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STUDY THE EFFECT OF POLYPROPYLENE FIBERS IN SOME MECHANICAL AND PHYSICAL PROPERTIES OF RIGID POLYURETHANE FOAM COMPOSITES

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Abstract: A foam composite material was set by adding polypropylene fibers diameter of 18 µm and 6 and 12 mm length to rigid polyurethane foam with a weight fraction of (2.5-15)%wt. The results had shown improvement on (flexural strength, compressive strength, hardness, impact strength) and increase in flexural modulus, density and water absorption, with decreases in thermal conductivity of the resultant foam composite as compared with neat rigid polyurethane foam

Keywords: *Foam-composites, Rigid polyurethane foam, Polypropylene fibers, polymeric composite, Mechanical properties, Physical properties, Foam density Thermal conductivity.*

دراسة تأثير الياف البولي بروبلين في بعض الخواص الميكانيكية والفيزيائية لمادة متراكبة من رغوة البولي يورثان الصلبة

الخلاصة: مادة رغوية متراكبة تم تصنيعها بواسطة إضافة الياف البولي بروبلين بقطر 18 مايكرون و طول 6 و 12 ملم الى رغوة البولي يورثان الصلبة بنسب وزنية مئوية (2.5-15) % . اظهرت النتائج تحسناً في(مقاومة الانحناء، مقاومة الانضغاط، الصلادة ،مقاومة الصدمة)، وزيادة في معامل الانحناء و الكثافة و امتصاصية الماء مع انخفاض في الموصلية الحرارية للمتراكب الرغوي الناتج عند مقارنته مع رغوة البولي يورثان الصلبة الصرف.

1. Introduction

The Polymer foams are also known as cellular, expanded, or sponge generally consists of a gaseous phase resultant from a blowing agent and a solid polymer phase [1,2]. According to their degree of crystallinity, the degree of cross-linking, and chemical composition, they can be classified as flexible, semi-rigid, or rigid [2,3]. The cells (or air/gas pockets) can be open (interlinking) or closed. Open-celled foams tend to be flexible, whereas closed-celled foams tend to be rigid Hence, rigid polyurethane foams are generally used in thermal insulation applications and contribute a lot of energy saving appliances. [4,5].

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Polyurethane Foam (PUF) is available for pouring, injecting, spraying, spreading, laminating, extruding, pultruding, rotomoulding or casting. It can be prepared as a foam, in either rigid (for insulation, buoyancy, or structural uses) or flexible forms (for carpet underlay, bed cushioning and seat) [6]. Composite materials are usually used in engineering applications where traditional materials cannot meet the specific strength or stiffness requirements. A composite is distinct as a multiphase material that reveals a considerable portion of the properties of both component phases, such that a superior combination of properties is realized [7]. Fibrous reinforcement is used when extraordinary mechanical performance is necessary. The mechanical properties of a composite are dependent upon many factors, reinforcement properties and the fractions of each of these phases and interface between phases [8,9]. The efficiency of reinforcing foams or composites with a fibrous filler can be determined by its orientation in the material matrix, geometrical parameters, and volume content, in addition to on the properties of the filler and polymer and on the degree of interaction between polymer and filler [10-13]. Andrzej et.al (2001). had prepared Polyurethane based composites reinforced with jute fabrics and woven flax to study the effect of the reinforcing fiber type and microvoid content on the mechanical properties(impact strength and shear modulus) of polyurethane foam. The investigation results increasing the fiber content induces an increase in the shear modulus and impact strength[1٤]. Büyükakinci et.al. (2011) had used natural materials (bamboo, cotton and wool fibres as reinforcement fibres in a polyurethane matrix to develop the sound absorption and thermal conductivity properties of the composite and found that the reinforcement fibres to polyurethane foam does not effect in a significant change in the thermal conductivity of the material and found that the lowest thermal conductivity value was perceived with a composite containing 4% cotton fibre [15]. Yakushin et.al. (2011) had studied the effect of milled carbon fibres on the properties of polyurethane rigid foams in the density range from 50 to 90 kg/m^3 and found that the properties of rigid polyurethane foams in compression improve and increases in rigidity also greatest changes experiences in elongation at break [16]. Azmi et.al. (2012) had studied Coconut coir fibers as reinforcement in rigid polyurethane (PU) foam with the purpose of increase the properties of foam and had found the mechanical flexural test shows that the flexural properties increased at 5wt % of coconut coir fibre with shear stress and an average value of maximum force at 60 KPa and 88N. It was shown that the coconut coir fibers at 5wt% increased the mechanical and physical properties of composite foam panel [17]. Jamrichová et.al. (2013) had studied selected natural fibers (corn, hop, chestnut, and sunflower) were used as reinforcement in polyurethane rigid foam (PURF) so as to increase the foam properties. The mechanical tests of polyurethane foam samples by fatigue testing and three-point bending testing was revealed that the addition of natural fibers increases the properties of the polyurethane foam [18]. The structural response of a polymer foam strongly depends on the foam density, cell microstructure such as cell size, shape, type (open or closed)foams present very remarkable mechanical properties such as a high capacity of energy absorption, mostly useful for shock damping [19]. For some years, their study has been comprehensive to composite foams reinforced with the fibers or metallic or mineral particles. This modification of the polymer matrix foam can initiate an enhanced adsorption of the heat released throughout the polymerization reaction, an increase of the matrix rigidity, with still a large ability of energy absorption, and acceptable density [20]. The objective of the present work was a synthesis of rigid PUR foams modified with inorganic polymeric fibers such as polypropylene short fiber. Moreover, the effects of polypropylene fiber have been analyzed in terms of, density, thermal conductivity, and mechanical properties of the foams.

2. Experimental

2.1. Materials

Rigid polyurethane foam (PURF) obtained from mixture (POLYFOAM® 40) two-component polyol, and isocyanate were provided by POLYBIT (UAE). Modified diphenylmethane-diisocyanate (MDI) with catalysts and surfactants (viscosity of 200 ± 40 cps at 25 °C with a specific gravity of 1.24 g/cm^3 at 25 °C) were mixed throwly with, polyol containing physical blowing agents (a viscosity of 450 ± 50 cps with a specific gravity of 1.14–1.18 g/cm^3 at 20 °C.) [21]. Polypropylene fibers were provided by Sika® Fiber (Turkey) with different length of 6 mm and 12 mm with a nominal fiber diameter 18 μm have a specific gravity of 0.91 g/cm^3 Table 1 shows the properties of polypropylene fibers as provided by the supplier [22]. Distilled water was prepared in our lab. as a chemical blowing agent to generate foams.

Table 1. Properties of polypropylene fibers [22].

Chemical Base	Water Absorption	Specific Gravity	Melt Point	Thermal Conductivity	Electrical Conductivity
% 100 polypropylene fibre	Nil	0.91 g/cm^3	160 °C	Low	Low

Table 1. Continued

Fiber Diameter	Specific Surface Area of Fibers	Acid Resistance	Alkali Resistance	Tensile Strength	Modulus of Elasticity
18 micron-nominal	250 m^2/kg	High	% 100	300 – 400 N/mm^2	4000 N/mm^2

2.2. Preparation of Composite Foams

The foam composites were produced by In-situ method using the closed-mold made from wood and lined with aluminum foil with core size of 220×90×60 mm^3 At first, all the components were weighing in weight percentage, wt% of each component was calculated based on the total weight of rigid polyurethane foam resin that is 96 g. The polyurethane rigid foam content prepared in combination ratio of 40:40:1 ml that is polyol: isocyanate: distilled water. In general, the production methods of the foam composites fabrication were polypropylene fibers placed into the mold. Then after polypropylene fibers covered with polyol and distilled water mixture, Then subsequently carefully mixed together for 60 sec. and then after isocyanate was poured to polyol and fiber mixture and stirred about 20 sec. Then immediately closed the mold before the foam is expanded out the mold. Foam composite was left for 24 hr. to reach curing . It released from the mold as shown in(figure 1). For pure rigid polyurethane foam produced by mixing the polyol, distilled water and isocyanate without any fibers addition.

Figure 1. Cast of Polyurethane foam with polypropylene fibers composite.

2.3 Foam Property Measurements

1. At least three samples were tested from perpendicular to foam rise, and the average values were reported.
2. Tests are applied according to ISO 4898 standard [23].
3. Densities of the samples are determined using ISO 845:2006 without removing skin surface[24].
4. Compressive strength, flexural strength, and flexural modulus were measured on Tinius Olsen universal testing machine model H100KU at a crosshead speed of 5 mm/min.
5. Compressive strength were determined according to ISO 844with specimen (50×50×50) mm^3 [25].
6. Three points bending tests were implemented according to ISO 1209-2 using the specimen cut from foam cast with dimension (150×60×30) mm^3 and a span of 100 mm [26].
7. The impact strength was determined using an HSM41 Charpy impact tester with a 25J pendulum hammer were tested according to ISO 179 [27].
8. Hardness test was implemented by using QualiTest HPE Digital Shore Durometer according to F1957 – 99 five readings were taken from different places from the composite foam cast [28].
9. The water absorption test was implemented according to ISO 2896:2001 by weight dry specimens 50 mm diameter and 5 mm thickness and then immerse the test specimens and hold them under the surface of the water by using a piece of wire gauze for 24 hr. then after specimens removed from the water and submerge in ethyl alcohol concentration 95 % for about 5 sec. then the specimens removed from the alcohol and air-dry for 5 ± min and weigh immediately [29].

10. Thermal conductivity was measured using Lee's Disk with specimens dimensions of 5 mm thickness and 40 mm diameter with applied voltage across the terminal of the heating coil is 6 V. And the current is 0.2 A.

3. Results and Discussion

3.1. Hardness test

The relationship between the hardness and the weight fraction and the fiber length on the composite material consisting of polyurethane foam reinforced with polypropylene fibers was shown in figure (2). The figure illustrates that the hardness improves with an increasing weight fraction of polypropylene fibers and approaches its maximum at selected experiment conditions(15 wt.%) with a value of 76.2 and 75.48 for 6 and 12 mm as compare to unmodified PUF with 66.4, the improvement were 14.8% and 13.7% for 6mm and 12mm fiber length respectively. The improvement in hardness by increasing the weight fraction can be described due to the hardness of the polymer which is the material's resistance to localized plastic deformation of the surface. Also, hardness is a function of the relation between modules and fiber loading of the composites, since polypropylene fibers rise the moduli of composites, as a result, hardness will increase with weight fraction increases, However, The addition of long polypropylene fibers to PUF lead to reducing the hardness of the composite as compared with short fiber due to the poor distribution of polypropylene long fibers in the resin during mixing resulted in reduction in the matrix consistency [30].

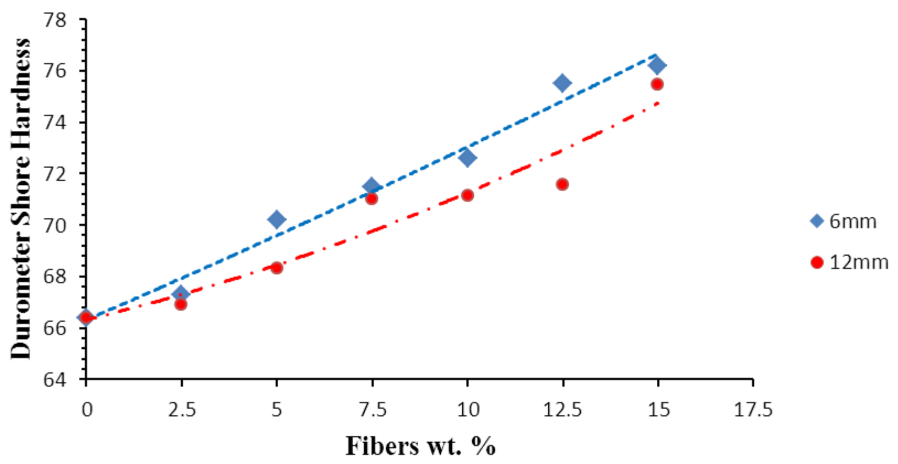


Figure 2. The effect of the weight fraction and fiber length of composite material consisting of polyurethane foam reinforced with polypropylene fibers on the hardness.

3.2. Flexural test

The flexural properties of polyurethane foam composites reinforced with polypropylene fibers at different fiber weight fraction and fiber length are shown in Fig. 3 and Fig. 4. Flexural strength and Flexural modulus were found to increase significantly as the polypropylene fiber weight fraction content increased as related to the neat foam and reach its maximum value for flexural modulus at 15% wt. and for flexural strength at 7.5% wt. the values vary between 1.267 MPa for 6mm PP. fiber and 1.447 MPa for 12mm as compare with 0.999 MPa for PUR with improvement of 27% and 45% for 6 and 12 mm PP. fiber length respectively. the improvement of flexural modulus (stiffness increases) of polypropylene foams composite can be described by the use of the rule of mixture, as the stiffnesses of the polypropylene fibers are higher(see table 1); the rule of mixture would predict the stiffness rises of polypropylene fiber-foam composites. The improvement of flexural strength of PP fiber/PUR foam composite can be accused from a creation of multiplied crack localities and/or multiplied crack branching due to the presence of microfibers within the polymer matrix that held the fracture processes in foam composites. Another reason for the flexural strength improvement of PP fiber/PUR foams is that the microfibers possess a higher specific surface area (see table 1) that promotes better adhesion(stronger interface) between PUR foam matrix and polypropylene fiber. Also, flexural modulus and strength increased with the increase in polypropylene fiber length in the composite. It points to that fiber length has an effect in the properties of PUR/PP fiber composites beyond fiber weight fraction. The 6mm polypropylene shows lower value as compared with 12mm fiber that may be related to the 6mm fibers are much shorter than the critical length so the failure of the composite take place after the separation(debonding) between fiber and matrix [31]. As a result, fiber cannot be increased to its failure stress and so cannot be broken. When the matrix failure finally occurs, the fiber simply slides out of the matrix, leaving behind an empty hole (see fig 11b.). When the content of polypropylene fiber reached above the 7.5% with The flexural strength decreases, these excessive fibers have an effect even incorporated between matrix and fiber, that reason for the failure of composites after 7.5% wt. is fiber fracture, void, weak bonding, fiber pull- out that appeared in the fracture surfaces [32].

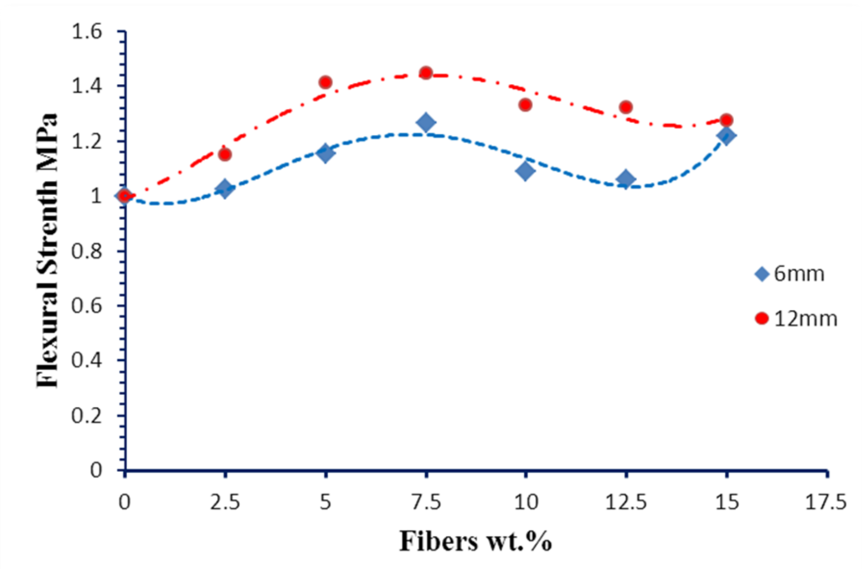


Figure 3. The effect of the weight fraction and fiber length of composite material consisting of polyurethane foam reinforced with polypropylene fibers on the flexural strength.

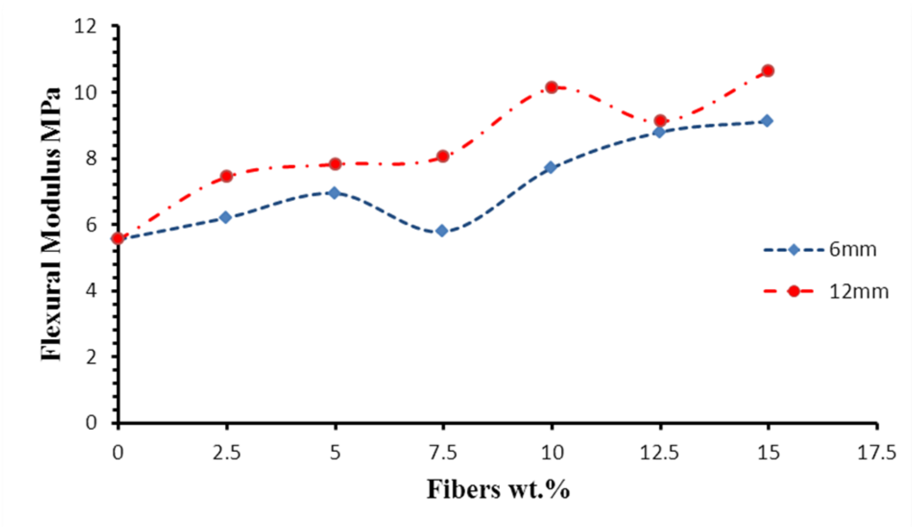


Figure 4. The effect of the weight fraction and fiber length of composite material consisting of polyurethane foam reinforced with polypropylene fibers on flexural modulus

3.3. Impact Test

The effects of fiber weight fraction content and fiber length on the impact strength of foam composites are plotted in Fig. 5. It can be seen that the impact strength of the composites increases with an increase in PP fiber content at 15 wt.% The enhancement in impact strength may be attributed to polypropylene microfibers which increase the fiber specific surface area as a result an enhanced interaction between fiber and matrix, and a strong bonding between the microfibers and the rigid polyurethane foam matrix. Consequently, enhanced stress transfer from the matrix to the microfibers as well as the dispersion of polypropylene microfibers throughout the PUR matrix, may resist the crack propagation by increasing energy dissipation from crack surface by acting as barriers and make crack path longer and that lead to the increases in impact strength as the wt.% of fiber increased. The figure also showed that the composite impact strength would better with rising fiber length, the rises in impact strength as fiber length increases are because of the increase in fiber pull out and fiber interface were long PP fibers can hold greater stress in the PUR matrix before breakdown as compared to the shorter fiber. The low impact strength of shorter fibers composites may be due to the presence of too many fiber ends within the composites (figure 11a.), which produce crack initiation. Furthermore, stresses are concentrated at regions round fiber ends, consequently, increase the possibility of the composite failure [31].

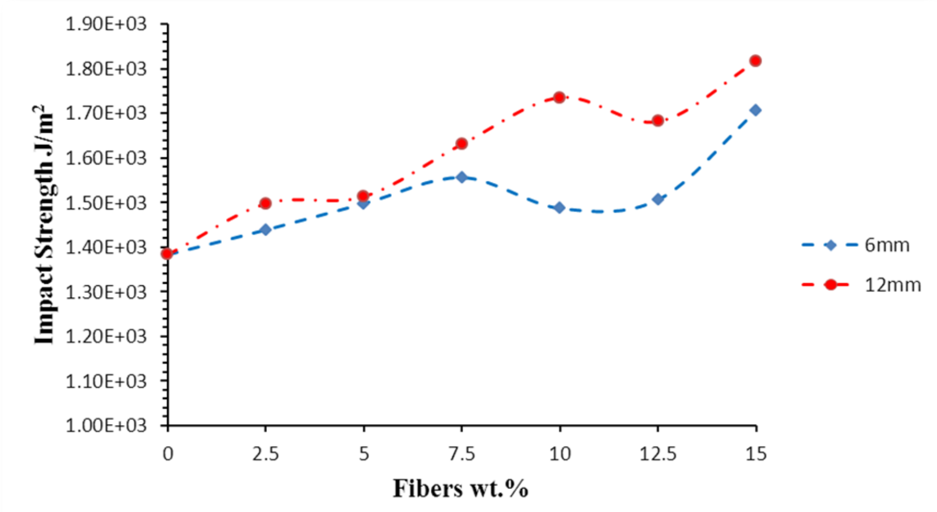


Figure 5. The effect of the weight fraction and fiber length of composite material consisting of polyurethane foam reinforced with polypropylene fibers on impact strength.

3.4. Compressive Test

The mechanical properties of rigid polyurethane foams are influenced by various factors, for example, the modifiers nature, apparent density and cell structure [16,33,34]. Compressive strength is a particularly important property of foams for the reason that they should remain dimensionally durable in the trade uses. Compressive strength at 10% deformation σ_{10} of reference material (PUR) modified with various weight fraction and different length of polypropylene fibers are compared in (Figure 6). This figure shows that the compression strength generally increases with fiber weight fraction this rise in σ_{10} can be related to increasing in the apparent density of rigid polyurethane foamed composites with an increase in polypropylene fibers content up to 5 wt.% upon addition of PP shorter fibers of the 6mm the compressive strength σ_{10} of the PUR foam increased by 26.5% with a value of 143 KPa, meanwhile the second type of 12mm PP fibers the compressive strength σ_{10} is increased by 39% with a value of 157 KPa. As compare with σ_{10} of reference material 113 KPa. but at wt.% content exceeding 5 wt.% the values of the composite are decrease, this reduction may be attributed to the moderately high amount of air bubbles trapped in the foams with a high content of fibers during mixing, subsequently, they had not sufficient time to take out to the surface due to high viscosity of the foamed polyurethane/PP. fiber mixture. The cause for the reduction in compressive strength 6 mm with compare with the addition of 12mm fibers may be related to that compressive strength of fiber composites is generally influenced by adhesion of the resin to the fibers and matrix stiffness. The character of the matrix is to maintain the fibers as strong column and inhibit them from buckling so as fiber length increase the amount of debonded fibers diminishes because the contact area and area of adhesion between long fibers to matrix increase. Therefore, in short fibers, the less-adhered fibers are debonded from the matrix quite easily.

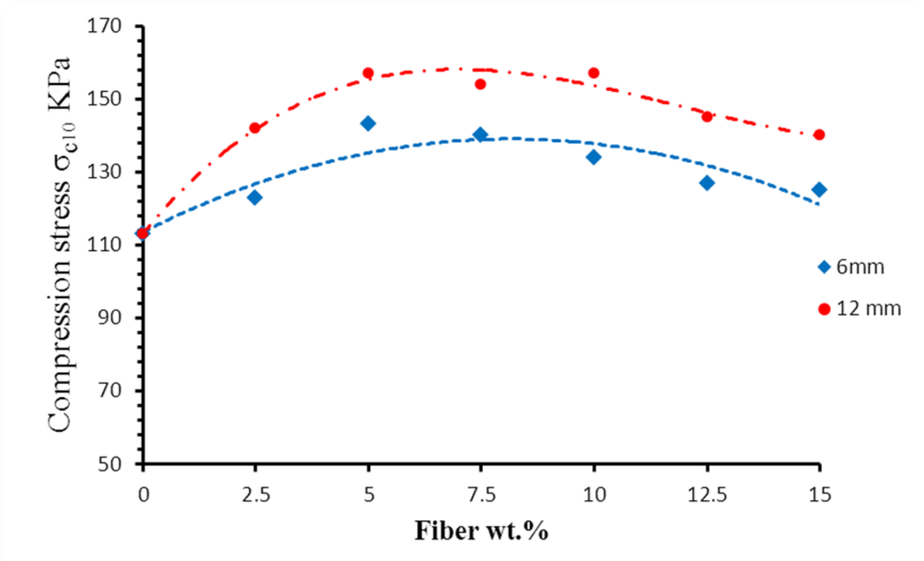


Figure 6. The compressive strength at 10% deformation versus the effect of the weight fraction and fiber length of composite material consisting of polyurethane foam reinforced with polypropylene fibers

3.5. Density

Figure 7 shows that the foam density increases with increasing polypropylene wt.%. This may be due to the addition of high-density polypropylene fiber as compared to rigid polyurethane foam and according to rule of mixture would predict the density intensifications of polypropylene fiber-foam composites, also, the PP microfiber increase viscosity during foam composite production so impedes the cells growth and thus leading to foam cell formation with smaller size, as a result, density are increased. The foam composite with 12 mm microfiber show slightly less dense as compared with 6 mm fiber that may be related to the longer fiber tendency to agglomerate and entangle during mixing and that lead to trapped gas bubble between fiber this is also exemplified from the void as shown in figure (11b) . In another hand when using 6mm polypropylene microfiber that lead to reduce foam expansion by producing bypass for the blowing gas that forming from PUR component reaction to dissipated from the matrix in another hand the blowing efficiency of rigid polyurethane foam with 6mm PP fiber is better and associate the foamability to create small cell nuclei and enhancing the constancy of the resultant composite foams.

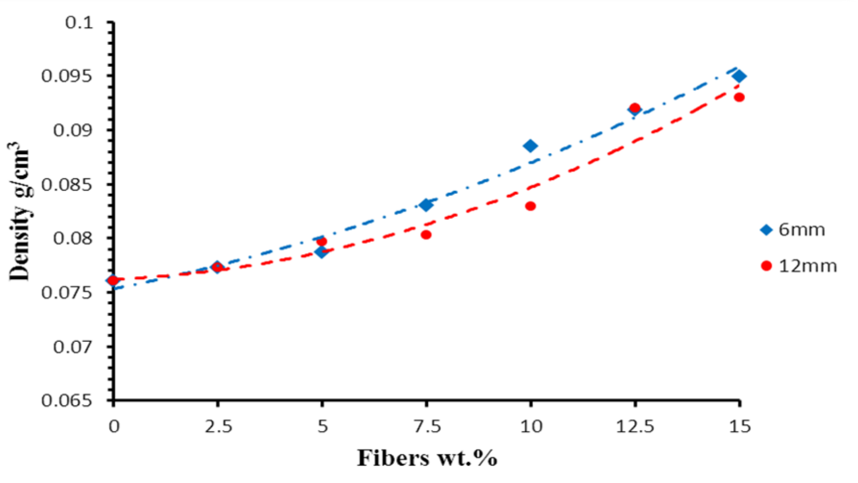


Figure 7. The density versus the weight fraction and fiber length of polyurethane foam reinforced with polypropylene fibers

3.6. Water Absorption Test

Figure 8 shows water absorption as a function of weight fraction for the different polypropylene fiber of 6 mm and 12 mm length of rigid polyurethane foam composites. The water absorption increased with the increased polypropylene fiber weight fraction. And reached to its maximum value at approximately at 12.5% wt. The an increase in water absorption of the foam can be related with the addition of wt.% polypropylene fibers since the cavities and voids in the foam matrix increases. generally the amount of water absorption of a cellular material essentially influenced by the cell structure of foam if it is open or closed and also on thickness of cell wall, and then slightly decrease at 15% wt. for both fiber length this decreases may be related to the polypropylene fiber for weak water absorb according to supplier (table 1). The foam composite with 6 mm microfiber show less water absorption as compared with 6 mm fiber that can be related to the 12 mm fiber are agglomerate and entangle during mixing and lead to increased trapped gas bubble between fibers and, in turn, lead to form void and increased open cell content in the resultant composite foam. Therefore, Composite with 12 mm is accommodated more amount of absorbed water

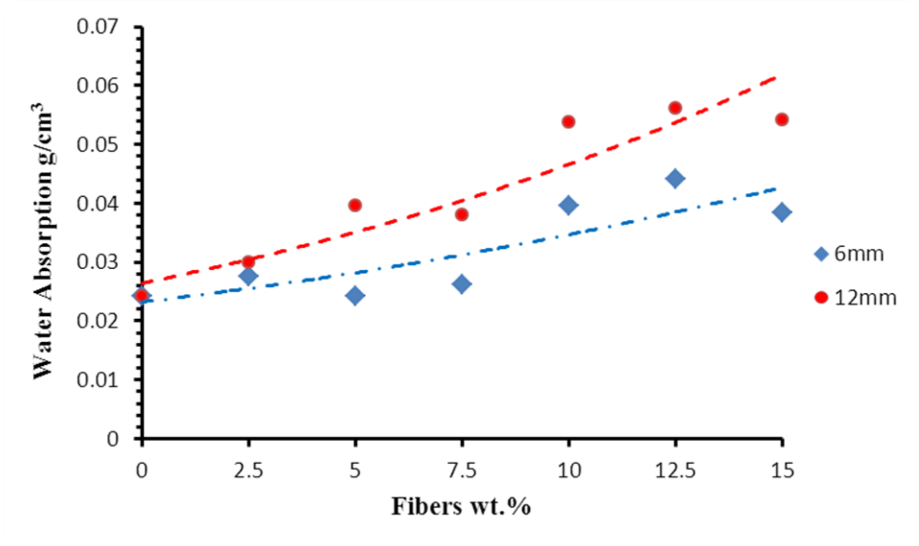


Figure 8. The water absorption versus the weight fraction and fiber length of polyurethane foam reinforced with polypropylene fibers.

3.7. Thermal conductivity test

The thermal insulation properties of materials are mostly expressed in terms of their k-factor, The insulating capacity increases as the k value decreases. The thermal conductivity can be defined as the amount of heat transfer across the unit area, through the unit thickness, for the unit temperature difference. Figure 9 shows thermal conductivity as a function of temperature for the different weight fraction of polypropylene fiber with 12 mm length in rigid polyurethane foam. Thermal conductivity curves for PUR composites with 6 mm fiber lengths are not revealed for the reason that they are practically superimposed with L=12 mm curves. The figure revealed that the thermal conductivity of rigid polyurethane foam is decreased as the weight fraction of polypropylene fiber increases, this decreases can be related to that low conductivity of polymeric fiber because in general all polymer materials have low thermal conductivity another reason, that the distortions in the matrix by adding PP. fiber that leads to increasing the ratio of closed cell content, as a result, decreases the thermal conductivity. The slight rise in 2.5 %wt. and 5 %wt. after 35°C can be related to the influence of density effect on the thermal conductivity of rigid PUF. In general, the thermal conductivity of PUF depends on the foam density, cell orientation, cell size and ratio of close to open cell content and on the thermal conductivity of the gasses (blowing agent), and filling materials.

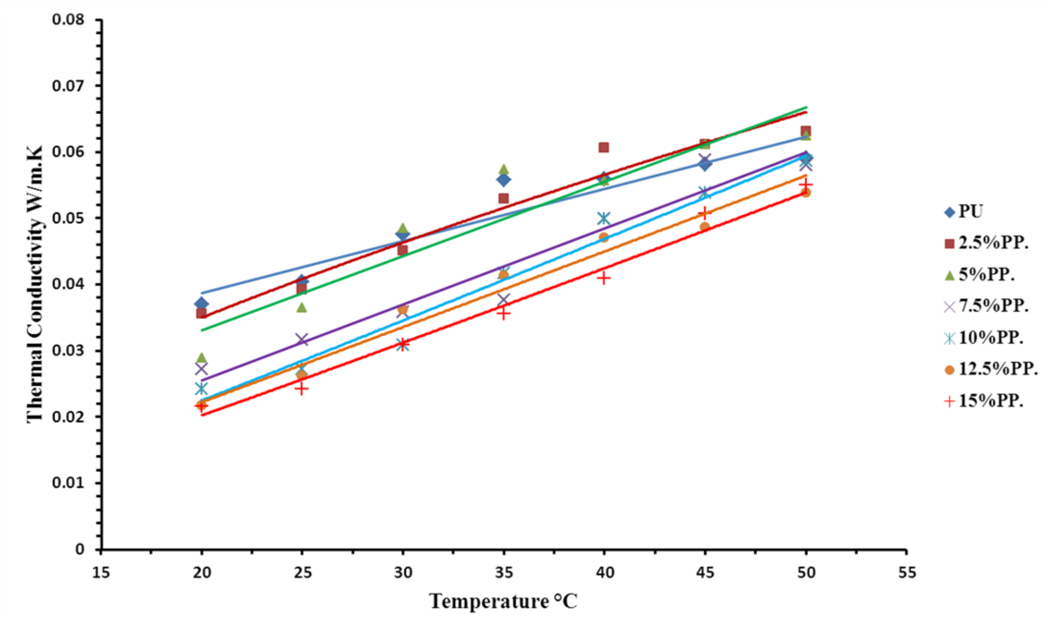
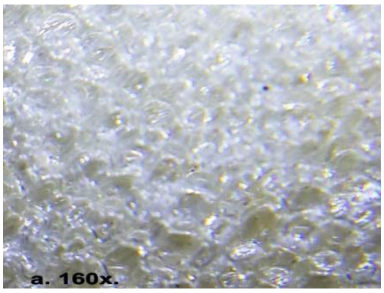
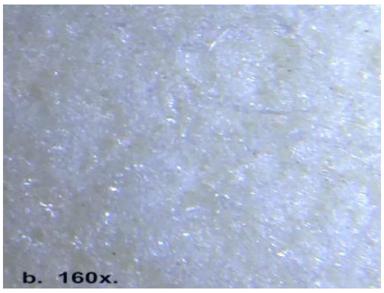


Figure 9. The thermal conductivity of % wt. polypropylene short fiber in rigid polyurethane foam at a different temperature

3.8 Macroscopic and SEM Morphology Examination

Figure 10 present macroscopic of rigid polyurethane foam with weight fraction (2.5% to 15%) of polypropylene fiber. Adding fibers to PUF makes the cells structure finer and the cell sizes become non-uniform (formless). Including 2.5-5% polypropylene fiber does not damage the PU foam structure, but till 7.5% polypropylene fiber, the cell structure is deformed. The fracture surfaces of the polypropylene fiber reinforced rigid polyurethane foam composites with selected weight fraction (7.5%, 10% and 15%) have been located under SEM and are shown in Figures 11. According to the SEM morphology the predominated in the fracture surfaces, fiber pull-out, fiber fracture, fibre-debonding, and matrix fracture, void, and matrix reach area, are observed after the impact test of selected composites. In fact, fiber breakage, fiber pull-out, fibre-debonding, such strengthening mechanisms increased the fracture properties of rigid polyurethane samples reinforced with polypropylene fibers. The cells around the polypropylene microfibers are mostly small, indicating that the fiber is hinder cell growth by hindered physically bubble rise and growth





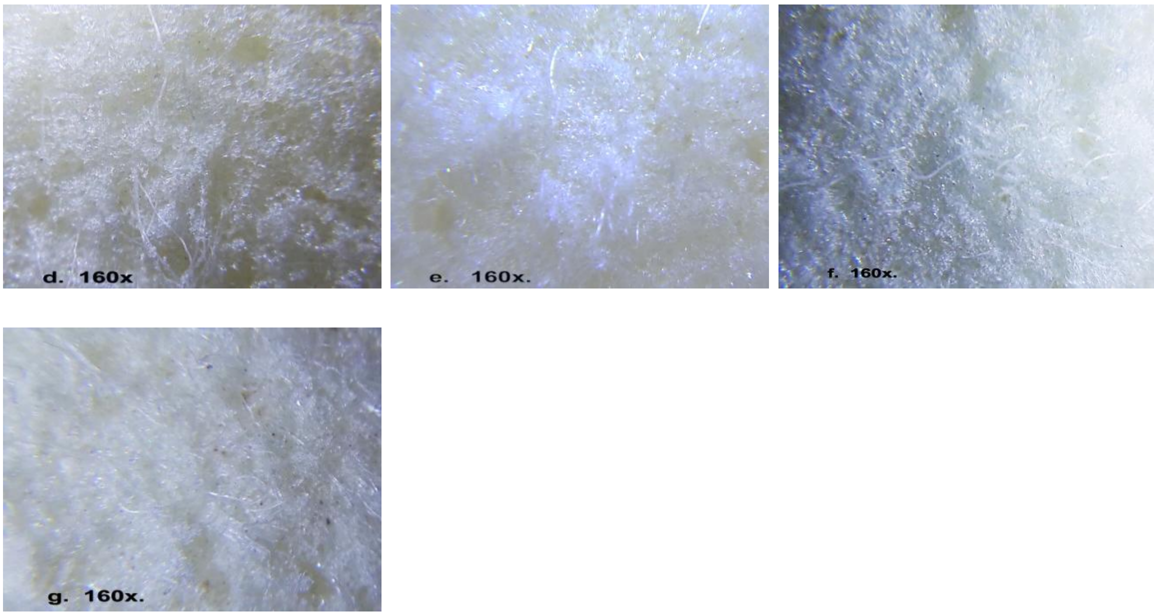
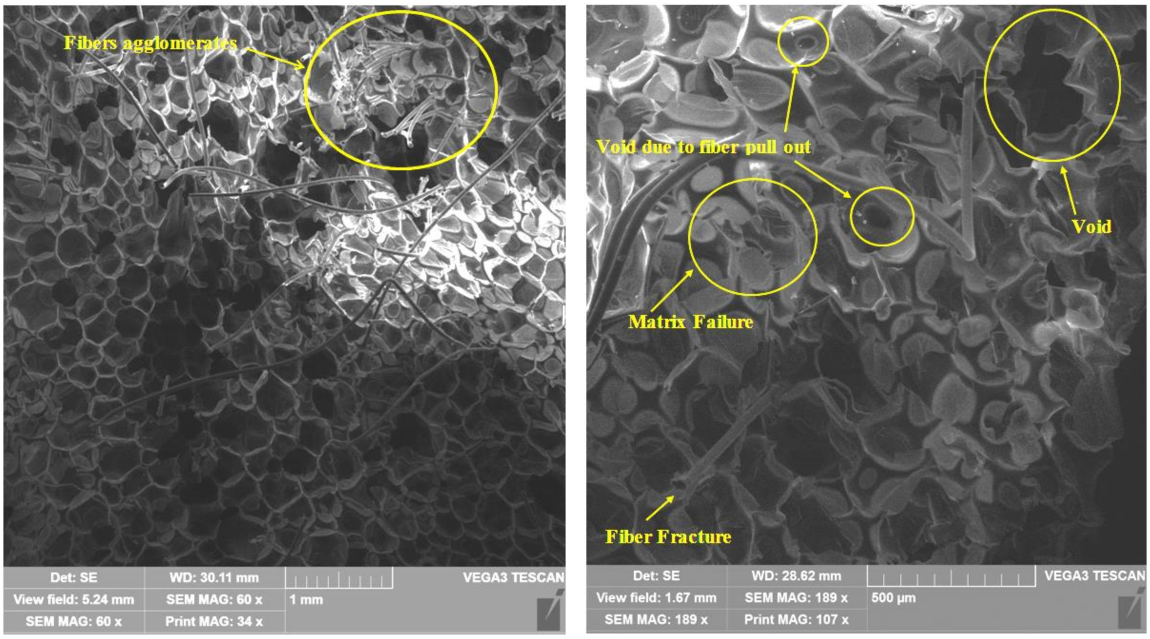
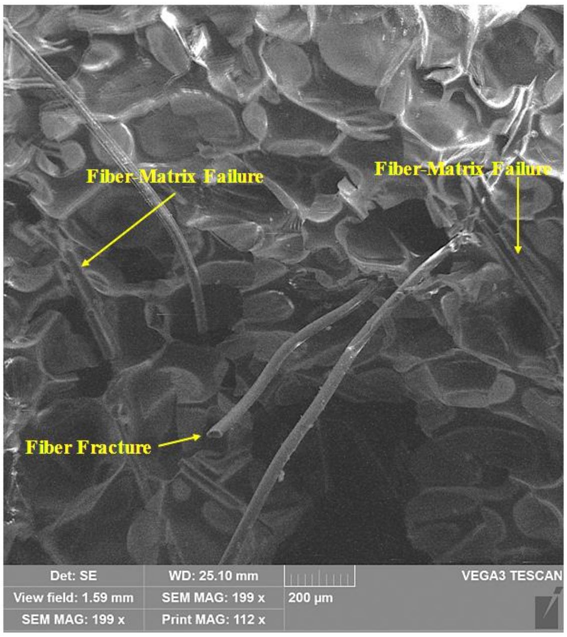


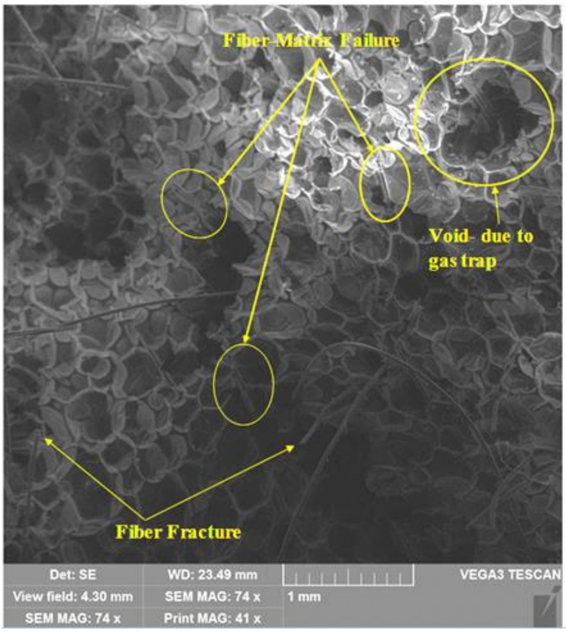
Figure 10: macroscopic image of cross section PUR foam - polypropylene fiber composite (a. PURF , b. 2.5%PP, c. 5%PP, d. 7.5%PP, e. 10%PP, f. 12.5%PP, g.15%PP)



(a) *(b)*

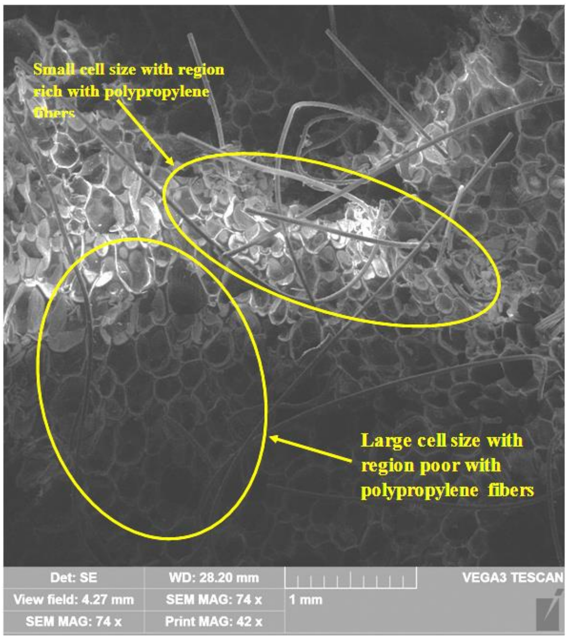


(c)



(d)

(e)



(f)

Figure 11: SEM image of impact test for selected sample of rigid polyurethane foam with polypropylene fiber composite 6mm (a. 7.5%PP;b. 7.5%PP; c. 10%PP) and 12 mm (d. 10%PP e.12.5%PP; f.15%PP)

4. Conclusion

Polypropylene Short fibers reinforced rigid polyurethane foam composites have been examined with different wt.% Fiber content and fiber length the following conclusion were noticed.

1. The characterization of the composites reveals that the wt.% fiber content and also fiber length is having a noticeable effect on the mechanical properties of composites, physical properties are noteworthy affected by fiber content as compared with fiber length.
2. It has been noticed that the properties of the foam composites such as hardness, flexural strength, flexural modulus, compression strength, and impact strength density, water absorption of the composites are significant increases when compared to neat rigid polyurethane foam except thermal conductivity are decreased with addition of polypropylene fiber. This notable enhancement is as a result of the distinctive properties of polypropylene fiber.
3. The current study showed that 15%wt. PP. fiber content shows higher hardness, and impact strength. Whereas, for flexural strength and compression strength show better in 7.5% and 5% wt. of fiber content respectively.
4. The effect of two fiber length on mechanical and physical properties of foam composites is, fiber length of 6mm shows higher density and hardness, conversely, flexural strength, flexural modulus, compression strength impact strength, and water absorption shows enhanced in fiber length of 12mm. on the other hand thermal conductivity in generally less affected by fiber length.
5. SEM micrographs illustration a strengthen mechanisms which include fiber-matrix failure, fiber fracture, fiber pullout, and matrix fracture. These strengthen mechanisms are the main factors that enhanced mechanical properties of polypropylene fibers-reinforced rigid polyurethane foam composites.
6. SEM micrographs also illustration matrix distortions which include void ,cell size reduction, fiber agglomerates these may be the main factors that have an effect on density, water absorption, and thermal conductivity.

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