JOURNAL OF NANO- AND ELECTRONIC PHYSICS *ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ*
Vol. **15** No 5, 05007(4pp) (2023) Том **15** № 5, 05007(4cc) (2023)

Effect of Broken Glass Particle on Stress Transfer of Nylon Matrix Composite

K. Mansouri[1,2,*], M. Chitour[1], A. Berkia[1], B. Rebai[1], F. Khadraoui[1], H. Djebaili[1,2]

[1] *University Abbes Laghrour, Khenchela, 40000, Algeria*
[2] *Laboratory of Engineering and Sciences of Advanced Materials (ISMA), Khenchela, 40000, Algeria*

(Received 25 July 2023; revised manuscript received 19 October 2023; published online 30 October 2023)

Some of the material demands in the advanced industries cannot be fulfilled by monolithic materials. Therefore, composite materials have been developed. The combination of desired properties of thermoplastics and glass particles (high strength and high modulus) is the aim of composites production Particles are becoming increasingly popular reinforcing elements in products made by injection molding. Particles reinforcement allows the polymer to be processed employing the same methods as those used for unreinforced polymers. The loads are not directly applied to the reinforcements, but they are applied to the matrix and some of the loads applied are transferred to the particles. The development of micromechanics equations for the particulate composites follows along the same lines as those for the short fiber reinforced composites. Particles are used to increase the strength or other properties of inexpensive materials during reinforcement with other matrix materials. The objective of this study is to analyse the particle breaking effect in composite made of nylon 66 (PA) matrix reinforced with glass particles, in which the particles diameters of 19.61, 26.15, 39.22 and 78.45 μm were used. A volume fraction of 20 % was assumed in each model.

Keywords: Broken particle, Nylon matrix, Composite, Stress transfer, Finite element.

DOI: 10.21272/jnep.15(5).05007 PACS numbers: 81.05.Qk, 81.07.Lk, 81.07.De

1. INTRODUCTION

The different types of composite materials are defined according to the nature of the reinforcements which can be of very different natures. The reinforcements are particles, short or continuous fibers [1]. The addition of stiff reinforcements in thermoplastics is an established practice in the polymer industry, introducing a stiff second phase, substantial improvements in stiffness, strength, creep performance, fracture toughness, can be obtained [2]. Fibers are often used as reinforcement, although this often results in anisotropic properties. This can cause problems and variations in component dimensions. The high costs and technical difficulties associated with the evolution of the manufacture of fiber reinforced composites sometimes limit their use in many applications [3]. Particulate fillers in the form of spheres can sometimes be a better choice when tight tolerances or isotropic properties are required [2].

A composite material is said to be particulate when its reinforcement is in the form of particles that do not have a preferred dimension (Fig.1). They are used to increase the properties of materials during the reinforcement of the matrix [4], they are used to improve characteristics such as the rigidity of the matrix, the resistance to abrasion or the resistance to temperature, to increase the modulus of the composite, decrease permeability and also decrease ductility. They are also often used to reduce the cost of the material [5]. The geometric arrangement of the constituents and the shapes of the particles only play a secondary role [6], generally, the particles are spherical, ellipsoidal, polyhedral or irregularly shaped, they are added to a liquid matrix which subsequently solidifies in a certain process.

Young's modulus is significantly improved by adding micro and nanoparticles to a polymer matrix because the hard particles have much higher stiffness values than the matrix [7]. The particles can be treated or untreated during reinforcement. Particle-reinforced materials are more attractive due to their cost-effectiveness, isotropic properties, and ability to be processed using technology similar to that used for monolithic materials [8]. The behavior of the macroscopically isotropic particle-reinforced two-phase composite is mainly determined by the behavior of the constituent materials, the volume fraction of the matrix and the inhomogeneities.

Fig. 1 – Different types of particles [5]

The purpose of this work is to analyze the broken particle effect of glass particle reinforced nylon 66 (PA) matrix composites considering the interaction between the matrix and particles interface. Particle reinforced composite is subjected to the longitudinal tensile loading.

2. FAILURE IN PARTICLE COMPOSITE

The incorporation of the particles in a matrix causes stress concentrations in the peripheries of the particle when the composite is subjected to loading [9]. Failure processes in particle-reinforced composites are related to the fundamental problem of a matrix crack interacting with second-phase particles [10]. The design against brittle fracture in composites is of critical importance [11]. Transmission electron microscopy has been used, but it is difficult to produce samples thin enough for the technique to be useful due to the presence of fragile reinforcements [12]. According to Vincent CARMONA [13], when the damage sequence is observed, the first visible mechanism is the rupture of large particles.

* mansouri.khelifab@univ-khenchela.dz

Smaller particles fracture later. The crack develops perpendicular to the direction of tension (Fig. 2). At low volume fraction V_f, the failure mode is mainly due to renfort tearing [14].

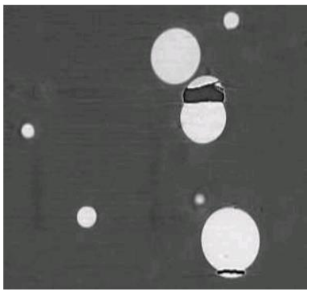

Fig. 2 – Particle failure [13]

3. FINITE ELEMENT MODELING

All the finite element models had a homogeneous distribution of reinforcement particles. The finite element software CASTEM was used to develop the models and generate the results. Composites with four different diameters of circular glass particles of 19.61, 26.15, 39.22 and 78.45 μm were modeled (Table 1) [15]. Composites were modeled and meshed with triangular elements to achieve the best convergence and accuracy of the results. The composite was subjected to a uniform tensile stress σ.

Table 1 – Composite dimensions for different particles [15]

N_p	V_f (%)	l_m (μm)	d_p (μm)	r_p (μm)
1	20	155.425	78.45	39.22
4	20	155.425	39.22	19.61
9	20	155.425	26.15	13.07
16	20	155.425	19.61	9.80

3.1 Composite Property

Each element will have an isotropic property. The model is small, so a fine mesh of elements was used [16]. For simplicity, it is assumed that all particles have the same diameter d_p [17]. Due to axisymmetry, the specimen can be considered as a 2-D elastic body, Following parameters are used in all calculations [15]:

1. Reinforced glass fibers with Young's modulus $E_f = 64$ GPa. Poisson ratio $\nu_f = 0.2$ and density of $\rho_f = 2.54\ g/cc$.
2. Matrix is of nylon 66 (PA) with Young's modulus $E_m = 3$ GPa. Poisson ratio $\nu_m = 0.35$ and density of $\rho_m = 1.14\ g/cc$.

3.2 Boundary Conditions

The boundary conditions represent the application of tensile loads to particles-filled composite, i.e. $x = 0$ and $x = l_m$, $U_y = 0$, matrix and particle have zero movement in the *Y*-direction (Fig. 3). Here the *X*-axis is in the direction of length and the model is axis-symmetric to it. We have applied $F_x = 5.65 \cdot 10 - 8\ N/\mu m^2$ [18] to the end faces of the matrix i.e. at $x = 0$, $x = l_m$.

4. RESULTS AND DISCUSSION

In order to study the behavior of multi-particle composite under simple tensile loading, the composite is subjected to a uniform tensile stress σ and for the same volume fraction $V_f = 20$ %.

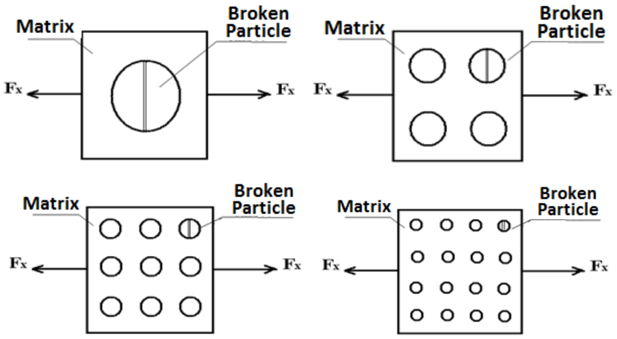

Fig. 3 – Boundary conditions for the composite reinforced with 1, 4, 9 and 16 particles for $V_f = 20$ %

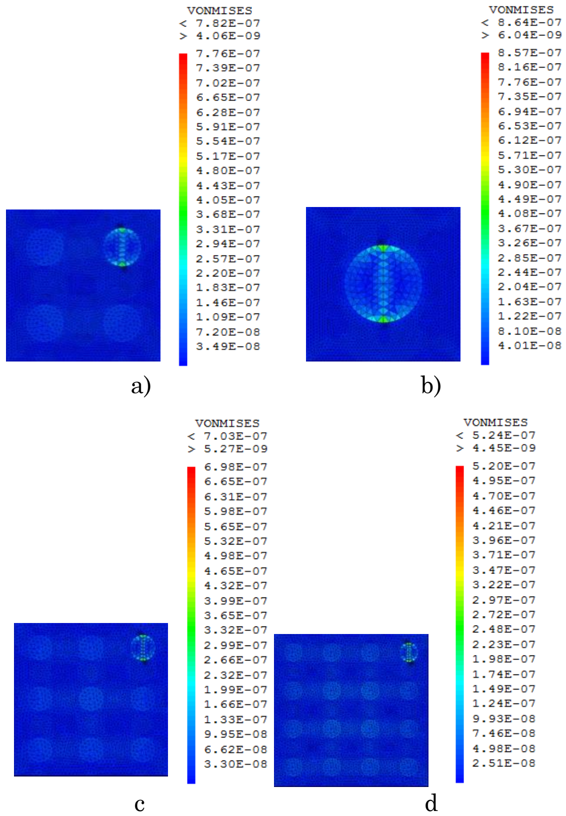

Fig. 4 – Von Mises stresses distribution for $V_f = 20$ %

Fig. 4 represents the distribution of the Von Mises stresses in the damaged models, we notice that the stresses are not concentrated in all the particles, but in the particle broken with a high value compared to undamaged models [15].

In Fig. 5, it is visible that, when the diameter of the particles decreases, the stresses also decrease and this for the same volume fraction (in both cases); and the same is true for the longitudinal stresses sigma xx.

We have presented in Fig. 6 the curves of the evolution of the Von Mises stresses in the two cases (broken and not broken) as a function of the diameter. We notice on this figure, that in the case of a broken particle, the stresses decrease according to the diameter. On the other hand, in the case of a (non-broken) particle the stresses decrease slightly and then we can say that the reduction in diameter has almost no effect on the strength of the composite.

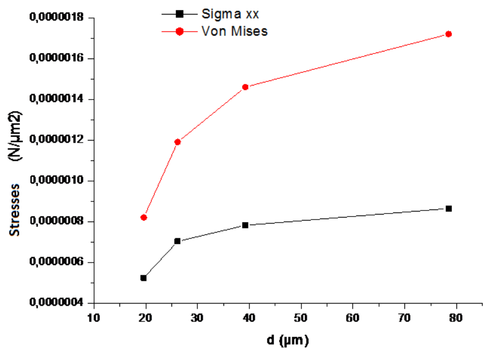

Fig. 5 – Evolution of Von Mises and longitudinal stresses as a function of particle diameter

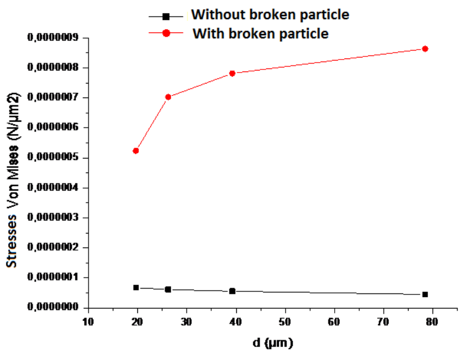

Fig. 6 – Evolution of Von Mises stresses and function of particle diameter

It can be deduced that the reduction in diameter is not beneficial in the case of unbroken particles.

5. CONCLUSION

This study concerns the evolution of Von Mises stresses in a particle-reinforced thermoplastic matrix composite. The use of glass particles in a thermoplastic matrix constitutes a composite with much improved thermomechanical characteristics compared to resins alone. The glass reinforcements considered here are of type E. These reinforcements are the most common for mass market composites. A remarkable property of glass is that it exhibits a brittle isotropic linear elastic mechanical behavior, which is moreover independent of the temperature below its softening temperature. The prediction of the strength of composites is difficult; the difficulty comes from the fact that the strength of composites is determined by the failure behaviors which are associated with the extreme values of parameters such as adhesion at the interface. Since the particles are subjected to higher stresses than the matrix, stress concentrations appear at the interfaces and activate the damage mechanisms. Reducing the diameter has almost no effect on the composite. On the other hand, in the case of a broken particle, the reduction in diameter leads to a reduction in the Von Mises stresses and longitudinal stresses (for the same volume fraction). The impact of a single particle break is less significant (case of a reduced diameter), and this is due to the increase in the contact surface.

REFERENCES

1. Mustapha El Mouden. « Une nouvelle méthode d'homogénéisation des matériaux composites élastiques ». Université Paul Verlaine – Metz (1995).
2. A. Sjogren: "Failure Behaviour of Polypropylene/Glass Bead Composites", Luleå University of Technology S-971 87 Luleå, Sweden (1995).
3. Subodh K. Mital, Pappu L. N. Murthy, Robert K. Goldberg, *National Aeronautics and Space Administration (NASA),* 1996.
4. P. Kamalbabu, G.C. Mohan Kumar, *Procedia Mater. Sci.* **5**, 802 (2014).
5. Matthieu AMBID, « Evaluation de nanocomposites polypropylène/silicate pour l'isolation électrique: Etude des phénomènes de polarisation, de conduction et des propriétés optiques», University Toulouse III - Paul Sabatier (2007).
6. Helmut J. Böhm, A. Rasool, *Int. J. Solid. Struct.* **87**, 90 (2016).
7. S.Y. Fu, X.Q. Feng, B. Lauke, Y.W. Mai, *Composites Part B*, **39**, 933 (2009).
8. N. Chawla, Yu-Lin Shen, *Adv. Eng. Mater.* **3** No 6, 357 (2001).
9. B. Lauke, "Fracture toughness modelling of polymers filled with inhomogeneously distributed rigid spherical particles", *Exp. Polym. Lett.* **11** No 7, 545 (2017).
10. Wenhai Wang, Keya Sadeghipour, George Baran, *Compos. Part A Appl. Sci. Manuf.* **39** No 6, 956 (2008).
11. Shao – Yun Fu, Xi – Qiao Feng, *Composites: Part B* **39**, 933 (2008).
12. J.F. COLLINS B.Sc. Hons, *"The strength and failure behaviour of short glass fibre reinforced polyamide 6"*, University of Surrey (1981).
13. Vincent CARMONA, *"Etude de l'endommagement de matériau composite par tomographie X et émission acoustique"*, Institue National des Sciences Appliquées de Lyon, (2009).
14. Paul Tyrrel Curtis B.A. Hons, "*The strength of fibre filled thermoplastics*", University of Surrey (1976).
15. K. Mansouri, H. Djebaili, M. Brioua, *J. Nano- Electron. Phys.* **12** No 5, 05004 (2020).
16. S. Houshyar, R.A. Shanks, A. Hodzic, *Exp. Polym. Lett.* **3** No 1, 2 (2009).
17. H.F. Lei, Z.Q. Zhang, B. Liu, *CSTE* **72**, 506 (2012).
18. Prince, M. Verma, S. Singh, *IJERA* 287 (2012).

Вплив розбитої скляної частинки на передачу напруги нейлонового матричного композиту

K. Mansouri[1,2], M. Chitour[1], A. Berkia[1], B. Rebai[1], F. Khadraoui[1], H. Djebaili[1,2]

[1] *University Abbes Laghrour, Khenchela, 40000, Algeria*
[2] *Laboratory of Engineering and Sciences of Advanced Materials (ISMA), Khenchela, 40000, Algeria*

Монолітні матеріали не повністю можуть задовольнити вимогам до матеріалів у передових галузях виробництва і технологій, тому були розроблені композиційні матеріали, в яких поєднувались властивості термопластів і частинок скла (наприклад, висока міцність). Частинки стають все більш популярними армуючими елементами у виробах, виготовлених методом лиття під тиском. Зміцнення частинками дозволяє обробляти полімер за допомогою тих самих методів, що й для неармованих полімерів. Навантаження не прикладаються безпосередньо до арматури, але вони прикладаються до матриці, і частина прикладених навантажень передається на частинки. Розробка рівнянь мікромеханіки для твердих композитів відбувається в тому ж порядку, що й для композитів, армованих короткими волокнами. Частинки використовуються для підвищення міцності або інших властивостей недорогих матеріалів під час армування іншими матеріалами матриці. Метою цього дослідження є аналіз ефекту руйнування частинок у композиті, виготовленому з матриці нейлону 66 (PA), армованого частинками скла з діаметрами 19,61; 26,15; 39,22 і 78,45 мкм. У кожній моделі було прийнято об'ємну частку 20 %.

Ключові слова: Розбита частинка, Нейлонова матриця, Композит, Передача напруги, Кінцевий елемент.