EFFECT OF GRAPHENE REINFORCEMENT IN SIC CERAMIC BASED COMPOSITES: A SHORT REVIEW

NIDHI KHOBRAGADE

Department of Metallurgical Engineering, OP Jindal University Punjipathra, Raigarh-496109, Chhattisgarh, India
E-mail: nidhi.khobragade@opju.ac.in

Abstract - The SiC ceramic matrix composites formed by introducing graphene as reinforcement to overcome the limitations of mechanical propertiesto a certain extent. SiC composites reinforced with graphene shows improved mechanical properties with different graphene content. This paper shows the effect of various graphene content in SiC using different routes with enhanced mechanical and structural properties.

I. INTRODUCTION

Silicon carbide (SiC) is non-oxides advanced ceramic with remarkable thermal, mechanical and tribological properties at low and high temperature with good oxidation and corrosion resistance [1-3]. Due to all these properties, SiC is used in many industrial applications for example cutting tools, bearings, valves, abrasives, electronics, aerospace and nuclear fission reactors. But due to poor fracture toughness and high brittleness their applications are limited. These properties can be improved with the development of ceramic based composites using chemical vapour infiltration, liquid polymer infiltration,melt infiltration and spark plasma sintering (SPS) methods [4-6]. During the last decades, various nanometric carbon-basedmaterials are used as reinforcement for ceramic matrix. Recently, graphene 2D carbon-based allotrope used as effective reinforcement due to its excellent properties such as large theoretical specific surface area (2630 m^2g^{-1}), high intrinsicmobility (200000 $cm^2v^{-1}s^{-1}$), Young's modulus (~1.0 TPa), thermal conductivity (~5000 $Wm^{-1}K^{-1}$) and electrical conductivity10^6 S m^{-1} [7-9]. In the present review, we focused in effect of graphene in microstructural and mechanical properties of SiC ceramic matrix composites.

II. MICROSTRUCTURAL AND MECHANICAL BEHAVIOUR OF GRAPHENE REINFORCED SIC COMPOSITES

In graphene reinforced ceramic matrix composites Al_2O_3 [10], TaC [11], SnO_2 [12], NiO [13], ZrO_2[14] etc. are used as matrix material. Reinforcing materials also play an important role in improving the properties of composites. Some of the present authors synthesized the [15] graphene nanoplatelets reinforced SiC with 1% boron as sintering additives using tape casting method. The relative density of SBC (containing 1 wt % boron and graphite flakes) is 98.9 % which decreases to 89.2 % in SBG composite containing 8 vol % graphene. The elastic modulus shows 22% increament in SB4G (4 vol% graphene) (424.3 ± 23.8 GPa) compared with SBC (345.3 ± 11.9 MPa) while 13% decline has been observed in SBG containing 8 vol% graphene. This attributed due to increase in porosity in SiC/graphene composites. Similarly, the microhardness decreases at higher graphene content (from 24.4 ± 2.9 GPa to 18.3 ± 4.0 GPa) due to decrease in density.

Belmonte et al. [16] fabricated the SiC/GNPs and SiC/rGO composites at 1800°C for 5 min using spark plasma sintering. In Fig.1 (a) the flexural strength of SiC is 350 MPa which increases to 600 MPa for SiC/rGO and slight increament in SiC/GNPs composite (622 MPa). The addition of rGO in Si3C shows excellent facture toughness 8.3 MPa.m1/2 then monolithic Si3C (3.2 MPa·m1/2) ceramic matrix which improves 162% fracture toughness (Fig.1 (b)). The superior toughness achieved because rGOs are small and thin as compared to GOs and liagments to bridge the cracks would be higher in rGOs. The fig.1 (c) and (d) shows the strength and fracture toughness of composites by varying the GNPs content. The maximum flexural strength is attained for SiC/5 vol% GNPs (622 MPa). But the slight decrease (602 MPa) in strength is observed in 10 vol% GNPs content.

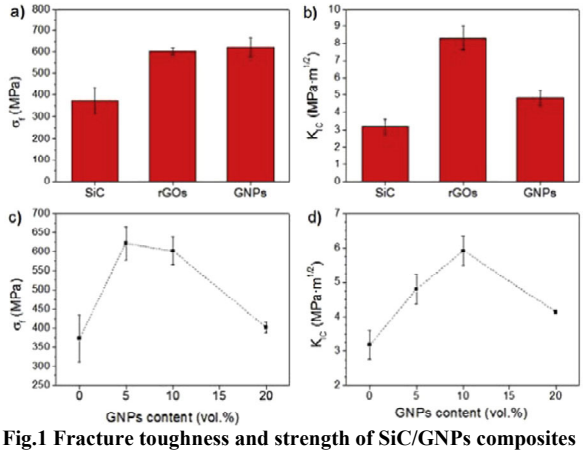


Fig.1 Fracture toughness and strength of SiC/GNPs composites [16]

The tribological performance of graphene reinforced SiC matrix were studied by Llorente and his co-workers consolidated by spark plasma sintering [17]

The maximum fracture toughness is achieved by 10 vol % GNPs composites (5.9 ± 0.4 MPa.m$^{1/2}$) with respect to monolithic SiC (3.2 ± 0.4 MPa.m$^{1/2}$) whereas rGO reinforced composite show 162% improvement (K_{IC} = 8.3 ± 0.7 MPa.m$^{1/2}$). This improvement is attributed due to crack shielding mechanism of graphene flakes in SiC matrix. The flexural strength of SiC is 373 ± 61 MPa increase to 602 ± 37 MPa in 10 vol% GNPs showing 70% increment.

The wear volume decreases from 0.11 mm^3 to 0.03 mm^3 respectively in SiC and 20 vol% GNPs/SiC composites respectively. Similar trend is observed in wear rate showing reduction from 1.5 x 10^{-3} (monolithic SiC) to 0.5 x10^{-3} mm^3 N^{-1}m^{-1} (20 vol% GNPs). In 2017, Sedlák et al. [18] consolidated SiC/GPLs composites using hot pressing technique and observed the increases in bending strength from 200 MPa (pure SiC) to 290 MPa (SiC/GPLs). The addition of GPLs in SiC results higher fracture toughness from 3.3 MPa.m$^{1/2}$ to 4.6 MPa.m$^{1/2}$ using IF method. In contrast the measured fracture toughness using reliable SEVNB method shows increment from 3.1 MPa.m$^{1/2}$ to 4.2 MPa.m$^{1/2}$ in SiC/GPLs composites. Fig. 2 shows the crack bridging of GPLs at micro as well as in the nano level.

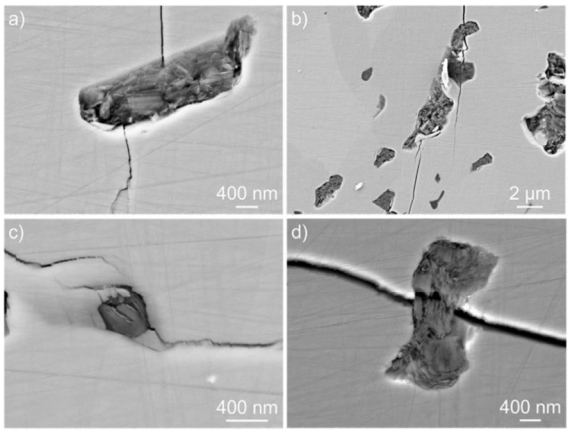


Fig.2 Characteristic toughening mechanisms on the fracture lines: (a) crack deflection at nano level, (b) crack branching at micro level, (c) crack branching at nano level, (d) crack bridging at nano level. [18]

III. CONCLUSION

From this review, it has been observed that because of remarkable properties of 2D graphene it can be used in different thermal systems for aerospace industries, bearings and structural applications. The studies reveals that the limited content of graphene can improve the fracture toughness and binding strength of SiC/graphene composites due to toughening mechanism in the form of crack bridging and crack branching in the composites.

REFERENCES

[1] S. E. Saddow, A. Agarwal, Advances in Silicon carbide processing and applications, Silicon carbide Overview, Artech House, Inc. Boston, (2004) pp. 1-23.

[2] K.A. Schwetz, Silicon Carbide Based Hard Materials-Handbook of Ceramic Hard Materials, WILEY-VCH Verlag GmbH, Weinheim, 2008.

[3] G. Roewer, U. Herzog, K. Trommer, E. Müller, S. Frühauf, Silicon carbide – a survey of shyntetic approaches, properties and applications, High Perform. non-oxide ceram.: I Struct. Bond. 101 (2002) 59–135

[4] Y. Wang, H. Wu, Friction surface evolution of carbon fibre reinforced carbon/silicon carbide (Cf/C-SiC) composites, J. Eur. Ceram. Soc. 30 (2010) 3187–3201

[5] Y. Ding, S. Dong, Z. Huang, D. Jiang, Fabrication of short C fiber-reinforced SiC composites by spark plasma sintering, Ceram. Int. 33 (2007) 101–105

[6] R. Inoue, J.M. Yang, H. Kakisawa, Y. Kagawa, Mode i fracture toughness of short carbon fiber-dispersed SiC matrix composite fabricated by melt infiltration process, Ceram. Int. 39 (2013) 8341–8346

[7] K.I. Bolotin, K.J. Sikes, Z. Jiang, M. Klima, G. Fudenberg, J. Hone, P. Kim, H.L. Stormer, Ultrahigh electron mobility in suspended graphene, Solid State Commun. 146 (2008) 351e355

[8] S.V. Morozov, K.S. Novoselov, M.I. Katsnelson, F. Schedin, D.C. Elias, J.A. Jaszczak, A.K. Geim, Giant intrinsic carrier mobilities in graphene and its bilayer, Phys. Rev. Lett. 100 (2008), 016602

[9] K.S. Kim, Y. Zhao, H. Jiang, S.Y. Lee, J.M. Kim, K.S. Kim, J.H. Ahn, P. Kim, J.Y. Choi, B.H. Hong, Large-scale pattern growth of graphene films for stretchable transparent electrodes, Nature 457 (2009) 706-710

[10] C. J. Lin, I. C. Lin, and W. H. Tuan, Effect of graphene concentration on thermal properties of alumina–graphene composites formed using spark plasma sintering, J Mater Sci (2017) 52:1759–1766

[11] A. Nieto, D. Lahiri, A. Agarwal, Graphene NanoPlatelets reinforced tantalum carbide consolidated by spark plasma sintering,Materials Science & Engineering A 582 (2013) 338–346

[12] L. Liu, M. An, P. Yang and J. Zhang, Superior cycle performance and high reversible capacity of SnO2/graphene composite as an anode material for lithium-ion batteries, Scientific Reports |5: 9055 | DOI: 10.1038/srep09055 (2015)

[13] S. H. Choi, Y. N. Ko, J. K. Lee and Y. C. Kang, Rapid continuous synthesis of spherical reduced graphene ball-nickel oxide composite for lithium ion batteries, Sci. Rep. 4, 5786; DOI:10.1038/srep05786 (2014)

[14] M. Boniecki, P. Gołębiewski, W. Wesołowski, M. Woluntarski, A. Piątkowska, M. Romaniec, P. Ciepielewski, K. Krzyżak, Alumina/zirconia composites toughened by the addition of graphene flakes, Ceramics International 43 (13) (2017)10066-10070

[15] K. Pereirados,S. Tonello, E. Padovano, C. Badini, S. Biamino, M. Pavese, P. Fino, Fabrication and characterization of laminated SiC composites reinforced with graphene nanoplatelets, Materials Science & Engineering A659 (2016)158–164

[16] M. Belmonte, A. Nistal, P. Boutbien, B. R. Manso, M. I. Osendi, P. Miranzo, Toughened and strengthened silicon carbide ceramics by adding graphene-based fillers, Scripta Materialia 113 (2016) 127–130

[17] J. Llorente, B. R. Manso, P. Miranzo, M. Belmonte, Tribological performance under dry sliding conditions of graphene/silicon carbide composites, Journal of the European Ceramic Society 36 (2016) 429–435

[18] R. Sedlák, A. Kovaľcíková, V. Girman, E. Múdra, P. Rutkowski, A. Dubiel, J. Dusza, Fracture characteristics of SiC/graphene platelet composites, Journal of the European Ceramic Society 37 (14)(2017) 4307-4314

★★★