

# Mechanical and Physical Properties of Glass Wool-Rigid Polyurethane Foam Composites

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## Abstract

This research is devoted to the preparation of foam polymer matrix composite materials by forming in place method, where the composite foam material was prepared from the rigid polyurethane foam (PU) as a matrix reinforced by glass wool insulator with weight fractions (2%, 4%, 6%, 8% and 10%). Several mechanical and physical tests were done and these include impact, flexural, compression, hardness, density, water absorption and thermal conductivity. The result shows that the values of mechanical and physical properties in general are increased with the increase of glass wool weight fraction content. The values of flexural strength decrease with the increase of weight fraction of glass wool fiber after 8% wt.

**Keywords-** Rigid polyurethane foam, Glass wool, foam composite, density, thermal conductor, flexural strength, hardness, impact strength, water absorption, polyol-isocyanate.

## 1. Introduction

In a country like Iraq, where large seasonal variations in temperatures occur, thermal insulation is quite important. Though designing the building for obtaining thermal and sound insulation characteristics involves additional expenditure, it is well compensated by the comfortable and healthy environment obtained.

The polyurethanes (PU) foams are widely used as insulating and core materials for furniture, cooling and freezing systems, in house building, ship building, piping, tanks, etc.[1,2]. The use of rigid foams is a result of their low heat conduction coefficient, low density, low water absorption and relatively good mechanical strength [3]. The PU foams have been applied also as core materials of sandwich constructions with steel plates, in building the industrial houses carrying freezers and cold stores, where they have to fulfill both insulating and mechanical requirements. In addition, polyurethane products, for the most part, are self-supporting, which makes them useful as construction insulation panels and as structural elements in construction applications [3, 4]. PU

foams are obtained by the reaction of isocyanate with polyols, which, depending on the formulation, regulate the properties of the material. Their foaming is possible due to the in situ generation of a foaming agent during the exothermal polymerization reaction, leading to crosslinked foams with changeable cellular structures[5]. Depending on the amount, proportions and characteristics of the components, it is possible to obtain three categories of polyurethanes foams which are flexible polyurethanes, semi rigid polyurethanes and rigid polyurethanes with different densities and cellular structures, and thus adjustable properties [5, 6]. Besides, given that both basic components are liquid at room temperature, it is relatively easy to incorporate fillers and reinforcements further, extending the applicability of these lightweight materials [7].

*Glass wool* insulation is felt materials made of glass with binder by heating and solidifying. It has good flexibility, affordable price and it is easy to install. Features of fiber glass wool are nature products, acoustical absorption, high thermal resistance with low thermal conductivity (Working temperature at about 450 °C), fire safe materials and environmental friendly materials [8-12]. Typical final nominal fiber diameters range from 4 µm to 15 µm. and softening point is 675 °C [13].

*Composite polymer foams* are materials of a polymer phase with voids and an additional solid or hollow phase distributed throughout the polymer, while *Foams* or cellular materials are materials that have a regular arrangement of cells and solid struts. Thus, the term *composite foam* excludes conventional, single-phase foams made by expanding polymers such as (polystyrene, polyurethane, or polypropylene), also excluded are structures with single-phase core materials and covered with a solid skin because the second phase, the skin, is not dispersed throughout the polymer phase [14].

Composite foams can be classified as follows: syntactic foam, particle reinforced foam and fiber-reinforced foam. The additional solid components are combined to enhance certain properties

important to the function of the composite foam part such as strength, stiffness, electrical or thermal conductivity [14, 15].

## 2. Objective

Polyurethane foam is very talented rigid polymer foam for shock, acoustic and thermal insulating applications, but it has limitations which exclude its application as a single material. Polyurethane properties are modified by controlling the stages of syntheses or by using fibrous reinforcement additives to overcome some of these limitations. For example, one of the main limitations of rigid PU foams comes from their reduced mechanical properties in the case of sandwich structures, increasing the risk of possible core crushing, shear or debonding from the surface skins. The aim of the present work is the synthesis of rigid polyurethane foams (PU) modified with short glass fibers in the form of (glass wool). The effects of glass wool insulation on the foams have been analyzed in terms of density, thermal conductivity, water absorption, mechanical properties (impact, compression and flexural).

## 3. Experimental

### 3.1 Materials

A two-component polyurethane foam (PU) system specifically formulated for the preparation of medium–high density rigid PU foams (POLYFOAM 55<sup>®</sup>) was produced by (POLYBIT), where part-A is a mixture of polyol, blowing and curing agents, catalysts and stabilizers, with a viscosity of 900 cps at 20 °C and a density of 1.14 g/cm<sup>3</sup>, and part-B is a modified diphenylmethane-diisocyanate (MDI), with a viscosity of 200 cps at 25 °C and a density of 1.24 g/cm<sup>3</sup>. Both components are liquid at room temperature [16]. Glass wool (URSA GLASSWOOL<sup>®</sup>) insulation was produced by URSA Uralita group –Turkey, have a density of 16 kg/m<sup>3</sup> and an individual fiber diameter between 6.1- 7.7 μm [17].

### 3.2 Composite Foam Preparation

Rigid PU-based foams were prepared by mixing equal amount 1:1 of part-A (polyol) and part B (isocyanate (MDI)) components for 15 s and pouring in a wooden mould (60×90×195 mm) as shown in Figure (1). The mould was closed with a lid and the mixture was allowed for PU's synchronized polymerization and foaming. Rigid PU reinforced composite foams were prepared by forming in place method by initially pre-mixing glass wool insulation (were dried for 24 hr. at 100°C) with the polyol prior to pouring into the mold with hand mixing for 1 min. after the mixture was allowed to degas for 2 min. into a wooden mould lined with aluminum foil.

Thereafter, part-B (MDI) was added to the mixture and mixed at a similar speed for another 15 sec. and the mixture was left to produce expanded foam. All composite foams were cured at ambient temperature (25°C) for 72 hr., and glass wool was added based on weight percentage of the overall weight of polyol and MDI resin (w/w %) which were (2, 4, 6, 8,10) %wt. as shown in Figure (2).

## 3.3 Foam Composites Measurement Methods

The specimens were cut according to the standard dimensions for each test. An average of three different determinations was obtained for all experiments except for hardness test, where five readings were taken from different places of one sample. The mechanical properties of the foams were conducted parallel to foam rise direction. Flexure tests are performed with 2.5 kN load at a speed of 2 mm/min. The tests were performed according to ASTM D 790-03 [18]. Compression strength was determined according to ASTM D1621-00 [19]. Impact test was performed according to ASTM D4812-99 for unnotched Izod impact test [20]. Density of the foam was measured according to ASTM D1622-03 [21]. Hardness test was performed by using Shore hardness (D) and according to ASTM F1957–99 [22]. Water Absorption test was performed according to ASTM D570-98 [23]. Thermal conductivity was measured using Lee's Disk with sample dimensions of 40 mm diameter and 5 mm thickness. The instrument consists of a heating coil and three brass disks. The specimen was secured between the brass disks (1, 2) and the heating coil was fixed between the brass disks (2, 3). The applied voltage across the terminal of the heating coil is 6 V. and the current is 0.2 A. A heating heater was used to heat the three brass disks (1, 2, 3) and heat transfer was through the specimen from the bass disk (2) to brass disk (1). The temperature of the disks increases gradually until it reaches the equilibrium temperature of all disks.

## 4. Results and Discussion

### 4.1 Physical Properties

#### 4.1.1 Water Absorption

Figure (3) show the relationship between water absorption percentage and weight fraction of the glass wool filler, which were added to the rigid polyurethane foam. Water absorption behavior of polymer filled composites at a particular environmental condition is determined by many factors, such as processing techniques, matrix filler characteristics, composition of the composites, and duration of immersion in water [24]. The results had revealed that the water absorption percentage increases with increasing

weight fraction of (glass wool) in another term the hygroscopicity of polyurethane / glass wool foam composites increases as glass wool content increases, and reaches 41.17% at 10 wt.% as compared to water absorption percentage of (4.785%) for rigid polyurethane foam. This increase may be due to the glass wool fiber filler which have a higher water absorption percentage than the matrix material; fiber glass wool has moisture absorption of 3% of weight at a relative humidity of about 90% [17]. In addition, reinforced samples have many channels which assist water to penetrate inside the sample. The presence of interfaces between the matrix and the short glass wool fibers are considered as capillary tubes for water transport and penetration inside the samples.

#### 4.1.2 Density

Figure (4) shows the variation in density of polyurethane foam at different wt.% of wool glass. From this figure, it is clearly seen that the density increases with increasing % wt. of glass wool. The density of solid polyurethane foam is ( $61.24 \text{ Kg/m}^3$ ) and reaches ( $119.44 \text{ Kg/m}^3$ ) at a weight fraction of (10 %wt.). This increase can be related to both the polyol-isocyanate exothermic reactions where carbon dioxide was generated from the reaction. Due to the release of heat from the exothermic reactions, the carbon dioxide bubbles grew (small size cell with spherical and polyhedral shape) and expanded the polymerizing polymer to form a foam volume [5]. When adding glass wool to polyurethane foam, bubble rise and growth are physically hindered by the presence of glass wool fibers and also cell size generally decreases as the glass wool %wt. content increases indicating that cell growth is hindered by the fibers. In addition, the closed cell content decreases with the glass wool fibers %wt. content, and that will lead to density increase of polyurethane composite.

#### 4.1.3 Thermal Conductivity

Figure (5) shows the relationship between the thermal conductivity with different values of weight fraction of wool glass. Thermal conductivity (k) is the most important property of foam for insulation application. The overall thermal conductivity of foam increases with increasing the %wt. wool glass content. Thermal conductivity of solid polyurethane foam is ( $0.0290 \text{ W/m} \cdot ^\circ\text{C}$ ) and reaches ( $0.0391 \text{ W/m} \cdot ^\circ\text{C}$ ) at a weight fraction of (10 %wt.). The overall thermal conductivity of the composite foams is increased due to the high thermal conductivity of glass wool fibers, and also when the reduction in cell size is accompanied by a noteworthy density increase, thus thermal conductivity practically increases as a result of the cell size reduction as shown in

Figure (6). However the thermal conductivity of rigid polyurethane foam composite changes a little in the fiberglass wool weight fraction range 2 to 10 % wt.

## 4.2 Mechanical Properties

### 4.2.1 Hardness

The reinforcement of rigid polyurethane foams with glass wool has a great role in obtaining a higher hardness. A shore D hardness test was used for specimen of rigid polyurethane before and after reinforcing with glass wool. Figure (7) shows the effect of glass wool weight fraction on hardness. It can be seen that the hardness of polyurethane foams increases with increasing the fiber glass wool weight fraction. Results have shown that the hardness of solid polyurethane foams is (71.46 shore D) and reaches (83.85 shore D) at weight fraction of (8%). Hardness is commonly defined as a resistance of material to local deformation. The increase in %wt. glass wool fibers content leads to an increase in the hardness due to the increase in material resistance against the plastic deformation. In other words, the addition of the glass wool leads to a decrease in the elasticity and an increase in the rigid polyurethane foams matrix surface resistance to the indentation.

### 4.2.2 Compression Strength

Figure (8) illustrates the compression strength of rigid polyurethane foam base matrix composite filled with different weight fraction of glass wool. Results have revealed that compression strength has increased with the addition of glass wool to polyurethane foam and the values were (264.77, 294.19, 343.23, 411.87 and 441.29) kPa at (2, 4, 6, 8 and 10) %wt. glass wool respectively. The compression strength of pure rigid polyurethane foam is (235.35 kPa). The increase of strength of the composite is due to the addition of higher strength and stiffness glass wool fibers. In addition, the decrease of cell size may also have an effect on the mechanical strengthening of the composite.

#### 4.2.3.1 Flexural Strength

Figure (9) show the relationship between flexural strength and weight fraction for the composite of polyurethane foam reinforced by glass wool. That flexural strength of the prepared foam composite material increases with an increase in the weight fraction up to 8 %wt., then the strength decreases. The reason behind such behavior is that short- fibers of glass wool are able to increase the flexural strength of the polyurethane foam since they offer appropriate fiber-matrix adhesion so as to resist deformation. The effect of fiberglass wool on flexural strength may be also due to the increase in the short fiber glass content in a polyurethane foam composite

and that in turn lead to an increase in effective surface fracture energy. The dispersed short fibers glass wool enhances the plastic deformation, make the crack propagation path longer, and absorb a portion of energy. Hence, the surface fracture energy increases and the flexural strength of composites increase with weight fraction percentage of glass wool. After (8% wt. glass wool), the flexural strength decreases with further additional increase. This may be related to an increase in the viscosity (during mixing) of the matrix at large additions of glass wool causing difficulty in matrix fluidity and reduced ability to penetration between fibers which reduces fiber wetting prior to hardening of the matrix causing a decrease in adhesion (weaker interface) between the matrix and the fibers, and as a result crack propagation will occur.

#### 4.2.3.2 Flexural Modulus

Results of flexural modulus of polyurethane foam before and after the addition of fiber glass wool have revealed that flexural modulus increases with the increase in weight fraction as shown in Figure (10). Flexural modulus of pure rigid polyurethane foam is (9.227 MPa.) and increases with increasing weight fraction until it reaches a value of (28.04 MPa.) at a weight fraction of (10%). This observation highlights the fact that the incorporation of glass wool into polyurethane foam matrix improves the stiffness of the latter because stress is transferred from the matrix to the fiber resulting in stronger foam composites. The result attained in this study is in agreement with the findings of Kim et. al. [2].

#### 4.2.4 Impact Strength

The addition of the fiber glass wool to the polyurethane foam enhanced significantly the impact strength as shown in Figure (11). The reason for impact strength improvement may be due to the increase in fracture surface area which results from unregular path of crack due to short fibers which act as traverse in front of crack propagation. Hence, the surface fracture energy increases and the impact strength of composites increase with %wt. of glass wool. Another reason might be the plastic deformation (plastic zone) that results from the short fibers, around the crack. That plastic zone would have to support part of the load in order to reduce stresses at the crack tip, and hence prevent fracture from occurring at low values of the applied load. In effect, the plastic zone that surrounds the crack tip acts as (crack tip shielding), because it applies a compressive force to the crack surfaces and closes the crack tip and as a result causes retardation of crack growth.

This indicates that as the content of short fibers of glass wool increases, the impact strength is

improved compared to that of pure polyurethane foam and so the foam composites have higher toughness to withstand the sudden loads compared to that of the pure foam.

### 5. Conclusions

The main conclusions of this study on rigid polyurethane matrix foam composites are as follows.

1. It was found that increasing the glass wool content within the rigid polyurethane foam matrix results in significant increase in the thermal conductivity. Therefore, it is not recommend to add glass wool for polyurethane foam for thermal insulation purposes.
2. The properties of the rigid polyurethane foam-glass wool composites are significantly improved by varying the amount of glass wool. It was found that increasing the glass wool content within the matrix material, resulted in significant improvement in mechanical properties like hardness, flexural strength, compressive strength, impact strength at the cost of increased density.
3. Peak values of mechanical properties like hardness, flexural strength were found at 8 wt.% glass wool and compressive strength, flexural modules, impact strength were found at 10 wt.% glass wool.

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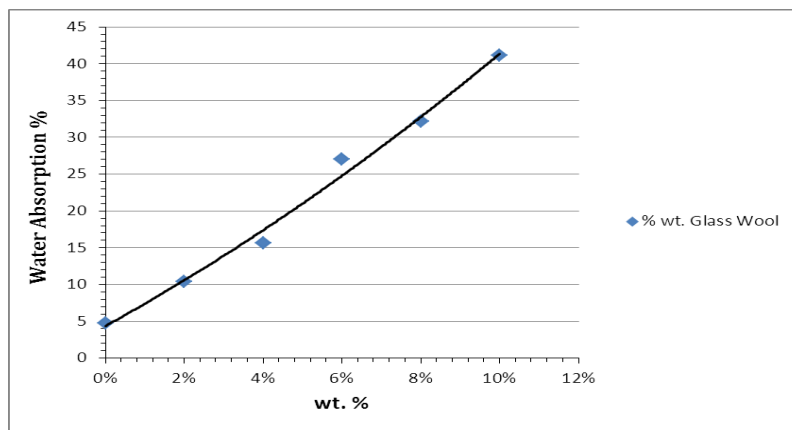
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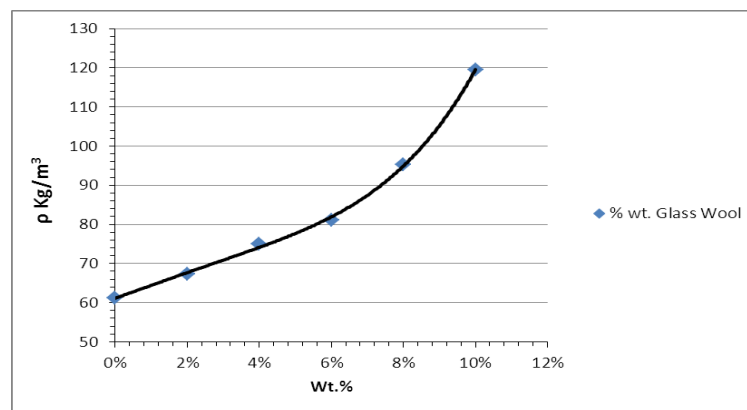
**Figure (1):** The form of the prepared mould



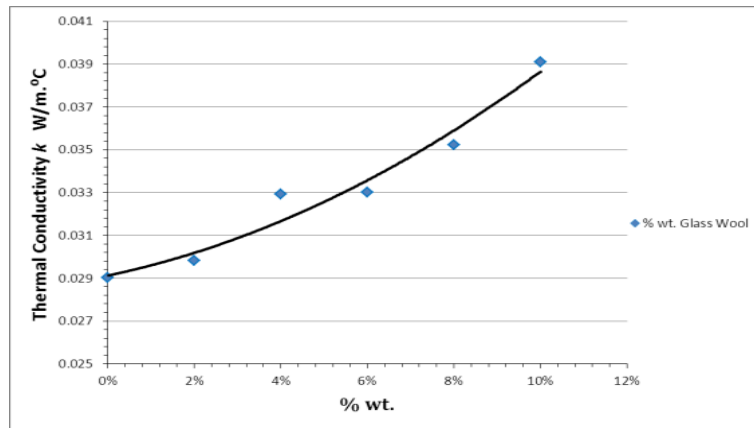
**Figure (2):** Polyurethane foam with glass wool fibers at a range of (0-10) % wt.



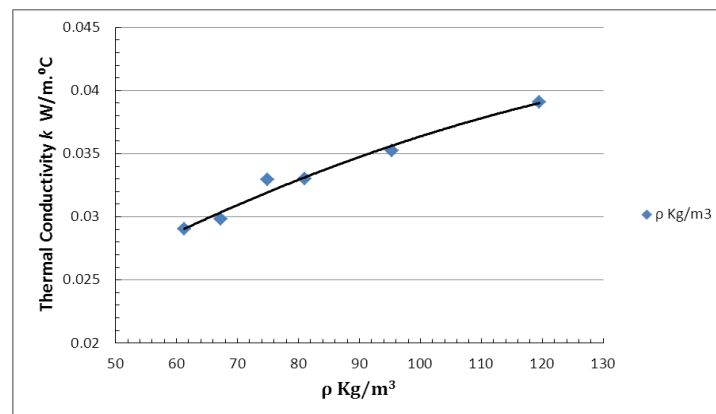
**Figure (3):** The effect of the weight fraction of glass wool on water absorption for rigid polyurethane foam at a range of (2-10) % wt.



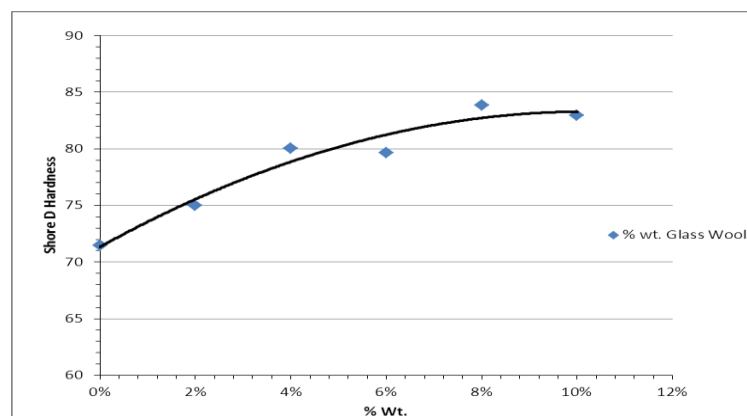
**Figure (4):** The effect of the weight fraction of glass wool on density for rigid polyurethane foam at a range of (2-10) % wt.



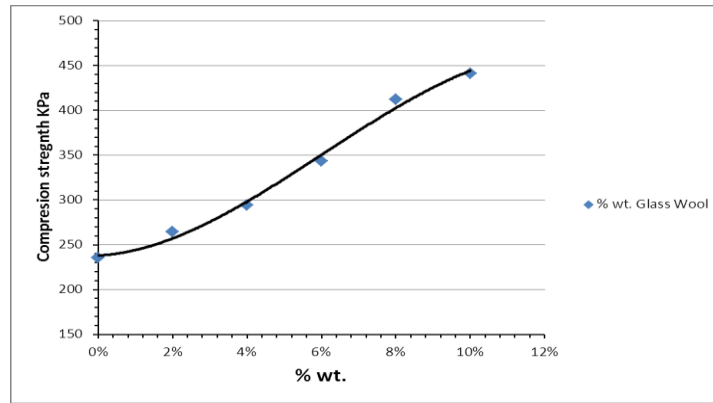
**Figure (5):** The effect of the weight fraction of glass wool on thermal conductivity for rigid polyurethane foam at a range of (2-10) % wt.



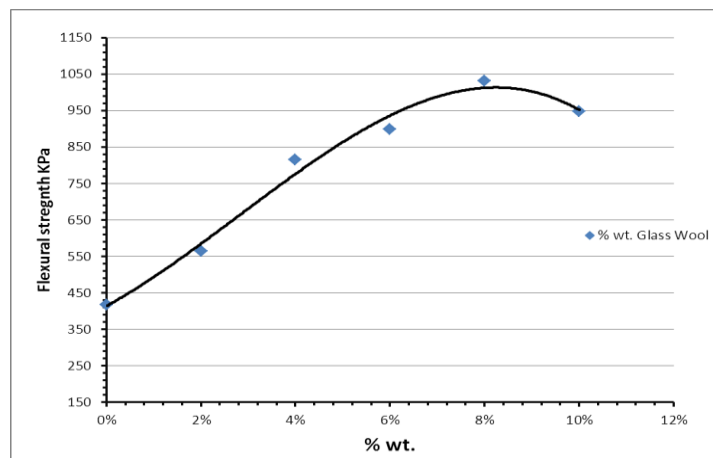
**Figure (6):** The effect of the density of glass wool on thermal conductivity for rigid polyurethane foam at a range of (2-10) % wt.



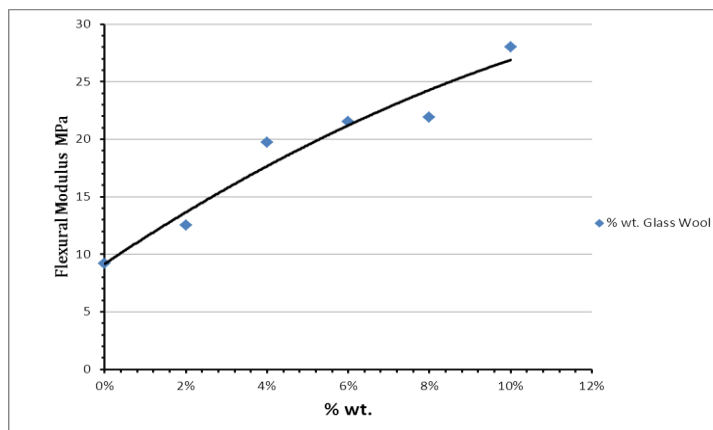
**Figure (7):** The effect of the weight fraction of glass wool on Hardness for rigid polyurethane foam at a range of (2-10) % wt.



**Figure (8):** The effect of the weight fraction of glass wool on compression strength for rigid polyurethane foam at a range of (2-10) % wt.

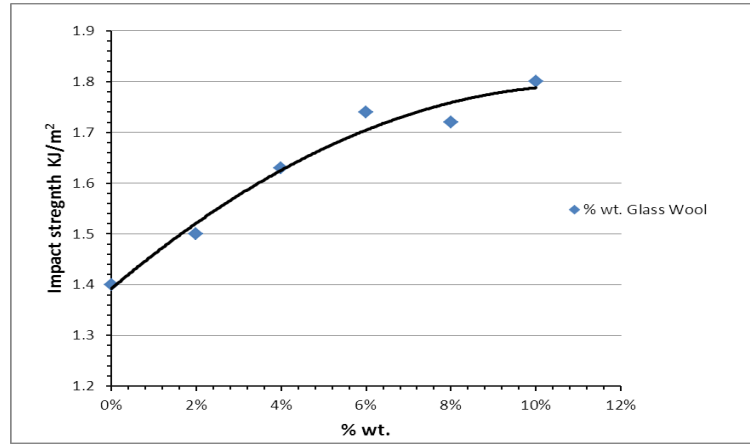


**Figure(9):** The effect of the weight fraction of glass wool on flexural strength for rigid polyurethane foam at a range of (2-10) % wt.



**Figure(10):** The effect of the weight fraction of glass wool on flexural modulus for rigid polyurethane foam at a range of (2-10) % wt.





**Figure (11):** The effect of the weight fraction of glass wool on impact strength for rigid polyurethane foam at a range of (2-10) % wt.

## الخواص الميكانيكية والفيزيائية لمادة متراكبة من الصوف الزجاجي - رغوة البولي يورثان

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### الخلاصة

يهدف هذا البحث الى تحضير مواد متراكبة ذات اساس بوليمري رغوي بطريقة التشكيل الموقعي وقد حضرت المواد المتراكبة من رغوة البولي يورثان الصلبة كمادة اساس مدعمة بالصوف الزجاجي بكسور وزنية (2%, 4%, 6%, 8%, 10%) وقد اجريت مجموعة من الاختبارات الميكانيكية والفيزيائية شملت (الصدمة, الانحناء, الانضغاط, الصلادة, الكثافة, امتصاصية الماء والموصلية الحرارية) وقد اظهرت نتائج الاختبارات ان قيم الخواص الميكانيكية و الفيزيائية بشكل عام تزداد مع زيادة محتوى الكسر الوزني للصوف الزجاجي لكن قيم مقاومة الانحناء تنخفض مع زيادة الكسر الوزني للألياف الصوف الزجاجي بعد كسر وزني 8% .