Thermal and Mechanical Properties of Polymer/Nickel Composites

L S faeq

Materials Engineering, University of Technology, Baghdad, Iraq
E-mail: lameessalam@yahoo.com

Abstract. This paper investigates the metal particles effect on the mechanical and thermal properties of polyester matrix composites. Nickel (Ni) particles were chosen as reinforcing constituents due to their well characterized mechanical and energetic properties. The effects of spatial distribution and volume fractions of the nickel particles on the mechanical behavior of polyester matrix castings has been examined by of reinforcing the polyester by 2,4,6,8,10 vol.% Ni which have been prepared using hand lay-out molding. Mechanical characteristics were the tensile properties; bending modulus of elasticity, shear stress and impact properties (fracture toughness and impact strength) has been studied. The results of the experimental work show an increase in the volume fraction of nickel particles to 10% led to increase in mechanical properties. While the thermal properties such thermal diffusivity, thermal diffusivity conductivity and specific heat capacity also affected by the incorporation of nickel powder to the matrix that increases slightly as the nickel content increases.

1. Introduction

Particle reinforced polymer matrix composites are increasingly being studied for use as structural materials in applications at high rates of strain. These types of composites are very complex due to their heterogeneous microstructures, and because their mechanical response can be significantly influenced by the physical and chemical interactions of the constituents at the mesoscale. Depending on the composite, such as a soft polymer matrix reinforced with relatively hard (ductile or brittle) or soft (polymeric) particles, drastic differences in their strength and toughness characteristics relative to the properties of the polymer or reinforcement by itself, can be observed. Additionally, these effects can be exacerbated by the relative amounts off each constituent. Polymer composites reinforced by particles is promising as structural energetic materials which may give a structural strength at the same time can release high amount of chemical energy during high exothermic reactions happening between the matrix and the particles. This advance type of material has many advantages because of it can decrease the amount of high density inactive casings required for typical energetic materials also it is capable of decreasing collateral damage and increasing payload expectancy. Structural energetic materials may be comprised of reactive particles which are suffering intermetallic or thermite reactions. [1]

Different types of polymers and polymer matrix composites reinforced by metal particles have many industries uses like electrodes, heaters, composites with high thermal durability. These polymer matrix composites are used because of their low cost, ease of fabrication, high corrosion resistance and low density. It is reported that with the inclusion of micro-sized particulates into polymers, a high filler content (typically greater than 20 vol. %) is generally required to bring the above stated positive effects into play [2]. But at the same time, this may also have detrimental effects on some important properties of the matrix polymers such as appearance, processability, aging performance and density. The filler particles have a huge effect on the determination of the properties and behavior of particles...
composites materials reinforced by more than 60% by weight of particles. The main principles of production and formulation of particles composite is mastic (filler matrix system) theory and filler theory [3, 4]. The filler theory stated that optimal composite characteristics can be attained when the distribution of particle size allows a maximum use of the filler particles. The matrix coats all filler particles by an optimal thickness according to mastic theory. This creates a bend among the filler particles leading to a stable and rigid composite mixture. Depending on these theories, the distribution of particles size of the filler and the optimal content of the matrix for this distribution affect the behavior of the composite. Different other parameters have an influence on the mechanical behavior of composite are the moistening the filler with the resin and the bond between the different components. Physico-chemical parameters of the filler that influence durability and the initial behavior of the composite mixture are size distribution, size, area, surface activity and shape. Karger and Stokes et al. [5, 6] report the effects of these parameters. The filler influences the tensile properties due to their interfacial bonding, size and packing properties. The maximum volumetric packing fraction of filler reflects the particle shapes and size distribution of it [7]. Elia M. S., has studied the effect of Sea Nodules powder filler with different particle size (<53, <75, <106 μm) and volume fraction of (3, 6, 9, 12) % on some mechanical properties of unsaturated polyester resin. Bending results had revealed a decrease with the increase of volume fractions, and decrease of particle size. While modulus of elasticity increased with increasing volume fraction and decreasing of particle size. Hardness and bending strength results had shown an incremental increase with volume fraction increase and a decrease with particle size decreasing also the maximum shear stress was increased [8]. Ataíwi A. H. use chip and powder copper as reinforcement phase in polyester matrix in composite production. Mechanical characteristics like impact test and flexural strength of polymer reinforced by copper (chip and powder) were conducted. The max. flexural strength of the polymer reinforced by copper (chip and powder) are (85.13 Mpa) and (50.08 Mpa) respectively was acquired. Also, the max. observed energy of the impact test for the polymer reinforced by copper (chip and powder) are (0.85 J) and (0.4 J) respectively [9].Junjie Y. studied the effects of particle shape, particle volume fraction, and loading condition on the mechanical properties. Comparison of simulation results obtained from the established method and published experimental data is presented. Good consistency can be found. On this basis, the interfacial cohesive strength and particle shape effects on the biaxial failure strength of particle-reinforced composites with interfacial debonding were also studied. The results revealed that both interfacial strength and particle shape have significant effects on biaxial tensile failure strength[10] Anshul V. investigated the effect of metallic fillers on the mechanical properties of commercial epoxide resin. Fillers (AL, Cu) having size less than 100μm. tensile strength, compressive strength, and Vickers hardness were evaluated. The resulted showed that with addition of fillers, tensile strength gradually degraded. Both hardness and compressive increases with increases fillers content [11].

The research aims to investigate some mechanical characteristics such as (bending, impact strength and tensile strength) and thermal characteristics (thermal conductivity, thermal diffusivity and specific heat) of the prepared composites.

2. Experimental part

2.1 material used

Nickel a metal particle which was used as reinforced materials has a particle size >10μm and metallic and sliver color. The unsaturated polyester resin has been chosen as a matrix in the production of nickel- polymer composites and was supplied by (SIR) company in Saudi Arabia. MEKP is stable organic peroxide that decomposes rapidly in the presence of certain metallic carboxylate salts. MEKP is used as hardener in the work.

2.2 procedures

The viscous liquid unsaturated polyester at room temperature has a transparent pink color. The resin transforms from liquid state to solid by the addition of hardener that is produced by the same company. It is methylethylketon peroxide and is known as (MEKP) that is having a transparent liquid
form is added to the resin by percentage of 2% at room temperature. The common manufacturing method for thermoset composites is depending on hand lay-up which is done by laying polymer layer on to a tool to produce a laminate stack. After mixing and stirring it for a period of (5-15) minutes to obtain Homogeneity and to avoid the occurring of bubbles the polymer and the hardener to produce a matrix, nickel powder with various rates (2, 4, 6, 8 and 10) % is added to the matrix.

An iron mold has been used to pour the mix in. Finally the composite plates have been cut into different dimensions and shapes, for an example the tensile specimen was cut depending on ASTM standard D3032. The cast duration was occurred for a night at room temperature.

2.3 characterizations

The tensile test conducted based on (ASTM D638) at room temperature with capacity of (20KN) Applying load and strain rate of (0.5 mm/min) depending on machine class WDW-200E. Shear Strength and flexural Stress tests have been conducted based on (ASTM D790) at room temperature by three point bending test machine (Lybold Harris No.36110). The specimens were cut to the dimensions of (100*10*5) mm, the flexural strength& maximum shear stress are calculated by $F.S=3PL^2bd$, $τ=3P4bd$ where $F.S$: flexural strength (MPa), $P$: force at fracture (N), $L$: length of the sample between Predicate (mm), $b$:thikness(mm), $d$:width(mm), $τ$:maximum shear stress ( MPa), $P$:force at fracture (N), $b$:thikness (mm), $d$:width (mm). Impact resistance of the specimens was founded from the relationship $Gc=UcA$ $Gc$: impact strength of material (J/m2), $Uc$: impact energy (J). A: cross- sectional area of specimen (m2). Fracture toughness can be expressed from the relationship $Kc=\sqrt{GcE}$ $Kc$: fracture toughness of material (MPa.m1/2), E: elastic modulus of material (MPa) and this test is performed according to (ISO-180) at room temperature. Samples have been cut into the dimensions (80*10*5) mm. As Two specimens having the same dimensions of (3 x 2) mm were manufactured based on the standard specifications to study the thermal characteristics. The transient plane source (TPS) method is most common technique to study the thermal transport characteristics.

3. Results and Discussions

Figure 1 and 2 illustrates the result values of ultimate tensile strength (UTS) and fracture strength for the composites. It can be seen that the (UTS) values of composites is higher than the unsaturated polyester for each percentages due to the ductile nature of nickel that can give little more resistance before reaching the fracture. On the other hand, the high UTS of nickel composites in Figure 1 may be a direct result of the good bonding among the composites constituents with the small grain size of nickel relative to other additives. In bending test the results of Elastic modulus (E(bend.)) for the UP reinforced with composites materials for each percentage are illustrated in figure 3. It is clear that the bending elastic modulus of UP is lower than that of composites. The reason is that UP has lower hardness than composites and this is due to the decrease in the deformation (δ) by increasing surface contact area between reinforcement and matrix, and nickel particles it also gives it a little more brittleness and defects. Figure 4 and 5 show the values of flexural strength and shear stress for UP and composites materials. They show that the flexural strength & shear stress of UP is lower than that of composites due to its lower hardness. Adhesive between matrix and reinforcing material has a large effect in giving the maximum shear stress that load to increase shear stress of particle reinforced (UP) to a higher amount than that of (UP) specimen alone. Figures 6 and 7 illustrates the values of fracture toughness (Kc) and impact strength (Gc) for UP and composites materials. The results of (Gc) & (Kc) for UP are less than the composites results. The reinforcing materials show a positive influence on the bearing impact load and increased the impact energy demanded for fracturing the sample due to the UP is brittle material. [12] The interfacial interaction between the polymer and filler is significant to enhance the thermal transport of polymer particles composites. The common thermos- physical characteristics of a material which are required to calculate heat transfer such as specific heat, thermal diffusivity and thermal conductivity depending on the equation: $α= Cp /λ$. Where:$α$: Thermal diffusivity (m2/s), $λ$:Thermal conductivity (W/m.K),$ρ$: Density (g/cm3), $Cp$: specific heat (J/Kg.K).

Figure 8 illustrates the resulted thermal conductivity for various rates (wt %) of nickel particles. The thermal conductivity of the composite of 10% nickel is more than pure polyester. The improving
of thermal conductivity in this composite can be related to the improved percolation due to better formation and dispersion of the particles [13]. It can be concluded that the composite thermal characteristics are controlled by the interface thermal transport between matrix and nickel interface [14]. The thermal diffusivity has a leading role in all problems related to non-steady state heat transfer. Figure 9 shows the influence of nickel content on thermal diffusivity for the composite with the highest content of 10% nickel which increase slightly be the increase of nickel content. The results of thermal diffusivity influenced by different factors such as heat losses as a temperature dependent thermo-physical property and it highly count on materials density also the specific heat capacity has a huge influence on thermal diffusivity. Figure 1 illustrates the heat capacity of the composite that is influenced by the content of nickel. The same behaviour occurred having the specific heat capacity with high value at 10% nickel which increases as the nickel content increases.

**Figure 1.** Ultimate tensile strength of composites and UP

**Figure 2.** Fracture strength of composites and UP.
Figure 3. Modulus of elasticity of composites and UP.

Figure 4. Flexural strength of composites and UP.

Figure 5. Shear strength of composites and UP.
Figure 6. Impact strength of composites and UP.

Figure 7. Fracture toughness of composites and UP.

Figure 8. Thermal conductivity vs Nickel content.
4. Conclusions
The nickel particles have an effect on the mechanical properties of the composites studied in the work. Non-reinforced unsaturated polyester (UP) has lower mechanical properties than polymer/nickel composites materials. Tensile, bending modulus, flexural strength, shear and impact strength and fracture toughness increased with nickel particles content compared with non-reinforced UP and the thermal properties affected by the incorporation of nickel powder which increased slightly with the Ni particles content.

References
[1] Ferranti Jr. 2007 Mechanochemical reactions and strengthening in epoxy-cast aluminum iron-oxide mixtures Georgia Institute of Technology.
[2] Groover M. P. 2007 Shaping processes for polymer matrix composites John Wiley & Sons Fundamentals of Modern Manufacturing, PP.1-4.
[3] Karger-Kocsis J. 1995 Microstructural aspects of fracture in polypropylene and in its filled, chopped fiber and fiber matreinforced composites In: Karger- Kocsis J editor. Polypropylene: Structure blends and composites. London: Chapman & Hall; pp. 142–201.
[4] Pukanszky B. 1995 Particulate filled polypropylene: structure and properties In: Karger-Kocsis J editor. Polypropylene: Structure, blends and composites. London: Chapman & Hall; pp. 1–70.
[5] Karger-Kocsis J. 2000 Swirl mat- and long discontinuous fiber matreinforced polypropylene composites-status and future trends *Polym Compos* **21**: 514–22.

[6] Stokes V.K Inzinna L.P Liang E.W Trantina G.G and Woods J.T. A phenomenological 2000 study of the mechanical properties of long fiber filled injection-molded thermoplastic composites. *Polym Compos.* **21**(5): 696–710.

[7] Srivastava V.K and Shembekar P.S. 1990 Tensile and fracture properties of epoxy resin filled with flyash particles. *J Mater Sci.* **25**: 3513–16.

[8] Elia S. M 2011 Studying the Effect of Adding Sea Nodules Powders on Flexural Strength and Hardness of Unsaturated Polyester Resin *Eng. & Tech. Journal* **29**(13): 2807-10.

[9] Ali H A Laith W 2012 study some mechanical properties of polymer reinforced by copper particles *Tech. Journal* **5**(18).

[10] Junjie Y. Chenchen C. Zhi Z. Yonkun W. Baoquan S,and Yuanying 2017 The interphase influences on the particle-reninforced composites with periodic particle configuration *applied sciences published*: 23 january.

[11] Anshul V. .Srivastava K 2015 Mechanical Behavior Of Particles Reniforced Polymer Matrix Composites *International Journal of Mechanical and Production Engineering* **3**(6).

[12] Jin J .Park Y. and Yoon K. 2007 Rheological and mechanical properties of surface modified multi- walled carbon nanotube filled PET composite *Composite Science and Technology* **6**(15-16): 3434-41.

[13] Alkhazarjy K 2009 principle of non- metallic engineerring djlah pulation institute.

[14] Kumar S. Alan M. and Murthy J. 2007 Effect of percolation in thermal transport in nanotube composite *Applied letters* **90**(10).