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REGULAR ARTICLE

Effect of Particle Shape and Size on Behavior of Composite Material Using Finite Element Method

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In this paper the effect of particle shape and size on the mechanic behavior of glass-particle reinforcing Nylon matrix composite is evaluated. There are many parameters effecting on the composite such as types, size, position and shape of reinforcement material. Particle morphology has received enormous interest in particulate composite; small particles adhere strongly to the polymer, which leads to a strong reinforcing effect. The objective of this research is to investigate the influence of reinforcement shape and size with different volume fractions and for three packing (square, hexagonal and random) using finite element method. The composite is subject to unidirectional tensile loading. Numerical results are presented for a variety of particle shapes and size including circular, triangular, square and two distributions grouping these shapes together. The results show that the variation of the Von Mises and longitudinal stresses consistently increased when the shape of the reinforcement changed from triangle to square, distribution 1 and distribution 2 to circular in this order.

Keywords: Composite, Particle, Shape, Size, Traction, Finite element.

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1. INTRODUCTION

The study of microscopic of a particulate reinforced thermoplastic matrix composites using finite element (FE) analysis is the aim of the current investigation. Adding rigid reinforcement to polymer materials is an established practice in the polymer industry. By introducing a rigid second phase, substantial improvements in stiffness, strength, creep performance, and fracture toughness can be obtained. When tight tolerances or isotropic properties are required, spherical or plate-shaped particle fillers are sometimes a better choice [1]. The combination of the required properties of thermoplastics and glass particles (high strength and high modulus) is the goal of composite production [2]. Particle-reinforced materials are more attractive because they are cost-effective, isotropic, and can be processed using similar techniques for monolithic materials [3]. The effective behavior of macroscopically isotropic, particle strengthened two-phase composites is primarily determined by the fabric behavior and volume fractions of matrix and inhomogeneities. Details of the geometrical arrangement of the constituents and therefore the shapes of the particles play solely secondary roles [4]; a decrease within the particle diameter (circular) doesn't have an effect on the composite [5].

Recent research on nano-particles has gained traction, with various studies conducted to explore the current state of this field. This discussion provides an in-depth analysis of the published articles, offering insight into potential applications of this technology. By examining current trends, potential improvements and applications, this research can help to further our understanding of nano-particles composite and their utility. In their study, K. Mansouri et al., [6, 7] investigate the broken and shape effect of particles reinforced composite, the results shows that the circular particles have the better resistance than all the other shapes. O. Guven et al., [8] analyses the shape for the minerals ground as single and mixture were performed, and their flotation behaviors determined with the micro-flotation experiments was studied, the particle shape of chromite favored serpentine in the mixture system which in turn suggested that the mineral with the high hardness value dominates the shape characteristics in binary grinding conditions. A. O. Balod et al., [9] studied the influence of reinforcement cross section area of fiber and particulate shape using finite element method. They concluded that when the volume fraction increase the von Mises stress of reinforced composite sheet increases while displacement decreases and the von Mises stress affected by fiber cross section area and particulate shape. A. Muc and M. Barski [10] give some information on the optimal design of the effective anisotropic properties taking into account the shape of magnetic particles. P. Shankaranarayana [11] proposed a study of microscopic and macroscopic response of a particulate reinforced metal matrix composites using

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finite element analysis, a technique is presented for the generation of artificial microstructures containing spherical and ellipsoid shaped inclusions. A. Berkia et al., [12] investigate the parametric homogenization models for nano beams materials which are composites made up of nanotubes; the work elucidates the complex interplay between nano-beam dimensions, materials and intrinsic size effects. B. Rebai et al., [13] investigates the effects of various homogenization models of nano plate, the accuracy of the proposed analytical model was verified by comparing their results with those obtained from other models available in the literature. The influence of particle dimension ratio on the mechanical properties was experimentally investigated by A Slipenyuk et al., [14] they concluded that the modulus of elasticity decreases due to increase particle ratio and the yield stress deceases with increasing particle dimension ratio.

The objective of this research is to investigate the mechanical behavior of Nylon thermoplastic matrix composites reinforced with E-glass particles, under unidirectional tensile loading by finite element analysis in which different shape are used (circular, triangular, square and two distributions grouping these shapes together (Fig. 1)) and for different packaging (square, hexagonal and random).

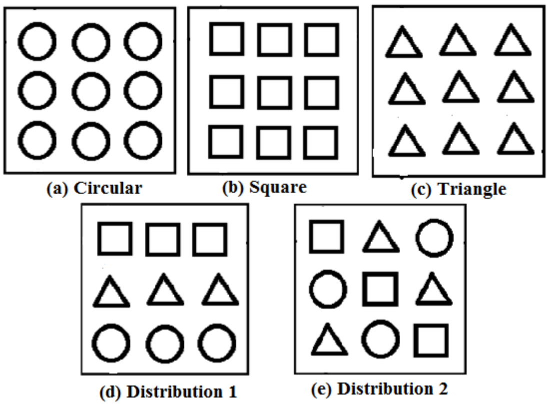


Fig. 1 – Different shapes used in simulation (square arrangement)

2. SHAPE PARAMETERS

Shape refers to the external form, contours, or outline of something regardless of its absolute size, whereas International Standards defines particle shape as the envelope formed by all the points on the surface of the particle [15]. As seen in Fig. 2, the particle shape of the particles can be very diverse, e.g., acicular, angular, flaky, lamellar, granular, irregular, spherical, modular, dendritic, needle-like and crystalline.

The particles are used to increase the modulus of the matrix, reduce permeability, and reduce ductility. Young's modulus is the stiffness (ratio between stress and strain) of the material in the elastic phase of the tensile test. Since the rigidity value of hard particles is much higher than that of the matrix, it can be significantly improved by adding micro and nano particles to the polymer matrix [16]. A particle may have one dimension or no long dimension. Composite materials consist of particles of one material dispersed in a matrix of another material.

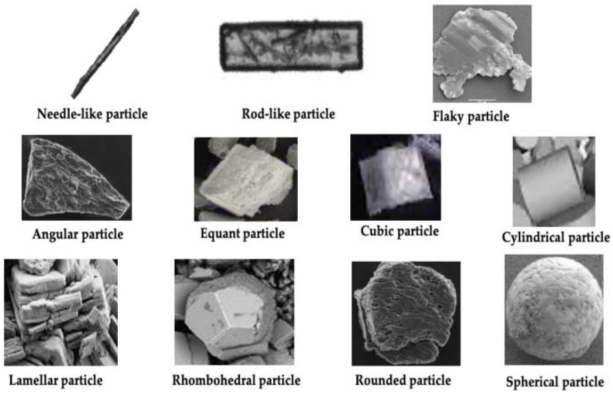


Fig. 2 – Industrial particles of various shapes [15]

The particles are added to the liquid matrix and then solidify in some process. The particles can be treated or untreated during the enhancement process. They are used to increase the strength or other properties of cheap materials during reinforcement with other base materials [17].

3. MODELING

In what follows, we will study the shape effect of (N_p = 9) glass particles on the mechanical behavior of a composite, the matrix is assumed have square form with length l_m = 155.425 (μm), particles dimension l_p and d_p are calculated for different value of V_f and are resumed in Table 1 [6].

Where :

V_f: Particle volume fraction
$V_{particle}$: Particle volume
V_{total}: composite volume
N_p: Number of Particles
l_m: matrix length
l_p: Particle length
d_p: Particle diameter

The finite element software Castem was used to develop the models and generate the results. Composites with particles shape: triangle, square, circular were modeled for three type of arrangement (square, hexagonal and random). To understand the effect of the shape reinforcement particles more easily, plane strain element behavior was selected in this study. Particles were assumed to be perfectly bonded to the matrix material. Composites were modeled and meshed with triangular elements to achieve the best convergence and accuracy of the results. The composite is subjected to a uniform tensile stress σ.

3.1 Particulate Property

Each constituent have an isotropic property, a fine mesh of elements is used because the model is small [18]. For simplicity, it is assumed that all particles have the same diameter d_p [19] for the circle shape and the same length l_p for the other shapes. Due to axisymmetry, the specimen can be considered as a 2-D elastic body, following parameters are used in all calculations [20]:

1. Glass particles: Young's modulus E_p = 64 Gpa. Poisson ratio ν_p = 0.2 and density of ρ_p = 2.54 g/cc.
2. Nylon 66: Young's modulus E_m = 3 GPa. Poisson ratio ν_m = 0.35 and density of ρ_m = 1.14 g/cc.

3.2 Boundary Conditions

The boundary conditions representing the application of tensile loads to particles composite (See Fig. 3).

– $x = 0$: the displacement $Uy = 0$,
– $x = l_m$: the displacement $Uy = 0$,

The x axis is in the direction of length, a load $F_x = 5.65 \times 10^{-8} N/\mu m^2$ [21] was applied at the end faces of the matrix ($x = 0$ and $x = l_m$).

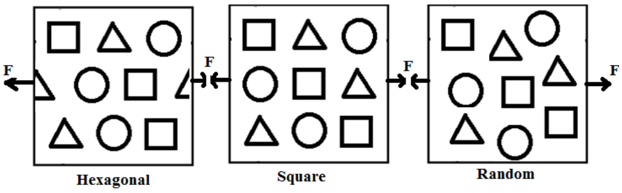


Fig. 3 – Boundary conditions for composite reinforced with 9 particles (Distribution 2)

4. RESULT AND DISCUSSION

Fig. 4a represents the Von Mises stress distribution in composite reinforced with 9 particles for distribution 1. It can be seen that's the stresses had high concentration in particles ends for square shape. For triangular, the stresses are highest in the base of the triangle which is in the parallel to the applied force direction. For circular shape no stress concentration. In Fig. 4b and for distribution 2, it can be seen that's the same observation are concluded.

Fig. 5a represents the evolution of V_{on} Mises stresses according to the volume fraction of the particles for different shapes and for square arrangement. It is noted that's the values of the stresses in the particles of triangular, distribution 1, distribution 2 and square shapes are much higher compared to the circular shape. It can be assumed that the angles in particle shape increase the stress concentration in the composite. Note that's when the volume fraction of particles increases the Von Mises stresses decrease for all shapes but only triangular shape increases when $V_f = 0.2$, the reason is that the space between particles became so small which leads to increase in stress concentration.

Table 1 – Particle length calculation for different shape (V_f = 20 %) [6]

№	Particles	Shape	Particle length [μm]	l_p values [μm]
1	Triangle equilateral	L_p	$l_p = \sqrt{2V_f l_m^2 / N_p \times \sin 60^0}$	$l_p = 26.49.$
2	Square	L_p	$l_p = \sqrt{V_f l_m^2 / N_p}$	$l_p = 17.37.$
6	Circular	d_p	$d_p = \sqrt{4V_f l_m^2 / \pi N_p}$	$d_p = 19.61.$

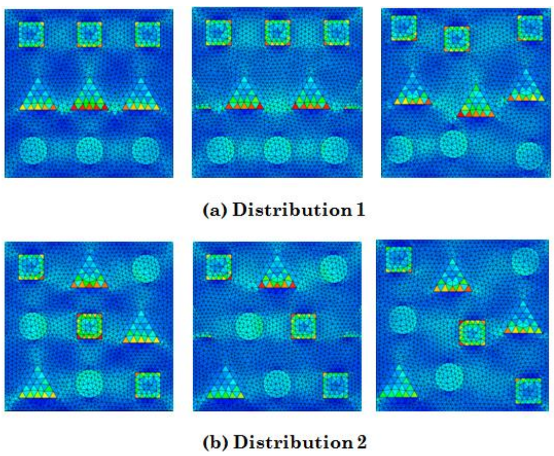
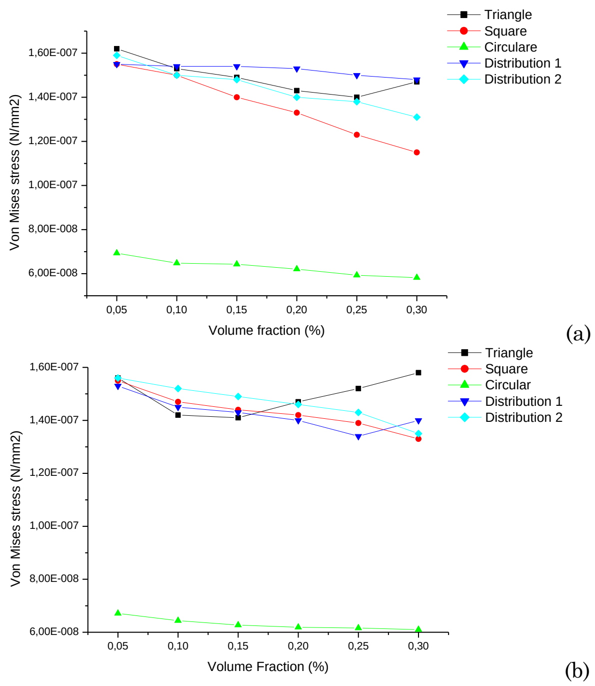
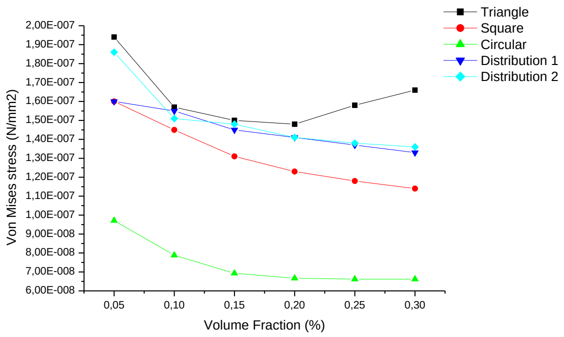


Fig. 4 – Von Mises Stress distribution for different shapes of particles with V_f = 20 %

Fig. 5b and Fig. 5c represents the stresses for the other arrangements (random and hexagonal successively), same remark as for the square arrangement.





(c)

Fig. 5 – Evolution of Von Mises stress on particle volume fraction, (a) Square, (b) Random and (c) hexagonal packing

It can be seen that's the circular shape of particles have the best resistance than all other shapes because there is no stress concentration.

We can deduce from the previous results that's the circular shape is the ideal shape for better resistance of composites reinforced by particles.

5. CONCLUSION

In conclusion, the effect of particle shape and size on behavior of Nylon/glass particle composite is studied. When the volume fraction of reinforcement increased, size of the particles decreases, the total surface between the matrix and the reinforcements increased. For lower volume fractions of glass particles, stress values are higher. For higher volume fractions (30 %), stress values are lower for the three arrangements and for all shapes. Circular particles have the lower stress values due to their shape who affect the distribution of stress concentration. These results imply that particles size and shape has little effect on composite. Smaller particles have a higher total surface area for given particle loading. This indicates that the strength increases with increasing surface area of the filled particles through a more efficient stress transfer mechanism. However, composite reinforced with spherical particles showed high strength than all other shapes.

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Вплив форми та розміру частинок на поведінку композитного матеріалу з використанням методу скінченних елементів

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У цій статті оцінюється вплив форми та розміру частинок на механічну поведінку нейлонового матричного композиту, що армує скляними частинками. Існує багато параметрів, що впливають на композит, наприклад типи, розмір, положення та форма армуючого матеріалу. Морфологія частинок викликала величезний інтерес до композитних частинок; дрібні частинки міцно прилипають до полімеру, що призводить до сильного зміцнюючого ефекту. Метою цього дослідження є дослідження впливу форми та розміру арматури з різними об'ємними частками та для трьох упаковок (квадратної, шестикутної та випадкової) за допомогою методу скінченних елементів. Композит піддається односпрямованому розтягуванню. Чисельні результати представлені для різноманітних форм і розмірів частинок, включаючи круглі, трикутні, квадратні та два розподіли, групуючи ці форми разом. Результати показують, що зміна фон Мізеса та поздовжніх напружень постійно зростала, коли форма арматури змінювалася з трикутної на квадратну, розподіл 1 і розподіл 2 на круглий у цьому порядку.

Ключові слова: Композит, Частинка, Форма, Розмір, Тяга, Кінцевий елемент.