IRAQI JOURNAL OF APPLIED PHYSICS
Vol. 22, No. 4, October-December 2026, pp. 533-540

Raed H. AL-Saqa [1*]
Omar A. Gadaan [2]
Ali H. Mohammed [2]
Mohammad M. Uonis [3]
Shahed A. Dheyab [2]
Hameed H. Ahmed [4]


# Enhance Unsaturated Polyester Resin's Mechanical and Thermal Properties by Adding $Al_2O_3$

From using aluminum oxide as a reinforcing agent and unsaturated polyester resin as the base matrix, a composite material was created in this manuscript. The study's main objective was to assess important mechanical characteristics, such as impact resistance, compressive strength, and hardness. Samples with different $Al_2O_3$ weight fractions ranging from 2% to 10% were prepared in order to examine the impact of filler concentration, the findings showed that an $Al_2O_3$ content of 6% produced the best mechanical performance improvement, furthermore, by curing the composite samples at 10°C, 25°C, 80°C, and 150°C the impact of processing temperature was investigated. The composites showed significant improvements in hardness, compressive strength, and impact resistance at 25°C, along with a decrease in Young's modulus. The mechanical properties showed different trends at different temperatures (10°C, 80°C, and 150°C), with some showing an increase and others a decrease. In addition, it was found that, in comparison to room temperature, thermal conductivity rose with increasing and decreasing temperatures. These results imply that the mechanical and thermal behavior of $Al_2O_3$ reinforced unsaturated polyester composites is strongly influenced by both filler content and processing temperature.

**Keywords:** Metal complexes; Polymeric composites; Impact resistance; Compressive strength

[1] Department of Chemistry, College of Education, Al-Iraqia University, Baghdad, IRAQ
[1] Directorate General of Education, Nineveh, Ministry of Education, Nineveh, IRAQ
[2] Department of Physics, College of Education for Pure Science, Tikrit University, Tikrit, IRAQ
[3] Department of New and Renewable Energy, Mosul University, Mosul, IRAQ
[4] College of Engineering-Shirqat, Tikrit University, Tikrit, IRAQ
* Corresponding author email: raed.h.alsaqa@st.tu.edu.iq

## 1. Introduction

Since ancient times, composite materials have been used in their most basic forms, the Assyrians used them to construct ziggurats, and the Egyptians made bricks out of straw to prevent them from breaking while drying [1]. Two or more distinct, heterogeneous materials are combined to create composite materials, when compared to the characteristics of each of their component materials, they have better qualities. [2]. By definition, composite architectures are engineered by physically combining distinct constituent phases without inducing chemical reactions, thereby allowing each component to preserve its intrinsic properties [3]. Integrating cost-effective secondary phases into a polymer matrix provides an economically viable pathway to fabricate high-performance materials featuring exceptional structural efficiency [4]. These synthesized systems possess a superior suite of characteristics, including lightweight profiles, high tensile strength, outstanding electrical insulation, and robust chemical and environmental resistance. Consequently global Industries consume over 2 million tons of composite annually to manufacture critical structural components for aerospace and storage applications 5 among these Matrices unsaturated polyester (UPE) resin stands out as a prominent thermos stating polymer however it standalone engineering applicability is severely constrained by its inherent brittleness and low fracture toughness to rectify these mechanical deficiencies UPE, is routinely reinforced with carbon fibres or glass fibre or glass waste powder which fundamentally alters its deformation mechanisms and cracked propagation behaviour [6]. Driven by modern technological demands polymers have become indispensable across diverse industrial sectors due to their ease of processing and excellent resistance to acidic and basic environments [7,8], recent evaluations of UPE, matrices modified with varying weight fractions of glass powder have confirmed that increasing the particulate filler loading systematically increases both hardness and compressive strength conversely and noticeable attenuation in impact toughness is observed with all mechanical parameters undergoing a sharp decline under elevated thermal environments [9,10].

Prior investigations evaluated the environmental stability of hybrid composites composed of epoxy and Novalac- type phenol formaldehyde resins reinforced with silica alumina, and Trace amounts of asbestos fibres specifically focusing on the degradation of the elastic modulus under acidic and basic aqueous exposures concurrently separate research lines explored the structural efficiency of unsaturated polyester matrices modified with distinct organic fillers

  

namely wood shavings and chopped reads fabricated via conventional hand layout techniques. To analyse their long-term mechanical degradation the synthesized specimens under when full immersion in water at an ambient temperature of 25°C for a duration of 30 days to achieve absolute saturation subsequent mechanical characterization including flexural strength and Young's modulus testing revealed that the reed reinforced composite configurations achieve the peak Performance metrics yielding a maximum flexural strength of 24.0 MPa and a corresponding Young's modulus of 5.1 GPa [11-13].

In a related investigation the mechanical characteristics of columns fabricated from recycled low density polyethylene (LDPE) matrices were assessed. This recycled (LDPE), sourced from post-consumer waste bags was reinforced with sawdust filler via an injection melding approach. The findings indicated that while higher sawdust content enhanced the material's rigidity, it simultaneously led to a reduction in tensile strength. Furthermore, the physical traits of an epoxy-based composite modified with varying weight percentages of sulfur were explored; the integration of sulfur was found to improve impact resistance, hardness, and compressive strength, whereas the thermal conductivity exhibited a downward trend [14, 15].

$Al_2O_3$ is very important for nanoceramic application, there for this study was very important to enhance most of ceramic that using in buildings.

## 2. Materials and Method

At room temperature, the Turkish-made unsaturated polyester from the TURKUAZ POLY ESTER company with a mass density of 1.17 g/cm$^3$, and a viscosity of 350–500 N. Sec/m$^2$. This kind of polymer is thermosetting. The addition of the hardener, which contains two different kinds of hardening agents, causes it to solidify and harden. The first is ethyl peroxide, a colorless liquid that is thought to be an initiator of the polymerization process, which accelerates the initiator's breakdown [16,17]. It is characterized by its oily consistency and purple color. When the catalyst and hardener are added to the mixture, then the hand mixing process with two and continue to three minutes, or until the mixture thickens [18]. The hardener is companied with unsaturated polyester and mixed in a 2:1 resin to hardener ratio. When this time is exceeded, the mixture heats up and be highly soluble, which speeds up melting and makes casting more difficult. The finished product also has big air bubbles in it. As seen in Fig. (1), polyester resin offers superior mechanical qualities in addition to superior electrical and thermal insulation [19][20].

Alumina, a chemical compound renowned for its exceptional chemical stability, serves as an effective reinforcement in aluminum-based composites. Owing to their lightweight nature and superior performance efficiency these composites find widespread utilization across various sectors including automotive manufacturing agriculture mining and Aerospace engineering [21]. Furthermore, the incorporation of $Al_2O_3$ enhances the thermal dissipation capabilities of composite matrices notably a synergistic enhancement in thermal conductivity is achieved when aluminium nitride is co-blended with $Al_2O_3$ within a polymer network. Duo to robust internal ionic bonding the material exhibits a remarkably high melting point of approximately 2072℃ [22]. Regarding its synthesis $Al_2O_3$ can be produced via the direct combustion of aluminium in an oxygen rich or ambient air environment or conversely extracted from kale in and clay minerals under regulated temperature in pH conditions alternatively as in Fig. (2). It can be synthesized by injecting air into a Multan alloy to generate bubbles where the oxide film subsequently develops around the bubble peripheries [23].

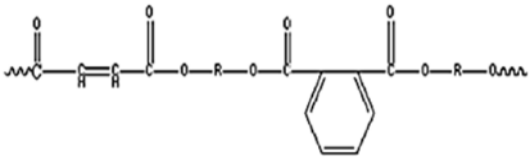

**Fig. (1) General structural formula of unsaturated polyester**

**Fig. (2) $Al_2O_3$ as powder form**

Unsaturated polyester was utilized when adding a hardener in a two to one ratio resulting in a gelatinous produce that hardens at 25℃ to fabricate the $Al_2O_3$-reinforced composites varying weight fractions ranging from 2% to 10% were incorporated into the Matrix using a manual casting methodology with custom models. The preparation involved blending the unsaturated polyester resin with a purple dyed promoter accelerator followed by the gradual addition of aluminum oxide this suspension was continuously agitated to guarantee uniform filler dispersion subsequently a transparent curing agent hardener was introduced in stirred slowly for 30 to 60 seconds to suppress the entrapment of microwaves or air bubbles within the liquid Matrix the resulting mixture was cast into the specialized molds and allowed to Crosslink at ambient temperature for 24 hours to achieve full curing. To investigate the influence of extreme environmental profiles and thermal effects (simulating harsh summer conditions), the demoulded specimens were subjected to systematic thermal conditioning at elevated

  

temperatures of 80 ℃ and 150 ℃.

By using the next equipment, the mechanical properties were studied. Specimen preparation was conducted in compliance with American standards (ASTMD 618), employing a measurement apparatus manufactured by Automax. The test specimens were melded into a cubic geometry to effectively withstand the ultimate compressive loads during a valuation to determine the peak compressive strength sustainable by each sample a hydraulic pressing system from testing machine Co. LTD was utilized. It is important to note that the device used to measure compressive strength is affiliated with the College of Engineering, Civil Department, Materials Testing Laboratory.


**Fig. (3) Compressive strength testing device**

Impact testing was performed using a Chirpy Impact Test apparatus manufactured by Tokyo koki Seizosho, Ltd, situated within the Metallurgy Laboratory at the T3echnical Institute. The evaluated specimens were prepared with precise dimensions of 10 mm × 10 mm × 55.55 mm. Following the guidelines outlined in the American Standard Specifications (ASTMD256-87), a V-shaped notch featuring a 2 mm depth than a 90° configuration was introduced into each sample

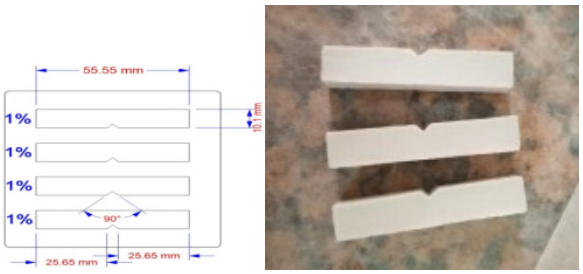


**Fig. (4) Shape and diagram of the specimen for compressive strength testing**

Shorty hardness measurements were performed using a Wulford (Germany) durometer located in the department of mechanics faculty of engineering. The instrument features of dial-life configuration equipped with a central indenter needle. Operationally the durometer was aligned perpendicularly against the specimen surface allowing the needle to penetrate the material. A dwell time of 3 seconds with strictly maintained after penetration to ensure a stabilized reading before documenting the displayed hardness value

Characterization of the composite's flexibility involved the simultaneous evaluation of two critical variables: stress and elongation. Tensile specimens were fabricated via a slice drawing technique to achieve specific dimensions of 1 cm in thickness and 20 cm in width, strictly complying with the ISO R527 standard benchmarks. This preparation was executed to systematically examine the mechanical behavior of the composite when subjected to bidirectional axial loading. Quantifying these properties was performed utilizing a 50 kTon, capacity universal testing machine from ELE (England), located in the Materials Testing Laboratory within the Civil Engineering Department at the College of Engineering..

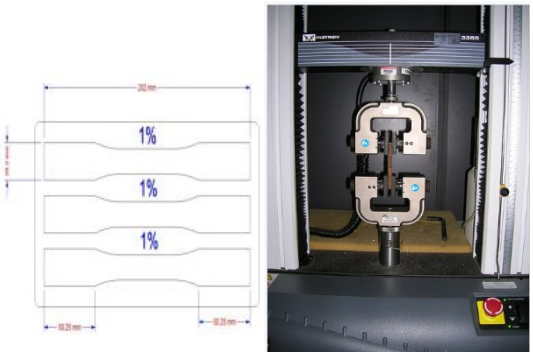


**Fig. (5) The shape and diagram of specimen for impact resistance testing**

## 3. Results and Discussion

To evaluate the mechanical performance of polymer-based composites, pure unsaturated polyester matrices were modified with varying weight fractions of $Al_2O_3$, compressive testing conducted at an ambient temperature of 25°C revealed that the materials structural resistance fluctuated as a function of filler loading notably as depicted in Fig. (6). The compressive strength reached its peak threshold at an optimum $Al_2O_3$ concentration of 6% the mathematical assessment of the composite's resistance to compressive loading with subsequently quantified using equation 1 [24]:

$$\text{Compressive Strength [MPa]} = \frac{F}{A} \quad (1)$$

F is the applied force (N), A represents the cross section in the shape of the cylinder, and its unit is ($m^2$)

As illustrated in Fig. (7), the compressive strength of the composite exhibits a clear temperature dependence decreasing systematically as the thermal environment rises to 150°C due to the thermal softening and structural relaxation of the polymer matrix. Conversely, cooling the specimens to a sub ambient

  

thermal state of 10°C promotes structural rigidity and immobilizes the polymeric chains, thereby yielding an enhanced compressive load capacity this inverse correlation highlights the highly temperature-sensitive nature of the composite's mechanical integrity under varying operational environments.

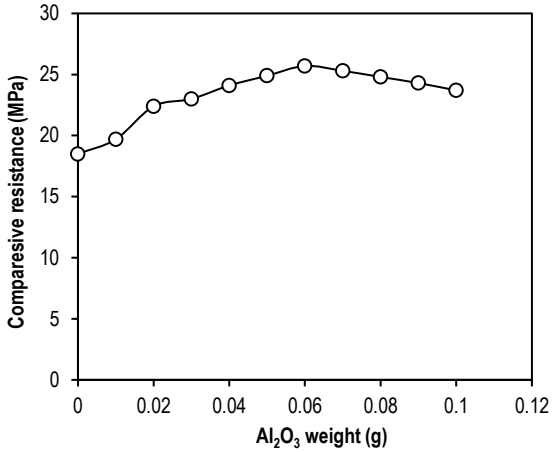


**Fig. (6) Unsaturated polyester's compressive resistance at 25°C before and after reinforcement**

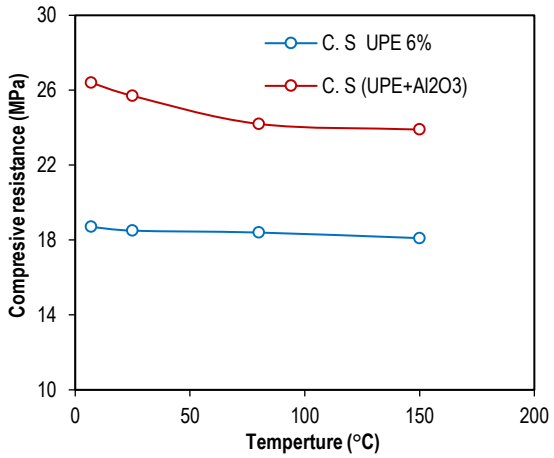


**Fig. (7) Compressive resistance comparisons of pure and reinforced unsaturated polyester resin at 10°C, 25°C, 80°C, and 150°C**

Evaluating the impact performance of polymeric materials is highly sophisticated due to the diverse array of testing configurations of available Nonetheless, it remains a cornerstone characterization within both quality assurance frameworks and product design Laboratories for plastic manufacturing among these methodologies, the Izod and Charpy tests are extensively utilized to quantify a materials fractured toughness when subjected to a sudden dynamic force with the failure energy expressed in joules or kilo joule [25]. To optimize the mechanical integrity of these specimens functional fillers are frequently incorporated to occupy microvoids within the polymer Matrix thereby preventing premature structural deformation [26]. From a practical standpoint this evaluation is vital as it directly measures the total absorbed energy required to rupture the specimen a parameter that can be acquired immediately from the instruments digital readout or theoretically verified using the following equation [27]:

$$\text{Impact strength (I.S)} = \frac{\text{Freature energy}}{\text{Area (m)}^2} \qquad (2)$$

As illustrated in figurate 8, neat polymers are highly susceptible to rapid, catastrophic fracture under sudden dynamic loading due to the immediate vision of macromolecular chains. To overcome this structural limitation and enhanced durability, secondary reinforcing phases or embedded within the polymer Matrix which significantly increases the total fracture energy and toughness. The failure mechanism of these composite systems systematically proceeds via a dual-stage process: the initial stage is governed by the structural cohesion and progressive yielding of the Matrix spawns whereas the subsequent stage involves the interfacial deboning energy dissipating pull out and ultimate rupture of the reinforcing elements consequently the cumulative energy threshold required to induce failure in the reinforced composite substantially surpasses the intrinsic rupture energy of the pristine polymer network .

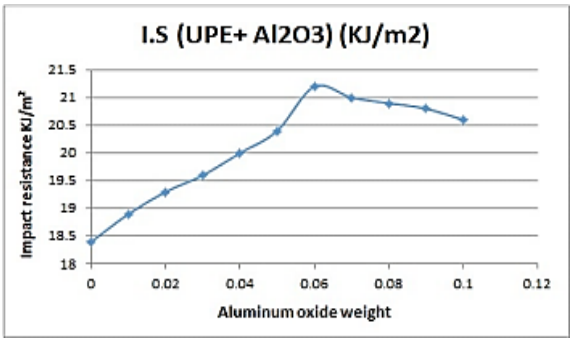


**Fig. (8) Shock resistance of unsaturated polyester before and after reinforcement that 25 °C**

When he treating samples with a concentration of 6% which is the optimal percentage compared to other concentrations at temperature from 10°C to 150°C, as the temperature drops, the impact resistance values drop as well. This structural attenuation is fundamentally driven by the steric hindrance and restricted mobility of the macromolecular polymer chains which severely constrains their freedom of movement conversely a noticeable elevation in impact resistance is recorded with increasing temperature reaching its peak expression that 150°C. This enhancement is ascribed to the thermal disruption of secondary bonds among overlapping molecular networks which consequently liberates the segments of the polymer chains. As a result the Matrix acquires a higher capacity for energy absorption facilitating the efficient distribution and dissipation of the mechanical loads required to induce fracture this behavioural transition is graphically substantiated in Fig. (9), which

  

depicts the mechanism of mechanical energy dissipation.

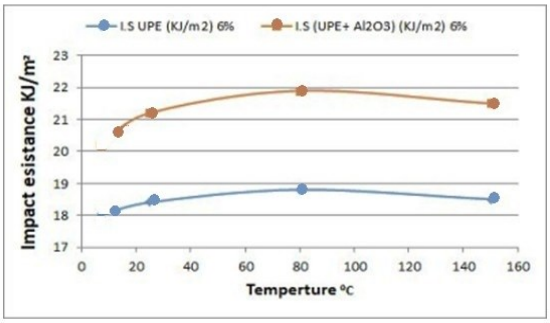


**Fig. (9) Shock resistance for unsaturation polyester before and after reinforcement at 10°C, 80°C, and 150°C**

Surface integrity can be susceptible to structural scratching and micro penetration by harder counter faces during operation deployment hence hardness constitutes a pivotal surface mechanical attribute this property reflects the intrinsic capacity of a materials surface to resist localized permanent deformation in induced by cutting abrasive where our scratching mechanisms [28]. To quantify this resistance against surface plastic deformation standardized indentation testing is implemented by penetrating the target matrix with precise high rigidity and indenter tips crucially the macroscopic hardness behavior is heavily modulated by thermal treatments high temperature testing environments atomic bonding energy in topographies incorporating $Al_2O_3$ particles in the unsaturated polyester matrix yields a discernible enhancement in surface hardness values this progressive upgrade is primary ascribed to the robust interfacial adhesion and cohesion between the polymer network in the aluminum fillers coupled with cross- linking densities that effectively restrict the segmental mobility of the polyester macro moleccules there by evaluating resistance to the mechanical deformation [29], an evolutionary trend visually evidenced in Fig. (10).

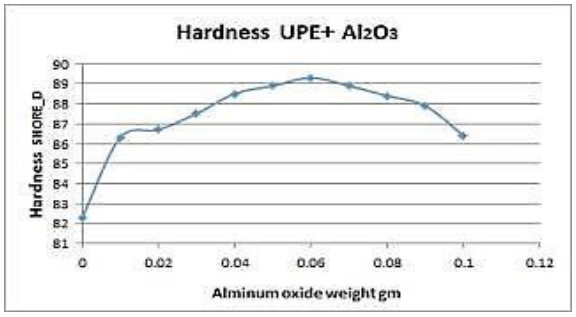


**Fig. (10) Hardness behavior of neat and reinforced unsaturated polyester at ℃**

Thermal aging at varying temperature (10°C, 80°C and 150°C), was performed on the optimized 6% composite formulation which previously demonstrated peak Performance relative to other concentrations (Fig. 11). Experimental profiles indicated that surface hardness values within the 80°C to 150°C, range were noticeably suppressed compared to ambient measurements at 25 ℃, this mechanical degradation is fundamentally driven by temperature induced structural softening we're in elevated thermal energy accelerates segmental chain mobility and weakens the intermolecular bonds within the polymer network. Consequently the materials resistance to localized scratching and surface puncturing is attenuated. Conversely, sub-ambient cooling to 10℃, yielded a distinct enhancement in hardness parameters. This behaviour is ascribed to the immobilization and steric constraint of the polymer backbone which severely restricts molecular motion and subsequently improves the composites resistance to mechanical indentation.

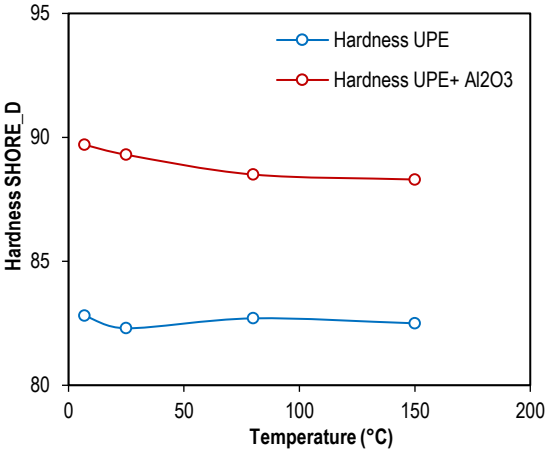


**Fig. (11) Comparative hardness of unsaturated polyester before and after reinforcement at 10°C, 25°C, 80°C and 150°C**

Young's modulus, can be define as: is the ratio of stress to strain, while it is under a load. It shows how resistant a material is to deformation [30]. A material will show some change, which is represented as a partial change in dimensions, when it is stretched, compressed, or deformed. Understanding the modulus of elasticity, which controls a material's response to deformation, is crucial for engineers and materials scientists because it aids in the design of materials and structures that can withstand specific loads and stresses while retaining their shape and functionality. Furthermore, Young's modulus plays a crucial role in the creation of advanced materials with particular properties for particular uses, like metals and composites. Resins have a very low tensile strength because they are brittle materials. Tensile strength can be considerably increased by adding reinforcing materials, as the reinforcing material particles help withstand the applied loads. Through experiments, the top of tensile strength was obtained at a weight percentage of 6% and at temperature 25°C. (Fig. 12).

If the heat treatment is conducted at (10, 80, and150 °C) with a weight percentage of 6%, it is observed that

  

the elasticity values decrease when the temperature increase from 80°C to 150°C, depend on the disintegration of the polymer chains caused by elevated Temp. Conversely, under sub-ambient cooling regimes such as 10°C, the elasticity parameters undergo a discernible decline; this deterioration is fundamentally attributed to the kinetic confinement of intermolecular linkages and the vitreous immobilization of the macromolecular polymer chains, which consequently induces a higher propensity for material brittleness [31], a behavioral trend visually substantiated in Fig. (13).

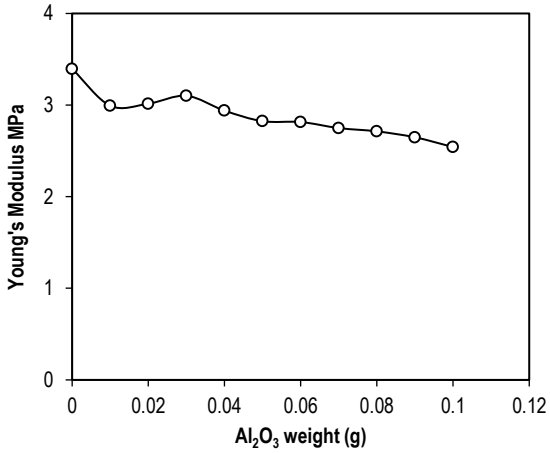


**Fig. (12) Comparative Young's modulus of unsaturated polyester before and after reinforcement at 25°C**

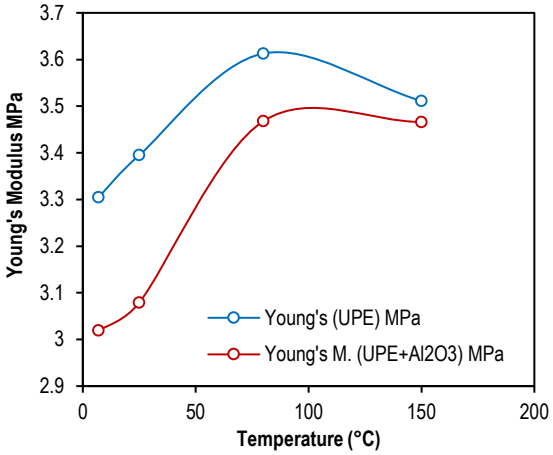


**Fig. (13) Elastic modulus of unsaturated polyester before and after reinforcement at 10°C, 25°C, 80°C, and 150°C**

Thermal conductivity is fundamentally defined as the intrinsic capacity of a material to transmit thermal energy across a localized temperature gradient [32]. The experimental data demonstrated a discernible elevation in thermal conductivity values following the incorporation of aluminum oxide ($Al_2O_3$) into the unsaturated polyester matrix, contrasting sharply with the neat polymer measurements. Mechanistically, since non-conjugating polymers generally lack abundant free electrons, their thermal transport is predominantly governed by localized molecular chain vibrations and phonon propagation, which are significantly enhanced by the highly conductive alumina filler pathways. To mathematically evaluate the temperature dependence of this thermal behaviour, the Arrhenius relationship denoted in Eq. (3) is implemented, as illustrated in Fig. (14):

$$k(T) = K^{\circ}\exp(-\frac{Ea}{KBT}) \qquad (3)$$

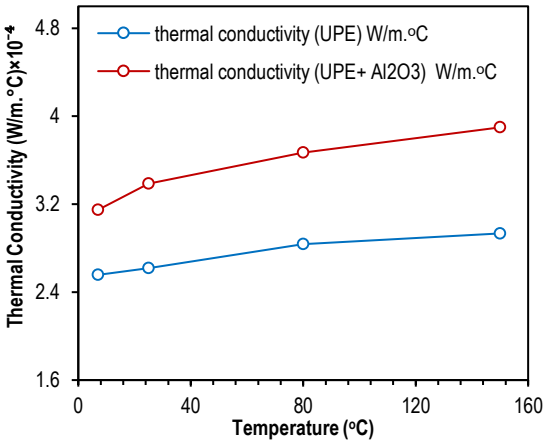


**Fig. (14) Thermal conductivity for unsaturated polyester before and after reinforcement at 10°C, 25°C, 80°C, and 150°C**

Figure (15) displays pictures from a scanning electron microscope for the pure polyester and $Al_2O_3$ with a polyester mixture. Because the polyester grains aggregated around the $Al_2O_3$ particles, the grain size increased from 215.28 nm for pure polyester to 516.81 nm for the combination. The exceptional homogeneity and uniform distribution of the $A_2O_3$ particulate phases are clearly manifested in the surface morphological imagery of the evaluated specimens. Concurrently, the micrographs reveal the presence of localized micro-voids and surface porosities, which are conventionally induced by CBD method deposition.

Before reinforcement the FTIR spectrum of pristine unsaturated polyester UPE prominently exhibited its characteristic vibrational modes including carbonyl (C=O) and hydroxyl (O-H) stretching, alongside (C=C) and (C-O) linkages [38]. Following the incorporation of $Al_2O_3$, no profound alterations were observed in the infrared profiles of The UPE Matrix, which verifies that the alumina operates strictly as a physical filler (Fig. 16). This minimal spectral variants is directly attributed to the outstanding chemical stability in a nerd nature of $Al_2O_3$, which induces only negligible shifts in the characteristic vibrational wave numbers of the Host polymer.

  

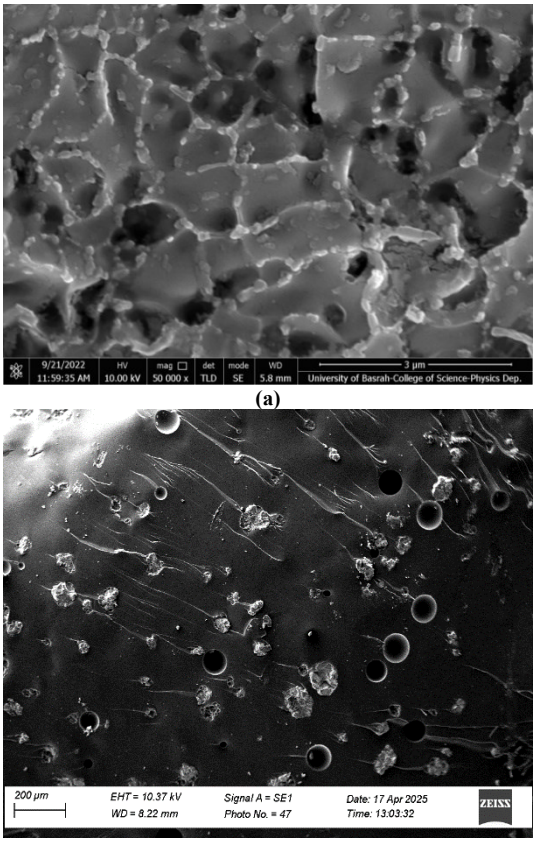


**Fig. (15) SEM images of (a) pure polyester, and (b) $Al_2O_3$ and polyester mixture**

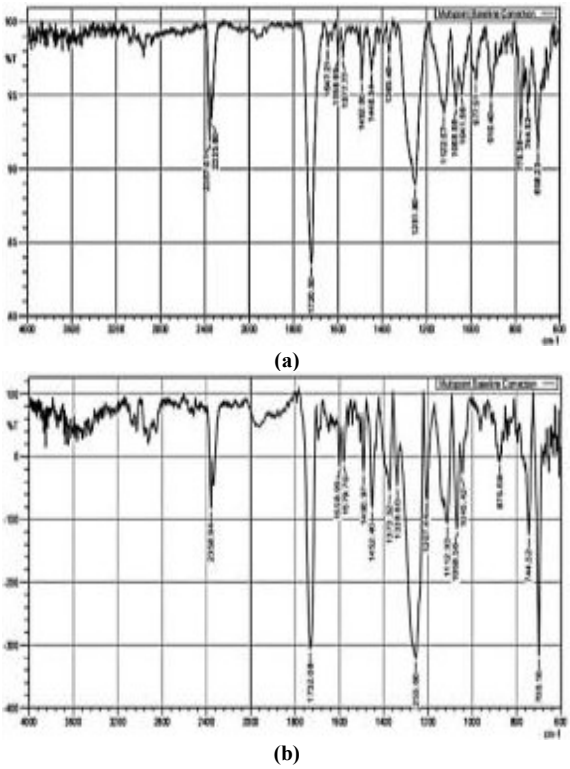


**Fig. (16) IR for polyester unsaturation, a: without hardeners, b: with hardeners**

## 4. Conclusions

The findings demonstrated that when unsaturated polyester was reinforced with $Al_2O_3$, and heat treated at (10, 80 and 150 ℃) mechanical properties such as compressive strength hardness and shock resistance increased while the elastic modulus decreased Furthermore, the properties (modulus of elasticity shock resistance) were computed at 80℃ and 150 ℃. Thermal exposure within the temperature range of 80 - 150℃, induced a noticeable degradation in the mechanical parameters specifically the compressive strength and hardness which is conventionally attributed to the thermal softening and structural relaxation of the polyester matrix. Conversely a recovery in these mechanical properties was observed during the subsequent cooling faces in terms of thermal transport thermal conductivity of the composite exhibited a direct correlation with elevated temperatures up to 150 ℃, a phenomenon significantly enhanced by the phone and assisted transport pathways of the $Al_2O_3$ particulate reinforcement. ultimately the comprehensive evaluation established 80 degrees Celsius as the optimum thermal threshold where the material retained its peak physical and mechanical integrity.

## References

[1] M. Broida, **"Ancient Egyptians and Their Neighbors: An Activity Guide"**, Chicago Review Press (2005).

[2] K.L. Edwards, "Selecting materials for optimum use in engineering components", *Mater. Design*, 26(5) (2005) 469-473.

[3] K.K. Chawla, **"Composite materials: science and engineering"**, Springer Science & Business Media (2012).

[4] A.N. Netravali and S. Chabba, "Composites get greener", *Mater. Today*, 6(4) (2003) 22-29.

[5] J.C. Williams and E.A. Starke Jr., "Progress in structural materials for aerospace systems", *Acta Materialia*, 51(19) (2003) 5775-5799.

[6] R. Mülhaupt, "Green polymer chemistry and bio-based plastics: dreams and reality", *Macromol. Chem. Phys.*, 214(2) (2013) 159-174.

[7] S.A. Umoren and M.M. Solomon, "Recent developments on the use of polymers as corrosion inhibitors-a review", *Open Mater. Sci. J.*, 8(1) (2014) 39-54.

[8] M.M. Saleh et al., "Structure and mechanical properties of cermet Ni-Al/MSZ thick coating prepared by flame spraying technique", *Ochrona Przed Korozja*, (1) (2024) 9-14.

[9] G.A. Khoury, "Compressive strength of concrete at high temperatures: a reassessment", *Magaz. Concrete Res.*, 44(161) (1992) 291-309.

[10] R.H. Al-Saqa, I.K. Jassim and M.M. Umis, "Effect of KCl on the optical and structural properties of

  

CaZn0 3 perovskite thin films", *Ochrona Przed Korozja*, 6(8) (2023) 243-246.

[11] A. Farhan and H. Jaffer, "Effect of Water on Some Mechanical Properties for Sawdust and Chopped Reeds/UPE composites", *Baghdad Sci. J.*, 8(2) (2011) 16.

[12] M. Jiménez-Espada, D. Herrero-Adán and R. González-Escobar, "Characterization of mechanical and hygroscopic properties of individual canes of reed", *Materials*, 14(9) (2021) 2193.

[13] S. Kareem, M. Uonis and R. Alsaqa, "High-Pressure Calibration TiN Equation of State", *Int. J. Thermodynamics*, 26(4) (2023) 41-47.

[14] O.A. Radwan et al., "Rebuilding with sand roses: Cold sintering of sand-gypsum mixture for sustainable brick production", *Construct. Build. Mater.*, 442 (2024) 137642.

[15] A.Y. Khidhaeir, I.K. Jassim and R.H. AL-Saqa, "Structural, Morphological, and Magnetic Properties of the Binary $Fe_{60}Co_{40}$ Alloy Synthesized by Mechanical Alloying Processing", *Nanosistemi, Nanomateriali, Nanotehnologii*, 23(1) (2025) 299-306.

[16] M.J. Martinez Velon, "Synthesis of polymers and copolymers of lactide through titanium initators", PhD dissert., Aston University (2007).

[17] R. Ahmadi, "Synthesis of Biobased Polyethers, Polyesters and Polyamides from Canola Oil Derived Monomers Using Microwave Irradiation", PhD thesis, University of Alberta (2021).

[18] E.K. Silviya et al., "Compounding and mixing of polymers", in **Advances in Polymer Processing**, Woodhead Publishing (2009), pp. 71-105.

[19] M. Malik, V. Choudhary and I.K. Varma, "Current status of unsaturated polyester resins", *J. Macromol. Sci. C: Polym. Rev.*, 40(2-3) (2000) 139-165.

[20] N.S. Sultan, R.H. AL-Saqa and S.J. AL-Faris, "Study the change of some physical and chemical properties of TiN under high pressure", *Tikrit J. Pure Sci.*, 28(3) (2023) 1427.

[21] K. Lakshmanan et al., "Studies on progress of aluminum based composites for automotive applications and its damping characteristics–A review", *Mech. Adv. Compos. Struct.*, 12(1) (2025) 25-42.

[22] J. Hübner et al., "Insights into combustion mechanisms of variable aluminum-based iron oxide/-hydroxide nanothermites", *Combus. Flame*, 184 (2017) 186-194.

[23] D.K. Koli, G. Agnihotri and R. Purohit, "A review on properties, behaviour and processing methods for Al-nano $Al_2O_3$ composites", *Procedia Mater, Sci.*, 6 (2014) 567-589.

[24] D. Rangeard et al., "Determination of the consolidation coefficient of low compressibility materials: application to fresh cement-based materials", *Mater. Struct.*, 48(5) (2015) 1475-1483.

[25] G.P. Marshall, J.G. Williams and C.E. Turner, "Fracture toughness and absorbed energy measurements in impact tests on brittle materials", *J. Mater. Sci.*, 8(7) (1973) 949-956.

[26] S.M. Zebarjad, M. Tahani and S.A. Sajjadi, "Influence of filler particles on deformation and fracture mechanism of isotactic polypropylene", *J. Mater. Process. Technol.*, 155 (2004) 1459-1464.

[27] J.K. Lancaster, "Abrasive wear of polymers", *Wear*, 14(4) (1969) 223-239.

[28] C.J. Chirayil et al., "Nanofibril reinforced unsaturated polyester nanocomposites: Morphology, mechanical and barrier properties, viscoelastic behavior and polymer chain confinement", *Indust. Crops Products*, 56 (2014) 246-254.

[29] D.C. Drucker and L. Palgen, "On stress-strain relations suitable for cyclic and other loading". *J. Appl. Mech.,* 48(3) (1981) 479-485.

[30] R.H. Al-Saqa and S.J. Al-Taie, "Theoretical Study of Mechanical, Elastic and Phonon Frequency Spectrum Properties for GaAs at High Pressure", *J. Siberian Fed. Univ. Math. Phys.,* 12(3) (2019) 371-378.

[31] J.A. Greenwood and J.B.P. Williamson, "Electrical conduction in solids II. Theory of temperature-dependent conductors", *Proceed. Royal Soc. London Ser. A: Math. Phys. Sci.*, 246(1244) (1958) 13-31.

  