact on the variation in the size of the RCFP. Figure 3 (a) shows the density results obtained from the variation in RCFP sizes. Based on the graph, it can be observed that a decrease in the size of the carbon powder leads to an increase in the density of polyurethane. RCFP with a 100 mesh size exhibits a high density of 0.075 g/cm^3. These results increased from polyurethane without the addition of RCFP, which only reached 0.058 g/cm^3. This shows that carbon powder with a small particle size can fill the empty spaces in the voids of polyurethane. The establishment of this RCFP fills gaps in PU and will enhance the material's density, thereby increasing its overall compactness. RCFP with a larger size will find it difficult to fill the small voids, resulting in several empty spaces that cannot be filled by RCFP. The smaller size of the RCFP will fill the smaller PU voids, ensuring that almost all of the voids will be covered by RCFP. This will increase the density of the polyurethane material.

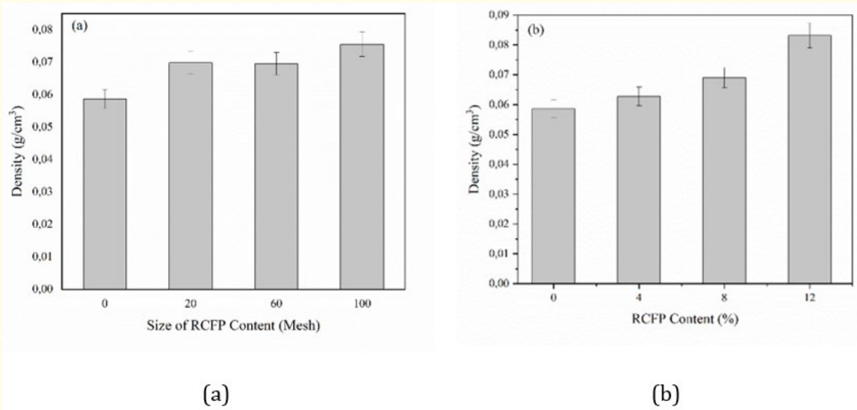

Figure 3: Density of Polyurethane (a) Based of Size RCFP; (b) Based of RCFP Content.

The carbon powder content in polyurethane affects the material's density. Figure 3 (b) shows a graph illustrating the results of density testing on polyurethane incorporated into RCFP. Based on the test results, it is shown that the addition of carbon powder increases the density of the material. The mass fraction of 12% has the highest density value of 0.083 g/cm^3, which is significantly higher than that of polyurethane (PU) without additional reinforcement, which is only 0.058 g/cm^3. This is because the increasing number of RCFPs will fill the voids in the material. The higher the number of RCFPs added, the more voids will be filled. When the void material is filled with carbon powder, it increases the density of the material, leading to an overall increase in the density of polyurethane.

Effect of Particle Size Recycled Carbon Fiber Powder

In the polyurethane bending test, it was observed that the flexural strength was highest for the 100 mesh size of the RCFP. Figure 4 (a) shows the results of the flexural strength test of the polyurethane (PU) with the addition of recycled carbon fiber powder (RCFP). In polyurethane, without the addition of RCFP, the flexural strength only reached 1.0 MPa. This shows that reducing the size of the RCFP increases the flexural strength of polyurethane. This relates to the results of the density test shown in Figure 3. RCFP 100 mesh has a small grain size, which enables it to effectively fill voids in PU, leading to an increase in density. This resulted in an increase in the resistance of polyurethane (PU) to bending loads. This result is also observed in the flexural modulus results of the material, as shown in Figure 4 (b).

The RCFP material with a 100 mesh has the highest flexural modulus. The bending modulus of the material with 100 mesh RCFP content reached 4.93 MPa. This result increased compared to the result of polyurethane (PU) without recycled carbon fiber reinforced polymer (RCFP) content, which was 4.03 MPa. The bending modulus tends to decrease at a 20-mesh RCFP size and then increase at a smaller size [14]. This suggests that the size of the recycled carbon fiber powder plays a significant role in determining the flexural strength and modulus of the polyurethane composite. The incorporation of recycled carbon fiber powder with a smaller size, such as 100 mesh, enhances the flexural strength and modulus of the polyurethane composite. This suggests a beneficial impact of integrating recycled carbon fiber powder on the mechanical properties of polyurethane.

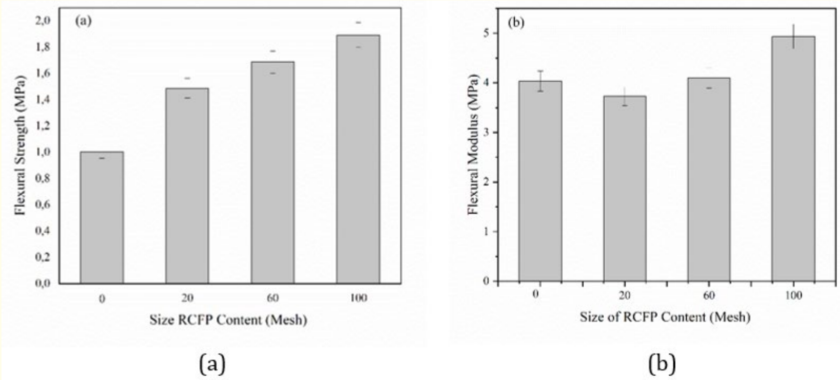

Figure 4: (a) Flexural Strength of Polyurethane Based of Size RCFP Content; (b) Flexural Modulus of Polyurethane Based of Size RCFP Content.

Effect of Particle Content Recycled Carbon Fiber Powder

The results of the flexural testing of the PU material with RCFP mass fraction are presented in Figure 5. The flexural strength of the PU/RCFP material is presented in Figure 5 (a), which shows that the PU material without the addition of RCFP reaches 1 MPa. On the addition of RCFP, the strength of the material decreased to its highest content, which was 12%. The strength of the 12% RCFP content decreased by more than 50%. This is because the increasing number of RCFPs in PU causes more and more voids to be filled by RCFPs. RCFP, which spreads over the entire material, is able to fill more PU gaps. This increases the stiffness of the material. RCFP, which is granular, will compact and have no bending strength. Therefore, polyurethane (PU) materials with a high RCFP experience a higher failure rate due to material stiffening [15]. This can be seen from Figure 5 (b), which shows the bending modulus of the material. The graph shows that the RCFP content of 12% has a high flexural modulus value. In contrast to the low RCFP content, the flexural modulus tends to have a smaller value.

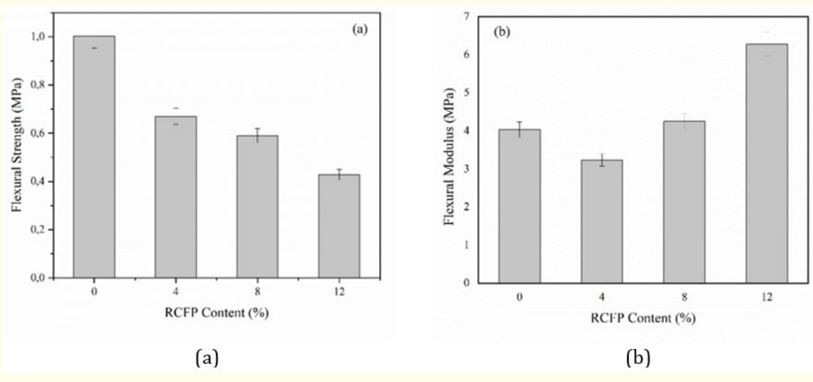

Figure 5: (a) Flexural Strength of Polyurethane Based of RCFP Content; (b) Flexural Modulus of Polyurethane Based of RCFP Content.

The results of the flexural testing indicate that incorporating a smaller size of recycled carbon fiber powder, such as 100 mesh, into polyurethane increases the flexural strength and modulus of the material, while higher RCFP content can lead to decreased flexural strength due to increased stiffness. These findings suggest that the addition of recycled carbon fiber powder can significantly impact the flexural strength and modulus of polyurethane composites. Furthermore, the study also highlights the importance of considering the size and content of the recycled carbon fiber powder when incorporating it into polyurethane. Therefore, it is crucial to carefully determine the appropriate size and content of recycled carbon fiber powder to optimize the desired mechanical properties of polyurethane composites while avoiding an excessive decrease in flexural strength caused by increased stiffness.

Effect of Fabric Reinforcement

The mechanical performance of polyurethane composites reinforced with FR is influenced by several factors, including the type and concentration of FR, the arrangement of reinforcement layers, and the properties of the polyurethane matrix. Polyurethane reinforced with FR was tested using various quantities of FR. The flexural load caused the emergence of compressive, shear, tensile strength, and shear loads. The test results of polyurethane with reinforcing fabric are presented in Figure 6. Test results showed that the addition of polyester FR reinforcement increased the flexural strength, reaching 2.1 MPa for 5 layers of FR. However, the flexural modulus decreased as more layers of FR were added, leading to increased flexibility in the polyurethane core. This finding indicates that using FR can enhance material durability compared to other reinforcing materials, such as cellulose nanofibrils. Furthermore, incorporating FR into polyurethane composites facilitates stress transfer from layer to layer, leading to enhanced flexural strength and ultimately improving composite structural integrity of the composite. The test results mentioned earlier indicate that incorporating polyester FR reinforcement enhances flexural strength by improving load-bearing capacity. On the other hand, an increase in flexibility within the polyurethane core leads to a decrease in flexural modulus when more layers of FR are added. This reduced modulus, increased flexibility can provide resilience to the material and decrease its vulnerability to catastrophic failure when subjected to bending or impact loads.

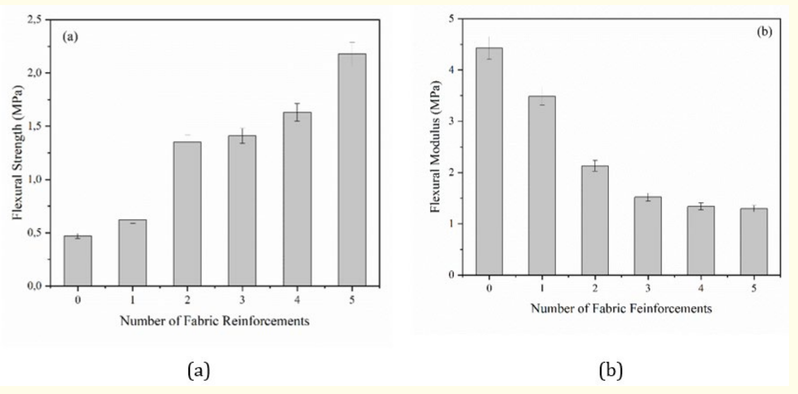

Figure 6: (a) Flexural Strength of Polyurethane Based of Fabric Reinforcements; (b) Flexural Modulus of Polyurethane Based of Fabric Reinforcements.

In addition to improvements in flexural properties, FR-reinforced polyurethane composites also exhibit enhanced compressive, shear, and tensile strength compared to unreinforced polyurethanes. This enhancement is attributed to effective stress transfer facilitated by the FR layers which distribute and dissipate loads more uniformly throughout the composite structure. Furthermore, the incorporation of FR enhances resistance against fatigue, wear, and environmental degradation thereby prolonging service life especially under demanding operating conditions.

Conclusion

This research aims to enhance the flexural strength of polyurethane, a versatile polymer with a wide range of applications but limited mechanical strength. Two main methods were studied: the addition of recycled carbon fiber powder (RCFP) and reinforcement with polyester fabric (FR). The addition of RCFP, especially with finer particles (100 mesh), was shown to significantly increase flexural strength and modulus. High content can increase the stiffness of the material but can also reduce the flexural strength. Reinforcement with fiber reinforcement has also proven effective in increasing the flexural strength of polyurethane. With 5 layers of fiber reinforcement (FR), the flexural strength can reach 2.1 MPa. FR also enhances the flexibility of the material, thereby reducing the risk of failure caused by impact or bending. Furthermore, fiber reinforcement increases the compressive, shear, and tensile strength of composites. This research demonstrates that RCFP and FR are effective methods for enhancing the flexural strength of polyurethane. This research shows that RCFP and FR are effective methods to increase the flexural strength of polyurethane.

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References

1. Kostopoulos V and Kollia E. "Development and Mechanical Characterization of a Non-Isocyanate Rigid Polyurethane Foam". Research & Development in Material Science 10.3 (2019).
2. Seydibeyoğlu M., et al. "Green polyurethane nanocomposites from soy polyol and bacterial cellulose". Journal of Materials Science 48 (2013): 2167-2175.
3. Gu R and MM Sain. "Effects of Wood Fiber and Microclay on the Performance of Soy Based Polyurethane Foams". Journal of Polymers and the Environment 21.1 (2013): 30-38.
4. Azmi MA, HZ Abdullah and MI Idris. "Properties of polyurethane foam/coconut coir fiber as a core material and as a sandwich composites component". IOP Conference Series: Materials Science and Engineering 50 (2013): 012067.
5. Musa B. "Effect of Glass Powder on Some Mechanical Properties of Polymer Matrix Composite Material". Journal of Al-Nahrain University Science 17 (2017): 108-115.
6. Visco A., et al. "Polyurethane Foams Loaded with Carbon Nanofibers for Oil Spill Recovery: Mechanical Properties under Fatigue Conditions and Selective Absorption in Oil/Water Mixtures". Nanomaterials 11.3 (2021): 735.
7. Li Z., et al. "Study on Road Performance of Polyurethane Cold-Recycled Mixture". Polymers 15.8 (2023): 1958.
8. Pramudi G, WW Raharjo and D Ariawan. "Investigation of the flexural and impact strength of recycled carbon fiber (RCF) i polyester composite". in AIP Conference Proceedings (2022).
9. Indayaningsih N., et al. "Production of activated carbon by using pyrolysis process in an ammonia atmosphere". Journal of Physics: Conference Series 817 (2017): 012006.
10. Pramudi G, WW Raharjo and D Ariawan. "Investigation of Flexural strength of Sandwich Panels Recycled Carbon Fibre/Polyester with Cotton Mesh Fabric Reinforcement in Polyurethane Core". Journal of Applied Science and Engineering (Taiwan) 25.5 (2022): 823-831.
11. Zhang J., et al. "Current status of carbon fibre and carbon fibre composites recycling". Composites Part B: Engineering 193 (2020): 108053.
12. Marhoon II. "Mechanical and Physical Properties of Polyurethan of Composites Reinforced with Carbon Black N990 Particles". International Journal of Scientific & Technology Research 6 (2017): 225-228.
13. Mohamed M., et al. "Manufacturing and Evaluation of Polyurethane Composite Structural Insulated Panels". Journal of Sandwich Structures and Materials 18 (2016).
14. Řepka J., et al. "Woven Carbon-Fiber-Reinforced Polymer Tubular Mesh Reinforcement of Hollow High-Performance Concrete Beams". Polymers 15.14 (2023): 3089.

15. Witkiewicz W and A Zieliński. “Properties of the polyurethane (PU) light foams”. Advances in Materials Science 6.2 (2006): 35-51.