The Effect of Adding Alumina Phases (alpha and amorphous) to Improve the Mechanical Properties (Compressive Strength and Hardness) of Polyester Matrix Composites

Asst. Lecturer Hanaa Dakhel Ahmed
Institute of Applied Art

Asst. Lecturer Manal Flayeh Hasan
Technical Engineering/ Baghdad

Abstract :-

In this research work a polyester composite material was prepared contains a matrix which is a polyester resin and reinforced with (15, 25, 35, and 45) (wt %) of alumina particles phases (crystal structure & amorphous).

All samples were prepared according to standard measurement.

Mechanical tests were done for the polyester composite materials to calculate the compressive strength and hardness, and the results showed a significant improvement in the properties of the polyester composite material reinforced with alumina with phase crystal (corundum-α), also noted the positive effect of the increase in the weight of the particles on the properties of the polyester composite material with that this increase has given better results.

Keywords: - Polymer matrix composites (PMCs), alumina phases, polyester, mechanical properties.

تأثير إضافة أطوار الألومينا (الألفا واللابلورية) على الخواص الميكانيكية (مقاومة الكبس والصلادة) لمتراكبات البولي استر

م.م. هناء داخل
معهد الفنون التطبيقية

م.م. منال فليح حسن
الكلية التقنية الهندسية / بغداد

الخلاصة :

تم في هذا البحث تحضير مادة متراكبة تحتوي على مادة أساس هي راتنجات البولي أستر مقواة بمادة الألومينا ذات الطورين (البلوري والعشوائي)، وبحجم حبيبي مختلف 45 ,35 (25, 15) وزنا.

ان جميع العينات كانت قد حضرت اعتمادا على الاختبارات القياسية .

اجريت اختبارات ميكانيكية لمتراكبات البولي أستر لحساب متانة الضغط والصلادة، واظهرت النتائج تحسنا كبيرا في خواص المادة المتراكبة المقواة بمادة الالومينا ذات الطور البلوري (α-corundum) ، كذلك لوحظ التأثير الايجابي للزيادة الوزنية للدقائق على خواص المادة المتراكبة حيث ان هذه الزيادة اعطت نتائج افضل.

الكلمات المرشدة:- المواد المتراكبة ذات المادة الاساس البوليمرية، اطوارالالومينا، بولي استر. الخواص الميكانيكية.

1. Introduction:

Polymer matrix composites (PMC_S) are the workhorse of the composites industries. They have excellent room –temperature properties at a comparatively low cost. The matrix consists of thermosetting resins and thermoplastics polymers [1]. They are increasingly gaining importance applications within the aerospace, automotive, marine, sporting goods, and in micro electronics include inter connections, printed circuit boards, substrates, encapsulations, inter layer dielectrics, die attach, electrical contacts, connectors, thermal interface materials, heat sinks, lids, and housing, electronic industries, also, this is the phase of particular interest for structural applications[2, 3].

Polyester resins are fast processing resins used generally for low cost applications [3]. They are cost effective because they require minimal setup costs and the physical properties can be tailored to specific applications. Another advantage of polyester resin composites that they can be cured in a variety of ways without altering the physical properties of finish part [1].

To expand their applications in different sectors, inorganic particulate fillers, such as alumina (Al_2O_3), is added to process polymer composites, which normally combine the advantage of constituent phases [4], alumina is the most cost effective and widely used material in the family of engineering ceramics, also it is hard, wear resistance, has excellent dielectric properties, resistance to strong acid and alkali attack at high temperatures, also high strength and stuffiness [5].The addition of ceramic particles into the matrix increases the yield strength of composites, compressive and tensile strengths, as well as the hardness at room and elevated temperatures[6].

In general the mechanical properties of particulate filled polymer composites depend strongly on size, shape, and distribution of filler particles in the polymer matrix and extent of interfacial adhesion between filler and matrix [7].

A.B. Brennan [8] studied the effect of the crystallization of bioactive glass reinforcing agents on the mechanical properties of polymer composites. The results indicate that glass-ceramic reinforced composites showed higher elastic modulus than glass reinforced composites. Therefore, crystallization of silicate glasses used as reinforcing agents in polymer matrices is a possible way to enhance the mechanical properties of composites. Ying Du, et al [9] studied the effect of the size filler particles on fracture behavior of polyester alumina composites materials; they are observed that the particle size has a clear effect on fracture toughness.

Aim o this search:

The major interest of this research was how the alumina phases (alpha and amorphous) affect the mechanical properties of polyester matrix composite.

2. Experimental Work:

2.1 Materials :

2.1.1 Matrix

The matrix material used in this work is polyester resin, which type EPLV (SIR) Saudi company and Methyl ethyl ketone peroxide ('MEKP') is 'hardening' agent.

Polyester resins are quite easily accessible, cheap and find use in a wide range of fields. Liquid polyesters are stored at room temperature for months, sometimes for years and the mere addition of a catalyst can cure the matrix material within a short time. They are used in automobile and structural applications.

The cured polyester is usually rigid or flexible as the case may be and transparent. Polyesters withstand the variations of environment and stable against chemicals. Depending on the formulation of the resin or service requirement of application, they can be used up to about 75ºC or higher. Other advantages of polyesters include easy compatibility with few glass fibers and can be used with verify of reinforced plastic accouters.

2.1.2 Reinforcing Material

The reinforcing material used in this work is alumina powder manufactured by Merck Germany with two phases α- alumina and amorphous alumina (the x-ray diffraction illustrate in**(Figure.1** And **Figure .2),** having the same grain size 45 µm. It was added to matrix resin with (15 – 45 wt %) weight fraction.

Table (1) the properties of alumina powder.

Properties	Alumina powder(Al_2O_3)
Density (gm/cm³)	3.9 gm/cm³
Purity according to the X-ray test	99.9%
Particle size from sieving and microscopic analysis	45µm
Melting point (C°)	2050
Source	Merck Company (Germany)
Crystal structure	Hexagonal

Intensity I/I.

2Θ degree

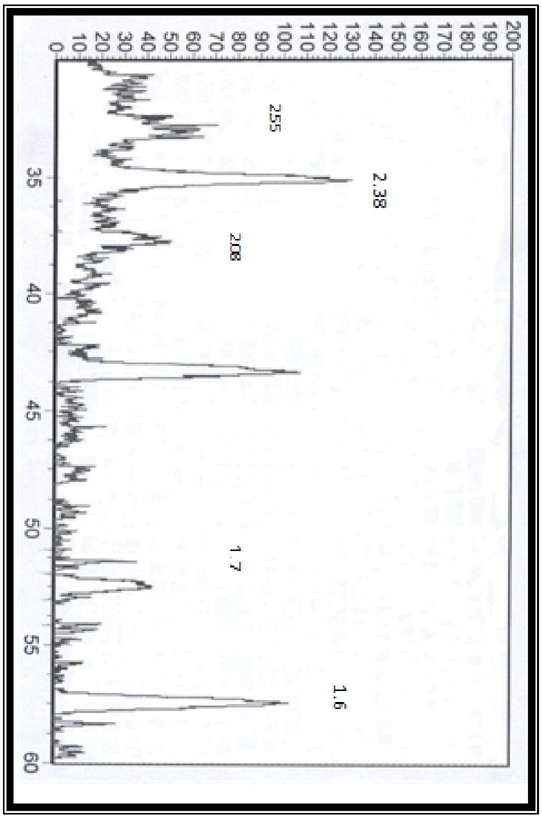


Fig .(1)X-Ray analysis of α-alumina powder.

Intensity I/I.

2Θ degree

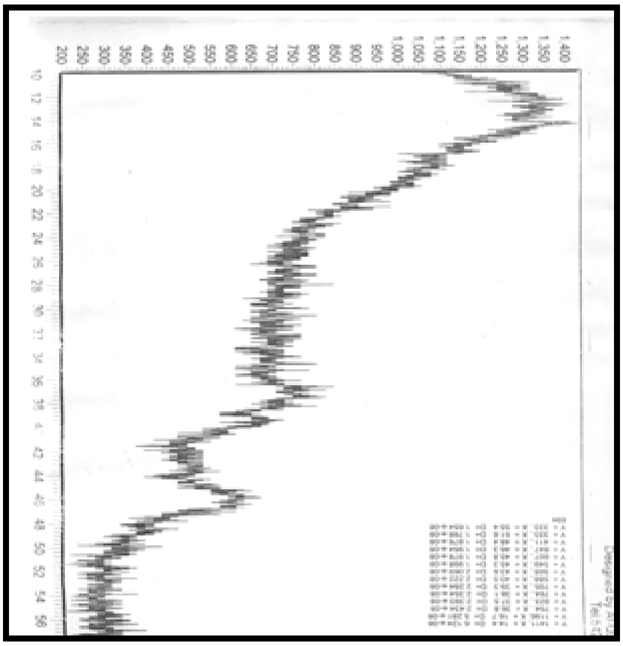


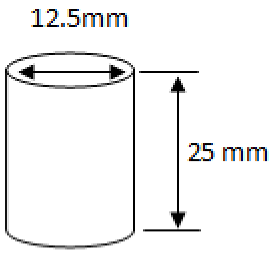
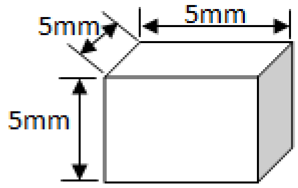
Fig.(2) X-Ray analysis of amorphous alumina powder.

2.2 Prepartion Technique :

Hand-layup method was used to fabricate the composite materials. The resin, premixed with some amount of the hardener, where added (2) gm from the hardener to (100) gm from polyester, then alumina particles are added to the polyester in different weight fractions (15,25,35,45) %, then specimens have been cut into a standard dimensions for hardness test according to the dimensions shown in **Table (2).**

A special mould has been used for the preparation of compression test specimens. The mould is hollow cylinder with 12.5mm diameter and25mm length. It is manufactured according to (ASTM-D695) standards, and the geometrical shape of the specimens illustrated in **Table (1),** the length to diameter ratio was nearly (2:1), the mixture was prepared as explained previously in, and poured into the mould, then after solidification, the specimen was released from the mould by pushing it from one end. Surface finish of the specimens was carried out using turning machine and was then followed by polishing process.

Table (2) Standard Dimensions of Specimens

1-Compressive Test Specimens		**ASTM-D695**
2-Hardness Test Specimens		**ASTM-E10**

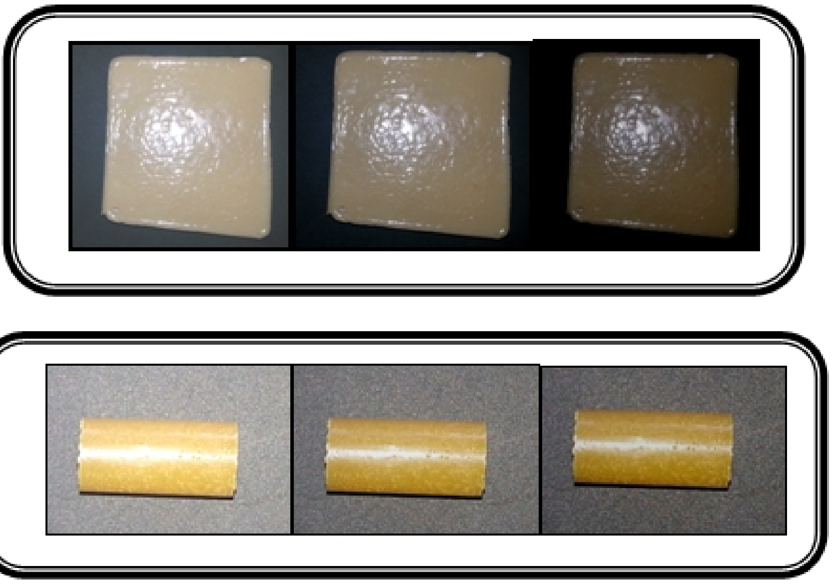


Fig .(3) specimens of the search

2.3 Results and Discussion:

2.3.1 Compressive Test:

Compressive testing machine type Test ometric Co. Ltd M500- 25KN. The compressive strength (σ_c), compressive strain (ε_c), and Young Modulus (E) are calculated from the following equations [10]:

$$\sigma_c = \frac{P}{A} \quad \text{................ (4), [10]}$$

Where , σ_c= compressive stress (MPa), P = Applied load in test (N), and A = original area of the test specimen $(mm)^2$.

$$\varepsilon_c = \frac{L - L_\circ}{L_\circ} \quad \text{.............. (5), [10]}$$

Where,ε_c = strain, L= length at any point during the elongation (mm), $L0$= original gauge length (mm).

$$\varepsilon_c = \frac{PL}{\delta As} \quad \text{.................... (6) [10]}$$

Where, $\frac{P}{\delta}$: slope of the initial linear portion of the load – deflection curve, L: Length (mm), As: Original area of the test specimen $(mm)^2$.

The test proves that the compression elastic modulus and compression strength are increasing with the increase in the particle weight fraction as clarified by **Table (1).**

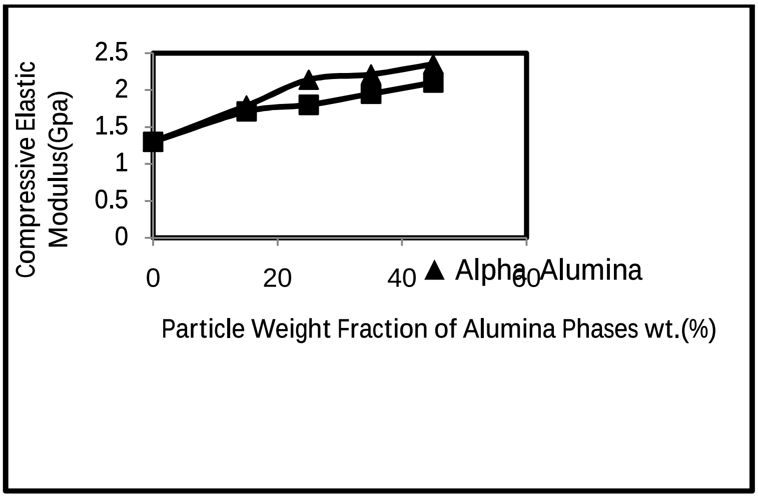


Fig .(4) Compressive elastic modulus versus alumina (wt %).

Figure. (4) Illustrates the effect of both amorphous and α-alumina on elastic modulus of composite specimens. Two types of ceramic reinforcement lead to an increase in elastic modulus, this means less ductility and this is an expected behavior because ceramic materials especially alumina (Al_2O_3 phases) is very hard material with very low ductility. The **Figure (4)** shows at first stages both amorphous and α-alumina have a similar effect until weight fraction exceeds (25) % where gap between them become very clear. Finally composite reinforced with amorphous alumina increases the elastic modulus from (1.3 up to 2.1) GPa when weight fraction increases from (0- 45) %, while composite reinforced with α-alumina increases the elastic modulus from (1.3-2.45) GPa for the same range of weight fraction. This difference is due to difference between mechanical properties of alumina phases where α-alumina has the highest hardness because it has hexagonal stable phase [5].

Table .(3) Hardness test Results of the Polyester Composites materials.

Materials		Particle Weight Fraction %	Hardness BHN (Kg/mm^2)	Hardness improvement percentage
Matrix	Reinforcement Particle			
Polyester	0	0	17.83	0
Polyester	α- alumina	15	25.52	1.43
Polyester	α- alumina	25	32.23	1.8
Polyester	α- alumina	35	39.81	2.23
Polyester	α- alumina	45	42.97	2.4
Polyester	Amorphous alumina	15	23.52	1.31
Polyester	Amorphous alumina	25	29.13	1.63
Polyester	Amorphous alumina	35	35.65	1.99
Polyester	Amorphous alumina	45	37.22	2.08

The compressive strength of two types of polyester composites with different ceramic phase's reinforcement is shown in **Figure (5).** At first stage the compressive strength of polyester resin is higher than polyester composites with (15% weight fraction) for both composite reinforced alumina particles and also due to the weak bonds between ceramic particles and polyester matrix. While, from (25-45% weight fraction) of both composites, the compressive strength increases with an increase in weight fraction of both alumina ceramic phases. The gap between two reinforcements is clear, because amorphous alumina has extremely disordered atomic arrangements and they have a considerable effect on the mechanical properties, while, crystalline alumina (alpha alumina) ceramics which inherently have a long range ordered structure [5].

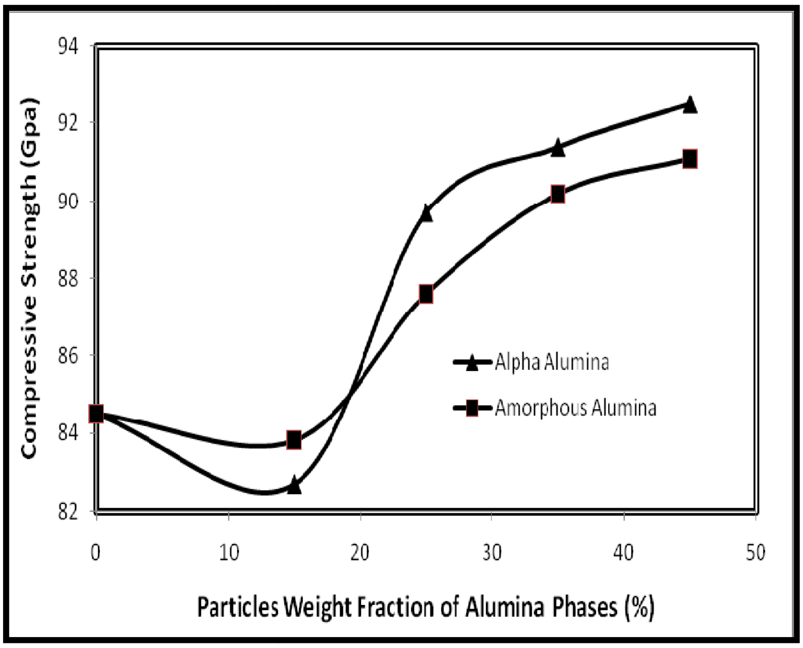


Fig .(5) Compressive strength versus alumina(wt%).

2.3.2 Hardness Test :

Brinell hardness test set is used to determine the hardness of the specimens. The equipment used is type Ley Bold Harris No. 36110. The Brinell test is conducted by impressing the indenter with diameter (5) mm under a load (1KN) into the surface of the specimen for a standard time, usually 30sec., after measuring the indention diameter (d) the hardness is calculated from the following equation [11]:

$$BHN = \frac{2P}{\pi D^{\circ}(D^{\circ} - \sqrt{D^{\circ 2} - d^2}} \quad \text{.......... (7)}^{[11]}$$

Where: BHN: Brinell Hardness (Kgf), P : applied load (Kg), $D°$:Indenter diameter (mm), d: Indention diameter (mm).

Result of this test proves that there is a significant increase in the hardness number with the increase particle weight fraction and the lowest value of hardness is the value of polyester resin (**Table(3)),** while the composite reinforced with α- alumina particles gives higher hardness number than the composite reinforced with amorphous alumina particles (see **Figure.(6).** The behavior of material depends on the role of particles as reinforcement. These particles may affect the bonds between the matrix and the matrix reinforcement causing it to become stronger, as a result the hardness is increased [5]**.** The behavior and properties of composites are determined by three factors: the intrinsic properties of constituents, the form and structural arrangement of the constituents, and the interaction between the constituents. The properties of constituents determine the general order or range of the properties of composite. The form (shape and size), the structural arrangement, and the composition and distribution of constituents give composites their versatility and contribute to the overall performance. The interaction between the constituents also plays a critical role in improving the mechanical properties of composites [1]**.**

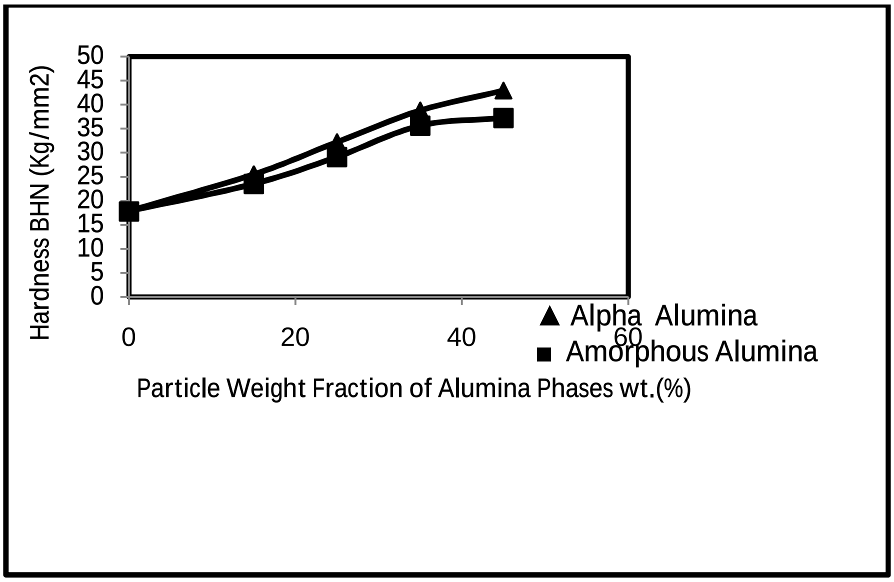


Fig.(6) The Relationship Between Hardness And Weight Fraction Of Composite Materials.

3. Conclusions:

A polyester matrix with two phases of alumina particles ceramics has been studied to observe the effect on the mechanical properties and the main conclusions are:

1- The compressive strength of matrix polyester composites increased with increasing weight fraction of alumina particles especially when adding alpha alumina ceramics.

2- The hardness of matrix polyester composites increased with increasing of weight fraction of alumina particles especially when adding alpha alumina ceramics.
3- The better mechanical properties are obtained between (25-45) % weight fractions of alumina ceramic reinforcement with polyester matrix.

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