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Fabrication and mechanical properties of silicon carbide nanowires/epoxy resin composites

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Abstract

An experimental investigation was carried out to study the fabrication of silicon carbide nanowires (SiC NWs)/epoxy resin composites. This material could exhibit excellence mechanical properties for example, hardness, wear resistant and especially lightweight which may be used to replace metal parts in vehicles. The SiC NWs/epoxy resin composites were prepared by using the ultrasonic mixing and casting techniques. The physical and mechanical properties such as density, tensile strength, hardness and wear test of composite samples were examined. Furthermore, microstructures of samples were also investigated by scanning electron microscopy (SEM). It was found that the ultrasonic mixing could be used for fabricating high wear strength samples of SiC NWs/epoxy resin composites.
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1. Introduction

In the recent years, there is a great need for composites because the combination of two or more materials can lead to enhance performance and outstanding properties compared to their constituents [1,2]. Especially, the polymer-based composites reinforced with a small percentages of strong fillers can significantly improve the mechanical, thermal and barrier properties of the pure polymer. Moreover, these improvements are achieved through conventional processing techniques without any detrimental effects on processability, appearance, density and aging performance of the matrix [3]. The realization of their unique properties, it has been considering for a wide range of applications including packaging, coating, sport, electronics, aerospace industries, aircraft and military, automotive, and marine engineering [3–6]. The conventional fibers, for examples, glass-fiber, carbon-fiber and aramid-fiber are widely used in nowadays. However, these materials are still limited in some applications, especially, the aircraft engine and aerospace industries which need high temperature materials, high mechanical properties that are lightweight [7]. Therefore, there are many works focus on the reinforcing polymer-based materials have incorporated various particle/whisker-type fillers especially, the functionally graded materials (FGMs) to fabricate the high performance materials for space-planes [8,9]. The new type filler, silicon carbide nanowires (SiC NWs) have been attracting considerable attention due to their excellent properties such as high thermal stability, high thermal conductivity, good mechanical properties and chemical inertness [10,11]. Besides, it has been suggested as good reinforcement materials and suitable to be used as the reinforcing material for composites due to their much larger strength over their bulk counterparts and strong interfacial bonding [12]. It is reported that the elastic modulus and ultimate bending strengths of SiC nanorods with several tens of nanometer thick were 610–660 and 53.4 GPa, respectively. The strength of these nanorods is a factor of two or more times higher than earlier observations for

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SiC whiskers of micrometer diameter [13]. Therefore, they can be used in nanoelectronics, field emission device, biomedical engineering, nanocomposites and applications in high temperature nanoscale devices [10,14,15]. Although there are many research works on SiC NWs, most of the works focus on the fabrication of SiC NWs and properties of SiC/ceramic composites [12,16–18]. However, improvement properties of materials by using SiC NWs as fillers in polymer matrix composites have not yet been reported.

In this work, composites samples between SiC NWs and epoxy resin were fabricated using ultrasonic mixing and casting techniques. The reinforced fiber, SiC NWs was synthesized by current heating technique (CHT). Physical and mechanical properties such as hardness, wear resistance, tensile strength and density of the composites samples were investigated. Moreover, microstructure of samples was determined using SEM technique.

2. Experimental procedure

The SiC NWs were synthesized via current heat technique (CHT) [19]. The raw materials, carbon powder (ultra high pure graphite, 99.9%), SiO_2 (Silica gel 60, Fluka) and Al_2O_3 (Extra pure, 98%, Reidel-de Haen) were mixed and pressed into rod shape with 12 mm in diameter and 25 mm in length. The rod was heated by DC power supply for 5 min under argon atmosphere. SiC NWs was taken out from surface of the rod were ground by using agate mortar for 10 min to get rid of hard agglomeration. A matrix was created by mixing epoxy resin (Thai Epoxy Resin Ltd., Thailand) with its hardener in the ratio 100:27 by volume. The density of the matrix is 1.176 g/cm^3. To fabricate composites, firstly, SiC NWs were added into epoxy resin with the different ratios varying from 5% to 15% of volume. Firstly, the mixtures of epoxy resin and SiC NWs were dispersed for 3 h in an ultrasonic bath. Secondly, hardener was added into the mixture and mixed in ultrasonic bath for 5 min. Thirdly, the mixture was poured into the rubber mould in the dog-bone shape (Fig. 1) with a sample thickness of 1 mm. It is noted that mylar films were put at the upper and the lower of the samples in order to obtain a smooth surface. Finally, the composite samples were left to settle at the room temperature for one day and then removed from the mould. Density of samples was measured by using Archimedes method. Tensile strength of the samples was measured by the universal testing machine (Lloyd Instruments, LRX) with a cross-head rate at 50 mm/min. The hardness was tested by Knoop's hardness testing machine (HK, Brooks Inspection Equipment Ltd., England). The wear resistance was examined by the Pin-on-Disk Tribometer with ball radius of 4 mm. Moreover, the microstructure of the composites samples was investigated by SEM.

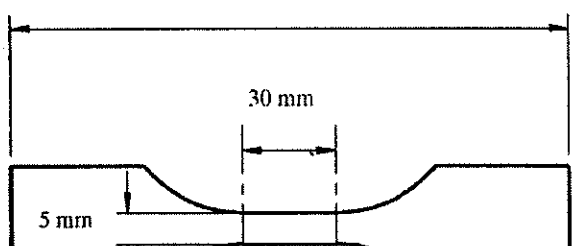

Fig. 1. The tensile test of composites samples.

3. Results and discussion

Table 1 shows density, hardness, width of wear track and tensile strength values of SiC NWs/epoxy resin composite samples. The results showed that density of composites samples increased with increasing of SiC NWs content which is in the range of 1.1455–1.1567 g/cm^3. However, it is noted that the density of the composites samples is higher than pure SiC NWs (0.996 g/cm^3) and slightly less than that of the pure epoxy resin (1.176 g/cm^3). Moreover, the hardness (HK) and tensile strength are in the range of 1.3–6.3 HK and 5.40–23.81 MPa, respectively. Furthermore, it is observed that the widths of wear track of samples are in the range of 329–550 μm. It is observed that hardness and tensile strength of 15 vol% SiC NWs composites increased to 384% and 341%, respectively, and the wear track of samples decreased to 40% when compared with that of pure epoxy resin. Fig. 2 shows the relationship between coefficient of friction and distance, it shows that friction values of pure epoxy resin are much higher than that of composites. The coefficient of friction of pure epoxy decreased to 83% when adding the SiC NWs into polymer phase. It could be assumed that adding SiC NWs into polymer-based, epoxy resin would decrease the friction and promote the wear resistance of the pure polymer. Fig. 3 shows the photographs of the width of wear track of pure epoxy resin and composites samples. It exhibits that the width of wear track are dramatically decreased (from 550 to 329 μm) with increasing of SiC NWs (0–15 vol%) contents which confirm that wear resistance of soft and ductile materials could be improved by using the SiC NWs filler.

Table 1
The density, hardness, width of wear track and tensile strength of composites samples

vol% of SiC NWs (%)	Density (g/cm^3)	Hardness (HK)	Width of wear track (μm)	Tensile strength (MPa)
0	1.176	1.3	550.0	5.4
5	1.14549	3.7	371.0	9.40
10	1.14747	4.7	356.0	15.41
15	1.15674	6.3	329.8	23.81

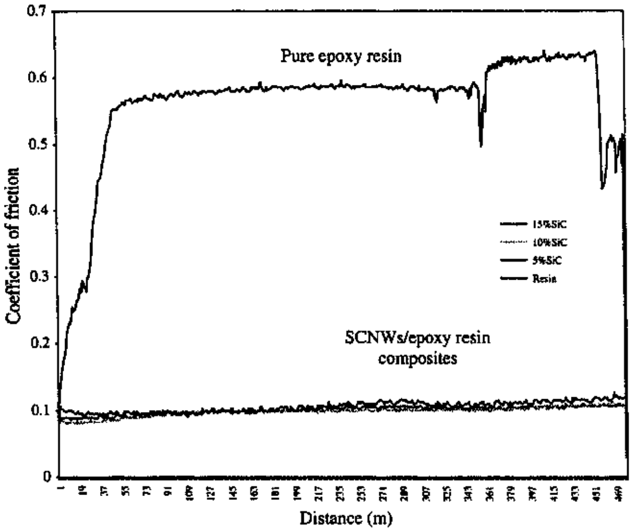

Fig. 2. Wear resistance of pure epoxy resin and SiC NWs/epoxy resin composites.

Fig. 4 shows the typical SEM micrographs at different magnifications and EDS spectrum of the obtained products. It reveals that the products consist of a large quantity of wire-like nanostructures with several micrometers in length and diameters varying from 50 to 70 nm. It is also revealed that SiC NWs were randomly oriented with straight or curved morphologies. These nanowires generally display smooth surface and very uniform diameter. Besides, the catalyst particles are observed at the end tip of wires as shown in the higher magnification SEM micrograph (Fig. 4). The EDS analysis showed that the elements of nanowires with a wrapping layer contain silicon, carbon and oxygen. The wrapping layer is thought to be SiO_2. This may be due to the reaction between SiC NWs and the remaining oxygen in the furnace. Fig. 5 shows the SEM micrographs of composites samples with different SiC NWs contents. It can be seen that the brighter phase is the filler phase (SiC NWs) whereas, the grey phase is matrix phase (epoxy resin). The fracture surface of the nanocomposites was coarse, which may imply that the composites have good toughness because of the presence of nanowires. Mostly area covered with polymer phase when small quantity of SiC NWs (1.0 vol%) was added into the sample as shown in Fig. 5a. However, very well distribution of nanowires can be obtained when the content of SiC NWs is increased for 5 vol% and 10 vol%, respectively. Moreover, it shows that epoxy resin evenly impregnated throughout the nanowires, which indicates good resin impregnation (Fig. 5b and c). Fig. 5d shows the micrograph of 15 vol% composites, it is found that the SiC NWs was covered by polymer matrix and some parts of SiC NWs embedded into epoxy resin which may cause to the much higher of mechanical properties. Therefore, it can be reported that adding the nanowires into the polymer-based phase can promote the mechanical of single phase polymer-based especially, hardness and tensile strength.

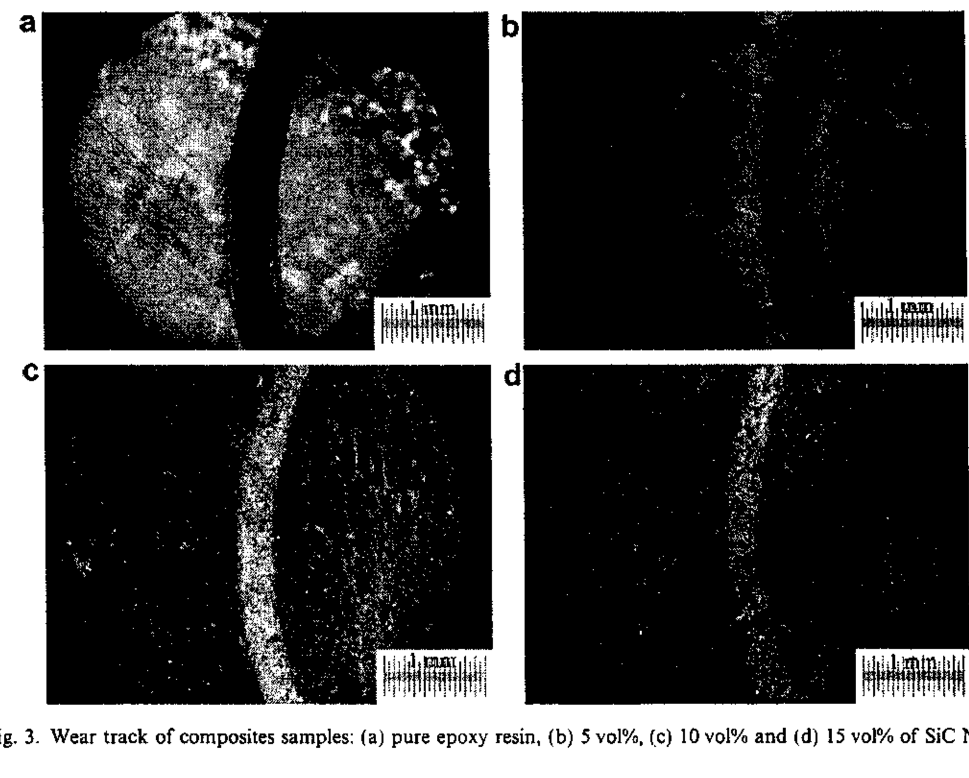

Fig. 3. Wear track of composites samples: (a) pure epoxy resin, (b) 5 vol%, (c) 10 vol% and (d) 15 vol% of SiC NWs.

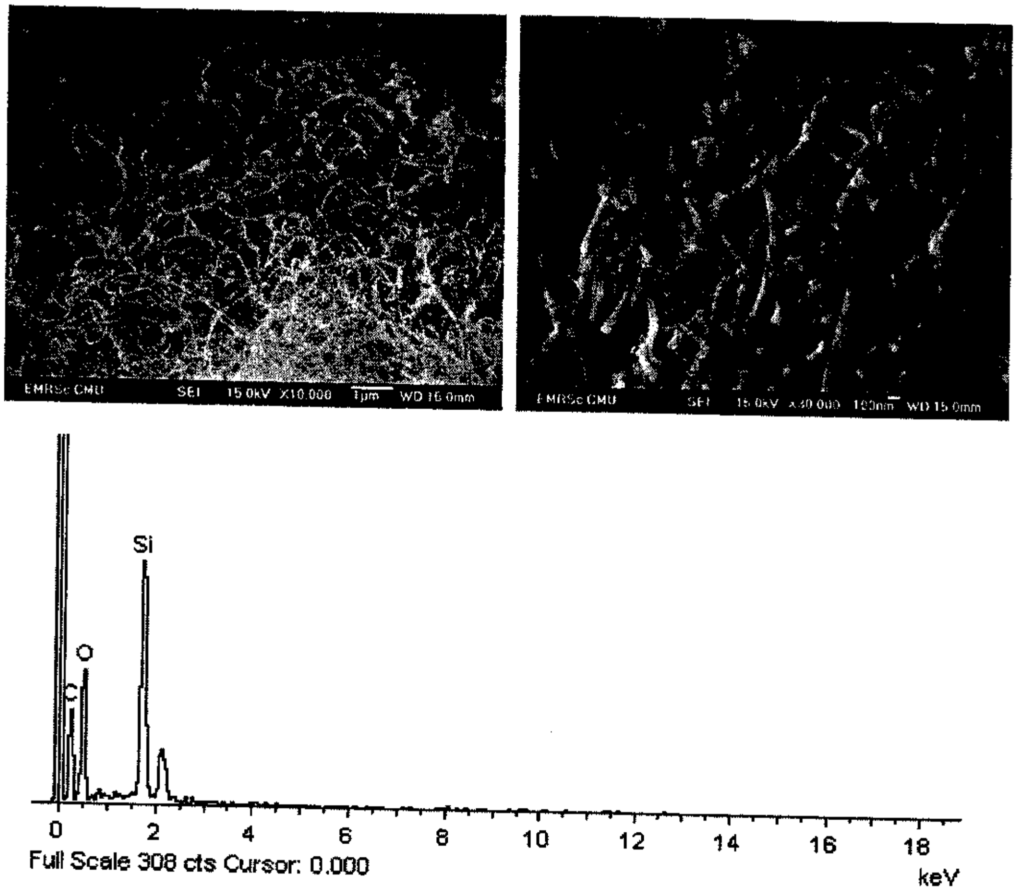

Fig. 4. SEM micrographs and EDS spectrum of SiC NWs.

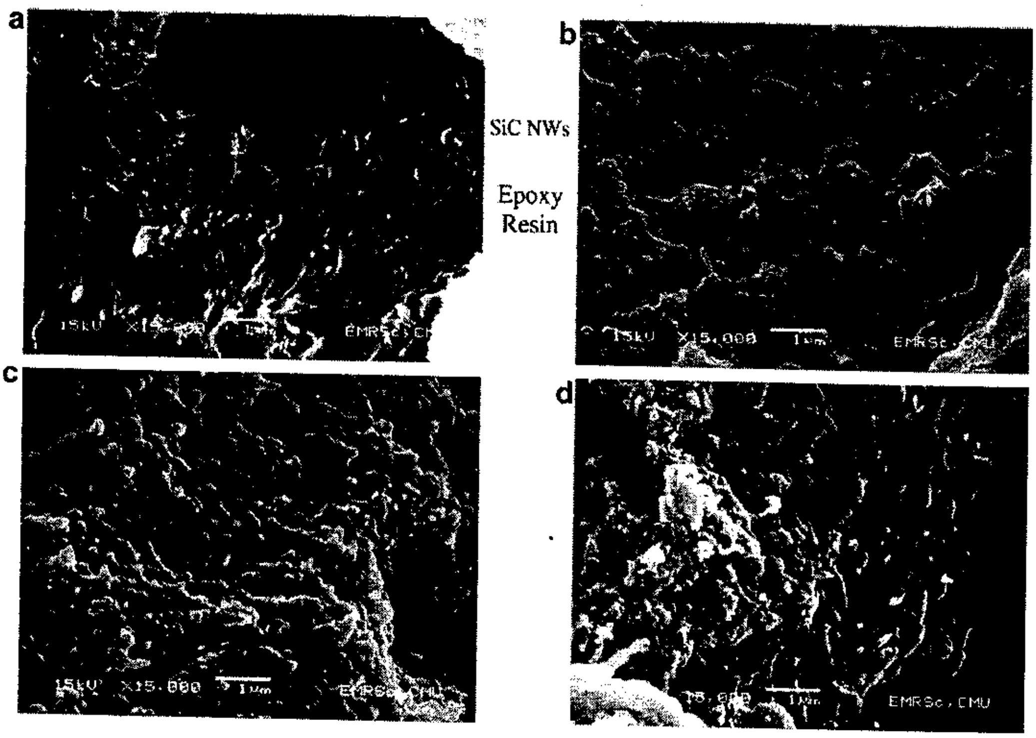

Fig. 5. SEM micrographs of SiC NWs/epoxy resin composites (a) 1 vol%, (b) 5 vol%, (c) 10 vol% and (d) 15 vol%.

4. Conclusion

SiC NWs/epoxy resin composites were fabricated by using the ultrasonic mixing and casting techniques. The SiC NWs were used as the reinforced fiber to promote the mechanical properties of the composites. The results revealed that the SiC NWs were well-dispersed within the epoxy resin matrix. The wear resistance of polymer-based materials could be improved by adding SiC NWs. The composites with 15 vol% of SiC NWs show the best wear resistance with the width of wear track of 329.8 μm which is much less than that of pure epoxy resin (550 μm) while there is no significant change in weight. Moreover, the hardness and tensile strength of composites was improved to 384% and 341%, much higher than that of pure epoxy resin.

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References

[1] X.F. Liu, C.X. Xiong, H.J. Sun, L.J. Dong, R. Li, Y. Liu, Mater. Sci. Eng. B 127 (2006) 261–266.
[2] R.J. Day, J.V. Cauich Rodrigez, Comp. Sci. Techol. 58 (1998) 907–914.
[3] N. Chisholm, H. Mahfuz, V.K. Rangari, A. Ashfaq, S. Jeelani, Comp. Struct. 67 (1) (2005) 115–127.
[4] P.K. Mallick, Fiber-reinforced Composites: Materials, Manufacturing and Design, Revised and Expanded, second ed., Marcel Dekker, Inc., NY, 1993.
[5] M. Walker, R. Smith, Comp. Struct. 80 (2002) 1457–1460.
[6] M.S. Mel, Composite Materials, Properties, Nondestructive, Testing and Repair, vol. 1, Prentice-Hall, NJ, 1994.
[7] K.L. Luthra, H.D. Park, J. Am. Ceram. Soc. 75 (7) (1992) 1889–1898.
[8] S. Chand, J. Mater. Sci. 35 (2000) 1303–1313.
[9] M. Krumova, C. Klingshirm, F. Haupert, K. Friedrick, Compos. Sci. Technol. 61 (2001) 557–5563.
[10] Q.G. Fu, H.J. Li, X.H. Shi, K.Z. Li, J. Wei, Z.B. Hua, Mater. Chem. Phys. 100 (2006) 108–111.
[11] Y. Ying, Y. Gu, Z. Li, H. Gu, L. Cheng, Y. Qian, J. Solid State Chem. 177 (2004) 4163–4166.
[12] W. Yang, H. Araki, A. Kohyama, S. Thaveethavorn, H. Suzuki, T. Noda, Mater. Lett. 58 (2004) 3145–3148.
[13] E.W. Wong, P.E. Sheehan, C.M. Lieber, Science 277 (1997) 1971.
[14] X.W. Du, X. Zhao, S.L. Jia, Y.W. Lu, J.J. Li, N.Q. Zhao, Mater. Sci. Eng. B 136 (2007) 72–77.
[15] J.Y. Fan, X.L. Wu, P.K. Chu, Prog. Mater. Sci. 51 (2006) 983–1031.
[16] Y. Baek, Y. Ryu, K. Yong, Mater. Sci. Eng. C. 26 (2006) 805–808.
[17] S. Tang, J. Deng, H. Du, W. Liu, K. Yang, J. Am. Ceram. Soc. 88 (1) (2005) 3253–3255.
[18] T. Ito, K. Sano, T. Akiyama, K. Nakamura, Thin Solid Films 508 (2006) 243–246.
[19] T. Jintakosol, P. Singjai, Key Eng. Mater 353–358 (2007) 2171–2174.