Evaluation Mechanical Properties of Polymer Composites Reinforced by different Metal Powders

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Abstract

This research covers reinforcement of unsaturated polyester resin by metal powders, and studying some of their mechanical properties. The samples were prepared by hand lay-out technique. The unsaturated polyester resin was reinforced by two types of metal powders Copper (15.598 µm) and aluminum (21.533µm) at selected volume fraction of (0, 5, 10. 15, 20 and 25 %). The study of mechanical properties includes tensile properties (strength at fracture point, elastic modulus and elongation at at break), flexural strength and flexural modulus, impact properties and hardness. The results show a noticeable increase in values of tensile strength at fracture point and tensile modules of elasticity, as the volume fraction of metal powder increase and reach to maximum value at 15 % volume ratio for both types, where as flexural strength, flexural modulus and fracture toughness reach to maximum value at 10 %volume ratio for both types composites, however elongation at break shows decrement as the volume fraction of metal powder is increased for both types composites.

Key words: composites, mechanical properties, metal reinforcement.

تخمين الخواص الميكانيكية للمتراكبات بوليمريه المقواة بمساحيق معدنية مختلفة

الخلاصة

يتضمن هذا البحث تقوية راتنجات البوليستر غير المشبعة بمساحيق معدنيه، ودراسة بعض خصائصها الميكانيكية. تم إعداد العينات بالتقنية اليدوية. وقد تمت تقوية البوليستر غير المشبع بواسطة مجموعتين من مساحيق المعدنيه (النحاس و آالامنيوم) (21.533،15.598 مايكرون)على التوالي. بكسور حجميه مختاره (0، 5، 10 ،15 ، 20 and 25%) وتشتمل دراسة الخواص الميكانيكية خصائص الشد (الاجهاد عند نقطة الانهيار، ومعامل مرونة والمطيلية) واجهاد الانحناء ومعامل مرونة الانحناء ، وخصائص الصدمة والصلادة. أظهرت النتائج زيادة ملحوظة في قيم إجهاد الشد عند نقطة الكسر ومعامل المرونة

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بزيادة الكسر الحجمي للمساحيق المعدنيه ووصلت إلى أقصى قيمة عند النسبة 15% لكلتا المجموعتين. بينما قيم مقاومة الانثناء ومعامل الانثناء ومتانة الكسر ووصلت إلى أقصى قيمها عند النسبة 10% لكلتا المجموعتين. في حين أنخفضت قيم المطيليه عند نقطة الكسر بزيادة الكسر الحجمي للمساحيق المعدنيه ولكلتا المجموعتين.

INTRODUCTION

The concept of composites was not invented by human beings, it is found in nature. An example is wood, which is a composite of cellulose fibers in a matrix of natural glue called lignin. Husks or straws mixed with clay have been used to build houses for several hundred years. Mixing husk or sawdust in a clay is an example of a particulate composite. These reinforcements are done to improve performance [1, 2]. A composite material is made by combining two or more materials to give a unique combination and superior properties that cannot be met by conventional monolithic materials, such as metal and its alloys, ceramics, and polymers. Composites may have different properties that its constituents do not possess [1, 3,4]. It was reported that the properties of composite materials depend on size and shape of particles, particles surface area, physical properties of particles, volume fraction of reinforcement materials in the composites and adhesion force between matrix and metal particles [5-10]. Alaa A. Abdul-Hamead et.al studied composite material properties of polyester material reinforced with iron weave wires with percentage (5,10,15 and 20). And concluded that most physical properties have been improved and the values increased with reinforcement content [11]. C.S. Obayi et,al investigated tensile behavior of polyester reinforced with petroleum-based carbon black (CB) Nano particles with 1 to 11% V_f .Results showed that mechanical properties including ultimate tensile strength, elongation and area under the curve (i.e toughness) improved as V_f of carbon black increased from until 5% and the maximum values was at 5%. While modulus of elasticity showed constant behavior from 1% to 5% but increased as volume fractions increased from 7% to 11%[12]. And other studies it was found changes in mechanical behavior of the samples and their effects on electrical resistivity which can be so effective to choose the proper composite as the collecting plate in electro static precipitators [14].The objective of this research is to assess the mechanical properties of two different polymer composites reinforced by metal powders (Cu and Al).

Material and Experimental Procedure

In this research unsaturated polyester resin has been used, provided from Gulf Chemicals and Industrial Oils Company- Saudi Arabia), this type has density 1.12 g/cm^3 and maximum work temperature 170 ºC. Powder fillers that used were copper supplied from (Himidia Company, India), The Atomic weight (63.55), Minimum Assay (99.7), and maximum limits of impurities as follows (Iron (Fe) = 0.005%, Lead (pb) = 0.01% , Arsenic (As) = 0.0001% Manganese (Mn) = 0.001%) and aluminum powder electrolytic particles supplied from (Angang Group Aluminum Powder Co., Ltd, china) with Purity: 99.75%-99.995% , Fe<0.08%, Si<0.08% 4, Water<0.02% , Figures (1 and 2) show localized chemical analysis and standard of Cu and Al powders by Energy dispersive x-ray analysis (EDX).

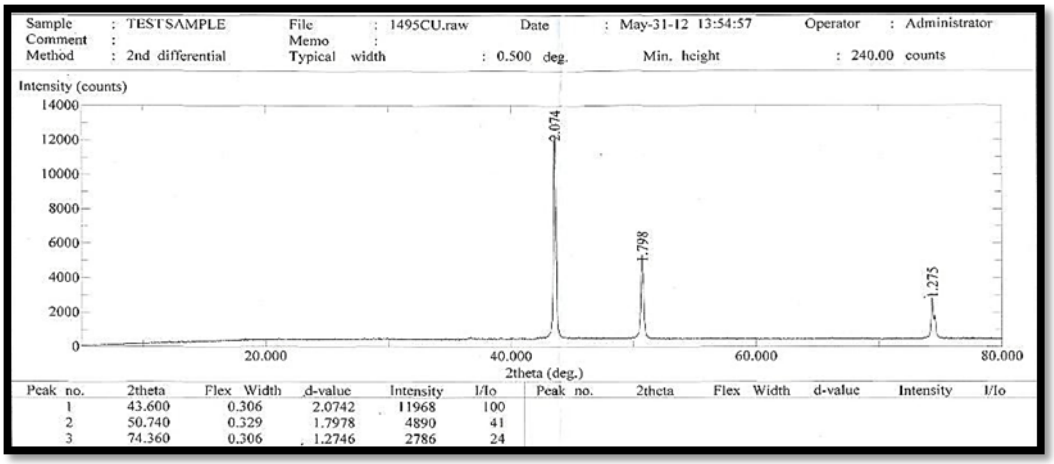


Figure (1) Localized chemical analysis for Cu powder by EDX.

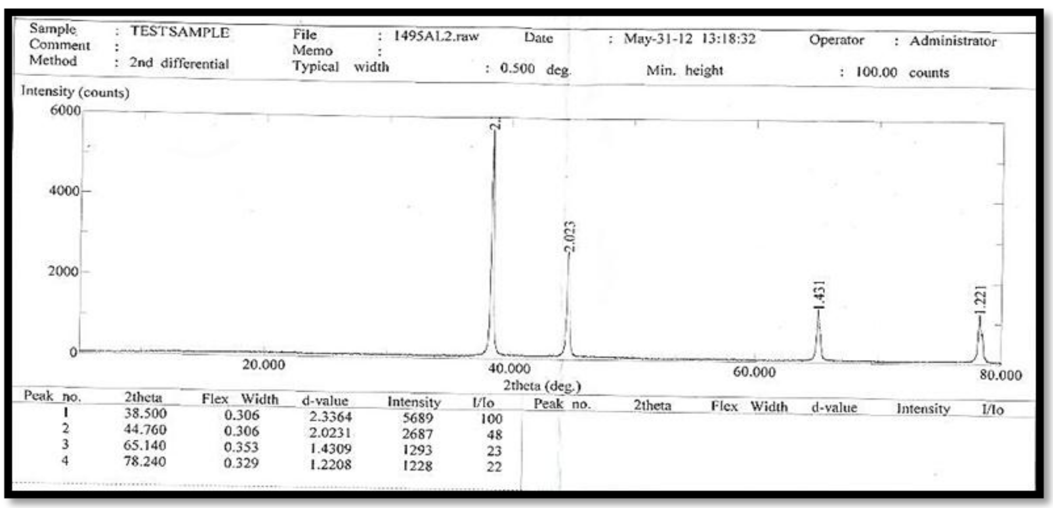


Figure (2) Localized chemical analysis for Al powder by EDX.

Particle size distribution of Al and Cu powders was carried out using laser diffraction particle size analyzer type (SHIMADZCE SAID-2101) in Science and Technology ministry/Baghdad. The results of particle size distribution of Al and Cu are shown in Figures (3 and 4) respectively. The mean diameter was (11.533μm) for Al and for Cu (15.598μm).

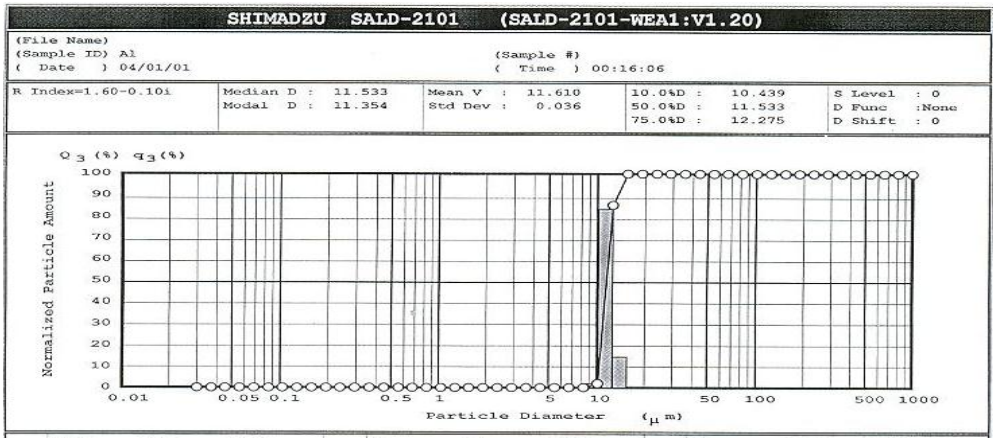


Figure (3) Particle size analysis of Al powder.

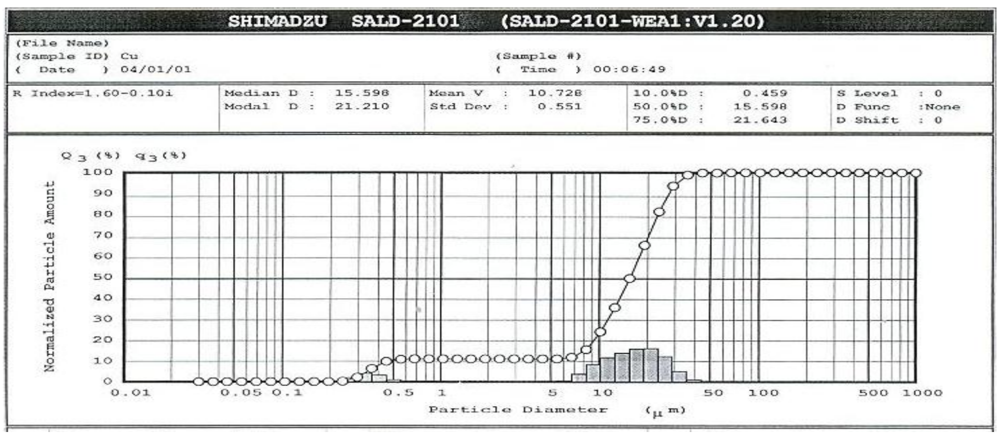


Figure (4) Particle size analysis of Cu powder.

Preparation of polymer composites

Hand lay-out technique was used to prepare the composite materials. Glass mold which have the dimensions of (35cm×35cm×5mm) used to prepare the samples. Metal powders were thoroughly mixed with unsaturated polyester resin by different loading (0, 5, 10. 15, 20 and 25 %) in terms of volume fraction, by using ultrasonic mixing device for this purpose, for at least half an hour to insurance riddance of pores, then the mixture was poured into the mould and allowed to cure for 48h at room temperature (27°C). All the specimens were then post cured in an oven at 50°C for 3h then the sheets were cut off and machined according to standard specifications to produce samples conforming for mechanical properties test.

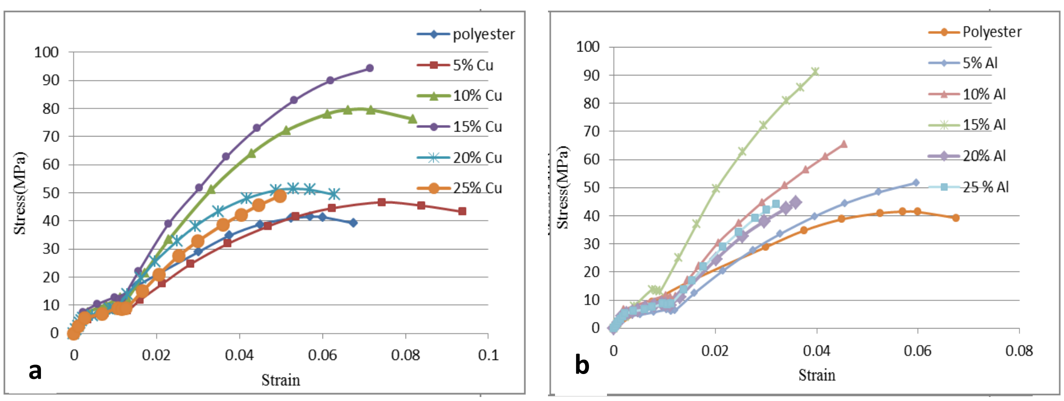
Mechanical test

Samples were prepared for the tensile test in accordance with ASTM D 638-87[15]. A computerized universal testing machine model (WDW-200D Jinan Shijin Group company-china) was used to conduct a test at a constant cross head speed of the order 2 mm/min. Tensile load was applied till the failure of the sample and stress -strain curve was obtained.. Impact test is performed according to ASTM ISO 179[15]. Izod / charpy tension impact (measurement test machines Inc, Amityville-New York). Bending modulus measured from three point test, this test is performed according to ASTM D-790-78 [16] at room temperature. Hardness test carried out on a Durometer shore D scale according to ASTM D-570[15-16]. All were carried out at room temperature (23 ± 2)˚C. Five specimens were used for most tests and final results represent the average. Optical microscope has been used to study the structure of samples.

Results and discussion:-

Tensile test characteristics

Tensile test results Figure (5 a) of unsaturated polyester composite reinforced by Cu particles shows that the stress-strain curve behavior changed from (soft and weak) for plain polymer to (strong and tough) when the volume fraction of Cu powder reach to 15 % in the composite material, then the behavior take back to (soft and weak) but still have higher tensile values as compared with unsaturated polyester. While when unsaturated polyester reinforced by Al particles Figure (5b) the behavior was changed from (soft and weak) to (hard and strong) when the volume fraction of Al powder reach to 15 % in the composite material, then the behavior take back to (soft and weak) at the ratio larger than 15 % of Al powder in the composite, but still have higher tensile values as compared with unsaturated polyester before reinforcement with A1 powder. These result related to Cu and Al powders which gives more ability to resist tensile stress.



Figure(5) The stress-strain curves of unsaturated polyester composites as function of particles content in the composite (a) of Cu and (b) of Al.

To compare the effect of metal powders (Cu and Al) addition with the same ratio (15 V_f%) on the stress-strain curves of unsaturated polyester composites are shown in Figure (6). There was significant change occurs in stress-strain behavior for each type of unsaturated polyester composite. As it mentioned in the above the behavior was changed from (soft and weak) for plain polymer, to (hard and tough) for unsaturated polyester resin and composite reinforced by Cu particles, and the behavior changed to (hard and strong) when polyester reinforced by Al particles.

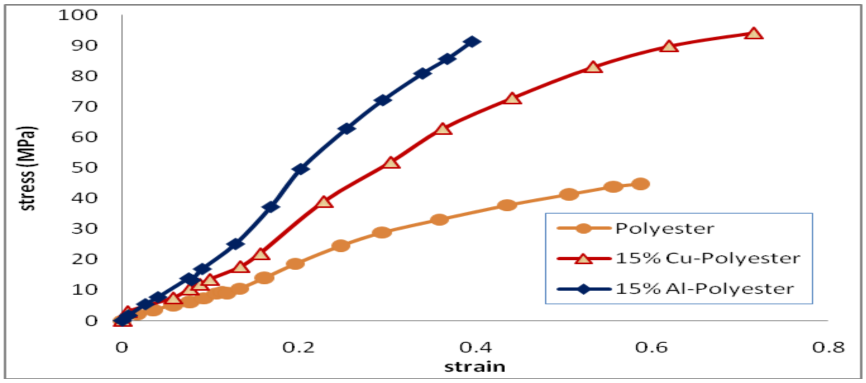


Figure (6) The (stress-strain) of unsaturated polyester and composites reinforced with the same ratio (15% V_f) of Al and Cu.

The tensile characteristics, which include tensile strength (σ) and Young modulus (E) and elongation (ε), are shown in Figures (7, 8 and 9) respectively. It can be noticed from Figures (7 and8) that there was an increase in tensile strength and Young modulus properties with the increase in the volume fraction of Cu or Al powders in the two types of composites until the volume fraction reach to 15% then these values decrease with the increase of Cu or Al powder into the two groups of composites until reaching to 20 % then these values become almost stable, with the increase ratios of metal powder (Cu or Al) in composite, except the Young modulus values for the composites decreased with an increase in Cu powder larger than 15% V_f in the composite content. The increase in tensile stress and Young modulus values may be related to the nature of Cu & Al micro particles which work as nucleus to increase the crosslinking, as well as these micro particles are dispersed and embedded into the polymer matrix, and then filled the open structure of the amorphous crosslink structure. Furthermore, it can be observed from Figures (7 and 8), that the tensile stress at break and young modulus values of the polyester composite which was reinforced by Cu powder, slightly higher than thus values of polyester resin reinforced by Al powder, and that may be related to the nature of Cu metal, which have higher mechanical properties than Al metal [16]. Whereas the effect of addition Cu and Al powder on the elongation values of the polymer composites shown in Figure (9). It can be noticed that the elongation values decreases when added aluminum powder to the unsaturated polyester, and the elongation values decreases with increasing of aluminum powder content in composites samples. But the elongation values was increased when adding Cu powder to the unsaturated polyester , until reach to 5% volume fraction , then the elongation decreases with an increase in Cu content in composites. These tensile properties may be due to different in the natural between these particles, in size , shape, density, the bonding force between particles and cross linking polymer and the nature of interface between each type of metal particles and thermosetting polymer [5-10].

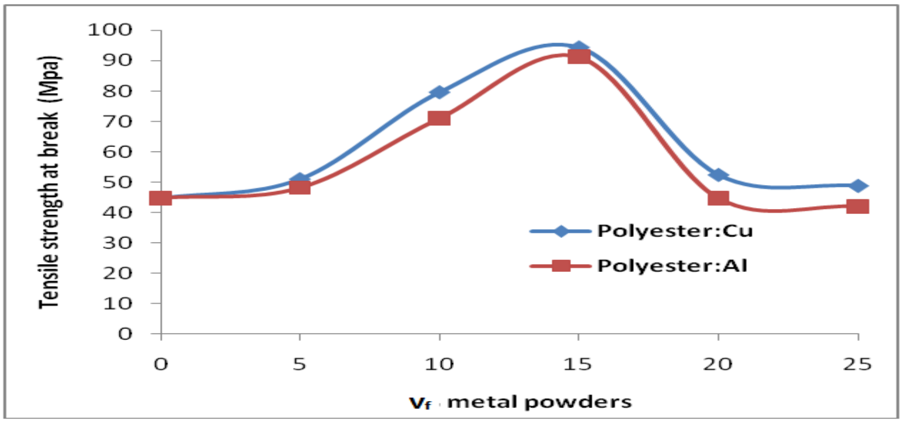


Figure (7) Tensile strength at break of polyester composites as a function of metal powders (Cu and Al) content in composites.

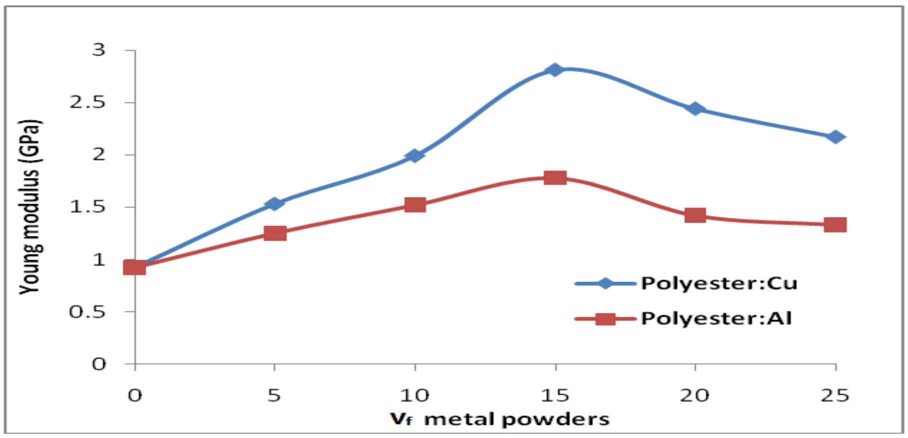


Figure (8) Young modulus of polyester composites as a function of metal powder (Cu and Al) content in composites.

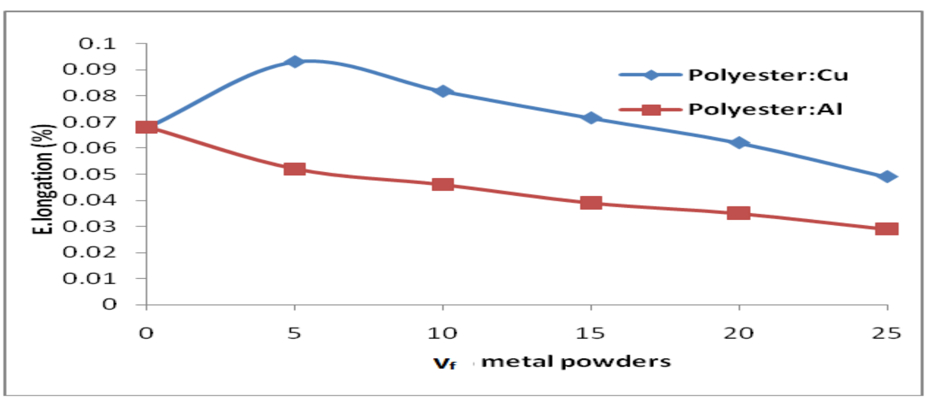


Figure (9) The elongation at break of polyester composites as a function of metal powder (Cu and Al) content in composites

Bending test characteristics

Bending characteristics, which include flexural strength and flexural modulus, are shown in Figures. (10, 11). It has been noticed from these figures, that there was an increase in flexural strength and flexural modulus values with the increase in the volume fraction ratio of Cu or Al powders in the two types of composites until the ratio reach to 10% ratio then these values decrease with the increase of Cu or Al powder into the two groups of composites until the ratio reach to 20 %, then these values become almost stable with the increase ratios of metal powder (Cu or Al) in composite. Except the flexural modulus values for the composites which have Al powder, increases slightly with increasing aluminum content in composite as shown in Fig. (11), these behaviors related to the same reasons mentioned in the above [5-10].

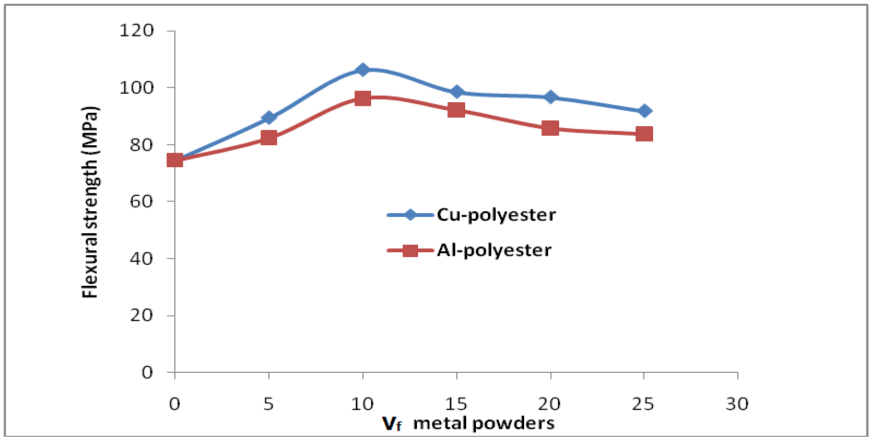


Figure (10) The flexural strength of polyester composites as a function of a metal powders ccontent in composites.

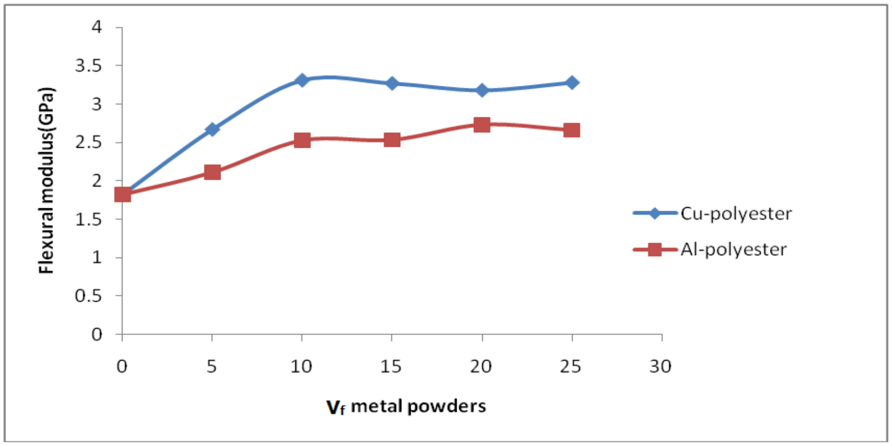


Figure (11) flexural modulus of polyester composites as a function of metal powders content in composite.

Impact results

The effect of adding metal powders, on impact strength (G_C) and fracture toughness (K_C) of unsaturated polyester composites, are show in Figures (12 and 13) respectively. It has been observed from Fig. (12) that the impact strength for both groups of polymer composites increases with adding of (Cu & Al) powders in unsaturated polyester composites until to reach to the volume fraction (5%) and then decreased as metal particles volume fraction increased in the composite.

Also it has been observed from Fig. (13) that the fracture toughness, for both groups of polymer composites increases with increasing of (Cu & Al) powders in unsaturated polyester composites until to reach to the (10%) volume fraction and then decreased as metal particles volume fraction increased in the composite, but remain higher than they are in the parent polyester material.

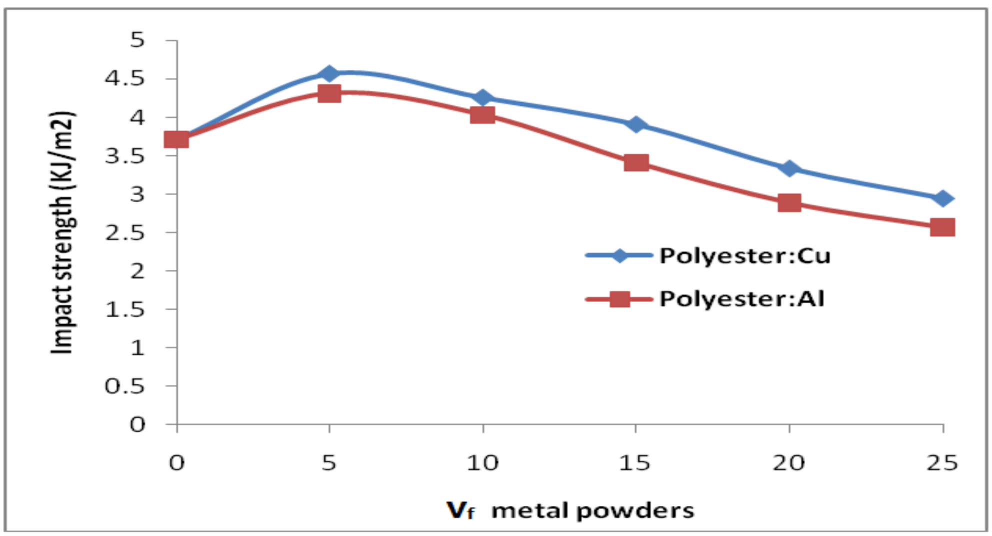


Figure (12) Impact strength of polyester composites as a function of metal powders content in composites.

And also it has been found that the impact strength and fracture toughness values of first type of composites which reinforced by (Cu) higher than values of the second type of polyester composites which were reinforced by Al powder and that related to natural of metal particles Cu and Al, size, shapes of the metal powders and particles distribution, volume fraction of reinforcement materials in the composites and adhesion force between matrix and metal particles in the prepared composites [5-7]

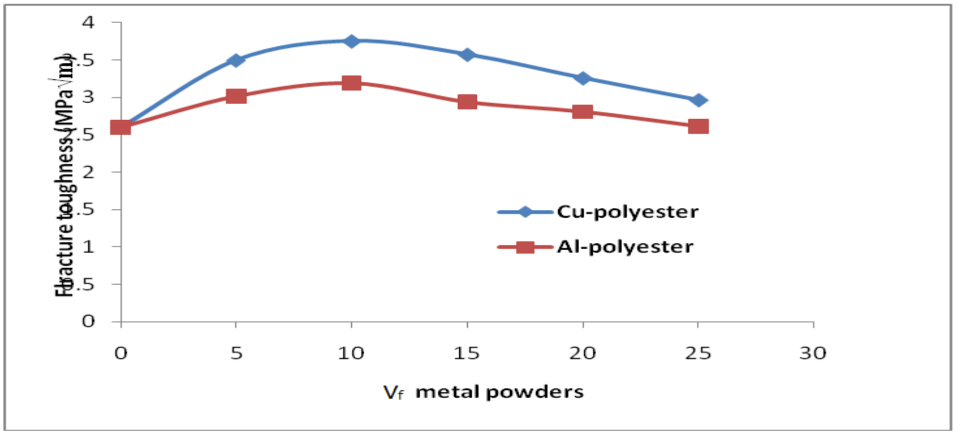


Figure (13) Fracture toughness of polyester composites as a function of metal powders content in composite.

Hardness results

Shore D Hardness of unsaturated polyester resin and its composites are shown in the Fig.(14). It has been found that the hardness values increase with the increasing of Cu or Al particles content in the polymer composite and from this figure it was observed that there was an increasing in hardness values as Cu or Al particles increase in polymer matrix until reach to 15% V_f and then become semi- stable as the metal particles increase in the polymer composite, the increase in hardness value may be related to the nature of Cu and Al micro particles which work as nucleus to increase the crosslinking as well as this micro particles are dispersed and embedded into the polymer matrix and then filled the open structure as the amorphous crosslink structure [7-9]. Furthermore, hardness values of the second type of polyester composite reinforced by Al particles were slightly higher than hardness values of composites reinforced by Cu particles and that related to the particles size of Al particles which are smaller than Cu particles.

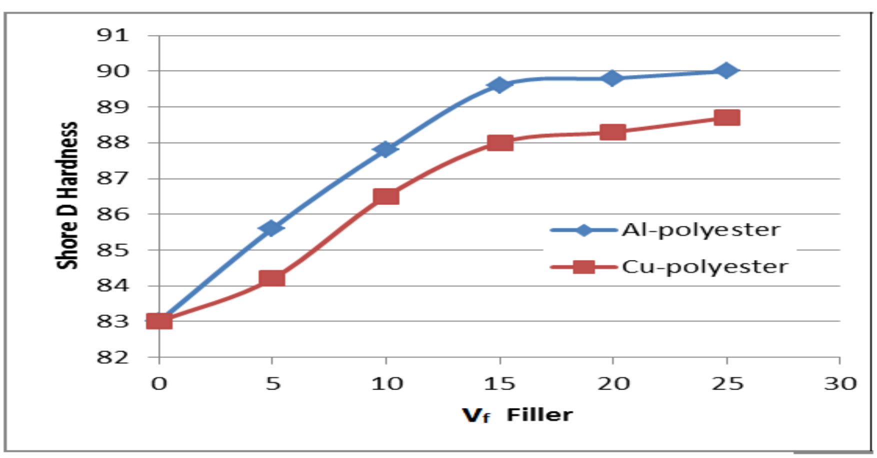


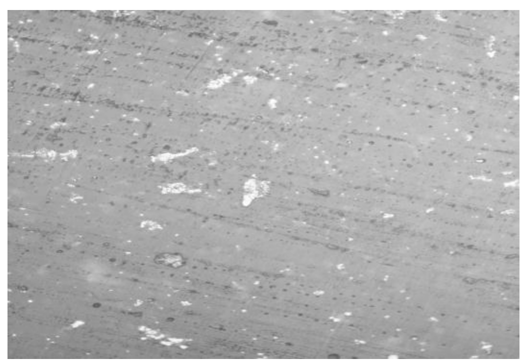
Figure (14) Shore D hardness of polymer composites as function of of metal powder content.

Morphology

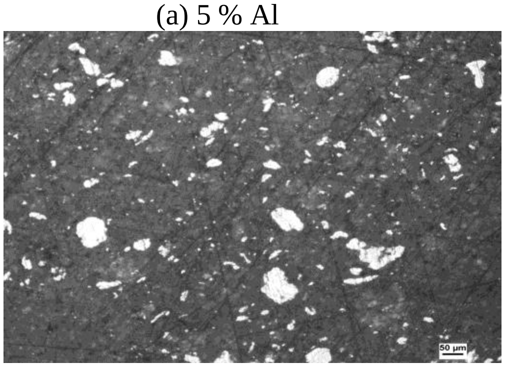
The effect of addition of the metal powders on the surface morphology for unsaturated polyester composites are shown in Figures (15a, b, c, d, e and f).

From the microscopy imaging it was shown there are a difference on the surface morphology of the composites samples which is depends on the type and content of metal powders in composites. For comparison, surface morphology clearly show that there are difference in the morphology of polyester composite reinforced by aluminum particles (Fig. 15 a ,c, and e) and composite reinforced with copper particles (Fg 15 b, d and f). Also the morphological results clearly show that the polyester matrix which was reinforced with the different ratios of metal particles for two groups powders, depends upon the nature, size and the distribution of the reinforcement particles. However, it can be observed that from the microscopy imaging Figures (15), there are homogeneous distribution of metal particles in the matrix, as well as good bonding between the metal particles and the matrix, and that returns to the adhesion force between matrix and metal particles, size and shape of particles, particles surface area, physical properties of particles, the bonds direction which depends on crosslinking network of polymer and volume fraction of metal powder in the composites samples [6-9].As well as from micrographs it has been observed that the concentration of particles in the matrix increase with increasing volume fraction ratio of metal powder for both type of composites, the number of particles per unit area and the agglomeration in Al composite is more than Cu composite at the same ratio, because of different density between these metals, the density of Cu is higher than Al which leads to difference in volume fraction at the same weight.

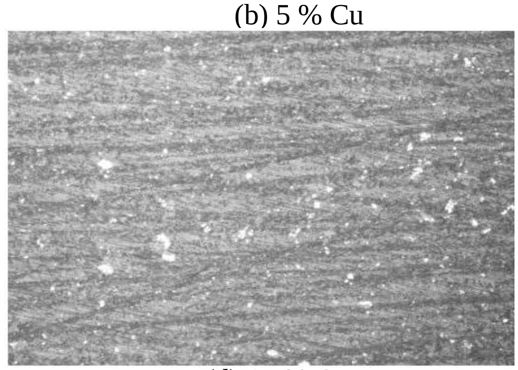
(a) 5 % Al



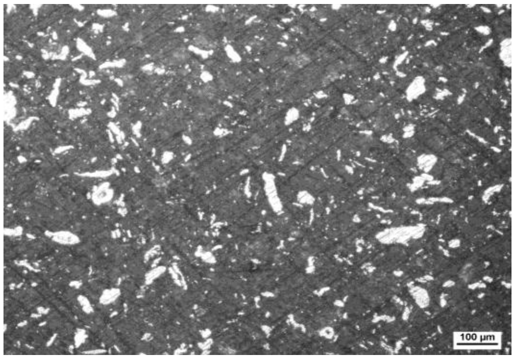
(b) 5 % Cu



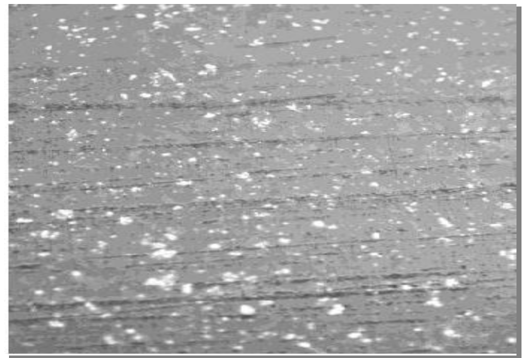
(c) 15 % Al



(d) 15 % Cu



(e) 25 % Al



(f) 25 % Cu

Figure (15) Optical photographs for unsaturated polyester reinforced with Aluminum particles (a, c and e) and copper particles (b, d and f) at different ratios (5%, !5 % and 25%) respectively (200 X).

Conclusion

In the present work using the inorganic fillers as the metal powders viz. Cu and Al particles added to the unsaturated polyester, an attempt to improve mechanical properties and it has been concluded the following items:

1- The mechanical properties of the composite were found to be a function of the particles, size, the dispersion and the interfacial interaction between the minerals and the polymer matrix.

2- There is a significant increment in the tensile strength and modulus with an increase in the filler concentration (Cu and Al particles) to 15% of volume fraction.

3- Decreased in the impact strength when the concentration of filler reach to higher than 5% and that reduction of elasticity of material and thereby reducing the deformability of matrix.

4- Morphological studies showed that there is a good interaction between the metal particles and the matrix. The agglomeration increases with increasing volume fraction for each type of composites, but the agglomeration in Al composite is higher than Cu.

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