STRUCTURAL APPLICATIONS OF SIC FIBER REINFORCED SIC MATRIX COMPOSITES

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Abstract: Boron-doped and sintered small-diameter SiC fibers are developed to enhance the thermo-structural properties for structural applications. Such enhancement processes is possible with single fibers, multi-fiber tows, or component-shaped architectural preforms without any loss in fiber strength. Further, environmental resistance is also enhanced during processing by the production of a protective in-situ grown boron-nitride (iBN) coating on the fibers. For high ceramic matrix composites toughness, two separate chemical vapor infiltration (CVI) steps are used, one to apply a boron nitride coating on the fibers of the preform and the other to form the SiC-based matrix. The heat-treatment is done to these fibers to increase creep resistance, temperature capability, and thermal conductivity.

The SiCf/SiC silicon carbide fiber reinforced silicon carbide composite studied in this article is part of the class of ceramic matrix composites in which a SiC fiber preform is infiltrated and densified by a matrix of SiC for improving its properties. The most common methods for the production of SiC matrix reinforced with high strength SiC are: chemical vapor infiltration, chemical vapor deposition, impregnation and liquid pyrolysis with reaction sintering and chemical vapor reaction, the latter being, the method used in this study.

Figure 1: Scanning electron micrographs of SiCf/SiC composite converted at 1400ºC for 3 hours.

Figure 1 shows the photomicrographs obtained by scanning electron microscopy of the cross section of converted SiCf/SiC composites. At the temperature of 1400ºC, the composite was not fully converted, because a difference can be observed a difference in the fiber color. This partial conversion can be proven by an X-ray diffractogram of the composite surface, which reveals a band of carbon, as shown in the Figure 2.

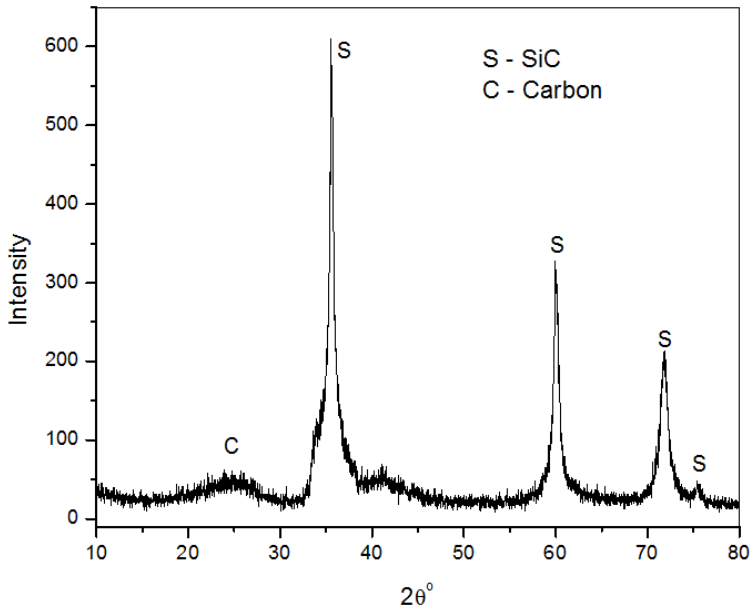

Figure 2: X-Ray diffractogram of phase transformation of carbon into SiC at 1400ºC for 3 hours.

The benefits of SIC fiber/SIC composites are as follows:

1. They have lower density, higher temperature capability, and lower thermal expansion as compared to metallic superalloys;
2. They possess non-catastrophic failure, higher toughness, better damage tolerance, and capability for large components compared to monolithic ceramics;
3. They have higher oxidative durability, more predictable life, and lower permeability compared to carbon fiber composites;
4. They own greater strength, higher temperature capability, better creep-rupture resistance and thermal conductivity, and lower permeability compared to oxide/oxide ceramic composites.

The industrial applications of SIC fiber/SIC composites are as follows:

1. Combustion and turbine section components of aero-propulsion and land-based gas turbine engines;
2. Heat exchangers, reformers, reactors, and filters for the chemical industry;
3. Preheaters, recuperators, and radiant tubes for the heat transfer industry;
4. Thermal protection systems, thruster nozzles, reusable rocket nozzles, and turbopump components for space vehicles;
5. Furnace components; and
6. Nuclear fission and fusion reactors as fuel cladding and radiation blankets.

References:

1. A. C. Reddy, B. Kotiveerachari, Effect of aging condition on structure and the properties of Al-alloy / SiC composite, vol: 2, No: 8, pp: 462-465, 2010.

2. A. C. Reddy, Micromechanical Modelling of Interfacial Debonding in AA1100/Graphite Nanoparticulate Reinforced Metal Matrix Composites, 2nd International Conference on Composite Materials and Characterization, Nagpur, pp: 249-253, 1999.

3. A. C. Reddy, Analysis of the relationship between the interface structure and the strength of carbon-aluminum composites, NATCON-ME, Bangalore, pp: 61-62, 2004.

4. A. C. Reddy, Two dimensional (2D) RVE-Based Modeling of Interphase Separation and Particle Fracture in Graphite/5050 Particle Reinforced Composites, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, pp; 179-183, 2002.

5. A. C. Reddy, B. Kotiveerachari, Effect of matrix microstucture and reinforcement fracture on the properties of tempered SiC/Al-alloy composites, National conference on advances in materials and their processing, Bagalkot, pp: 121-124, 2003.

6. A. C. Reddy, Effect of Particle Loading on Microealstic Behavior and interfacial Tractions of Boron Carbide/AA4015 Alloy Metal Matrix Composites, 1st International Conference on Composite Materials and Characterization, Bangalore, pp: 176-179, 1997.

7. A. C. Reddy, Wear and Mechanical Behavior of Bottom-Up Poured AA4015/Graphite Particle-Reinforced Metal Matrix Composites, 6th National Conference on Materials and Manufacturing Processes, Hyderabad, pp: 120-126, 2008.

8. A. C. Reddy, Finite Element Analysis Study of Micromechanical Clustering Characteristics of Graphite/AA7020 Alloy Particle Reinforced Composites, 4th International Conference on Composite Materials and Characterization, Hyderabad, pp: 206-210, 2003.

9. A. C. Reddy, Effect of Clustering Induced Porosity on Micromechanical Properties of AA6061/Titanium Oxide Particulate Metal matrix Composites, 6th International Conference on Composite Materials and Characterization, Hyderabad, pp: 149-154, 2007.

10. A. C. Reddy, Investigation of the Clustering Behavior of Titanium Diboride Particles in TiB2/AA2024 Alloy Metal Matrix Composites, 4th International Conference on Composite Materials and Characterization, Hyderabad, pp: 216-220, 2003.

11. A. C. Reddy, Effect of Porosity Formation during Synthesis of Cast AA4015/Titanium Nitride Particle-Metal Matrix Composites, 5th National Conference on Materials and Manufacturing Processes, Hyderabad, pp. 139-143, 2006.

12. A. C. Reddy, Stir Casting Process on Porosity Development and Micromechanical Properties of AA5050/Titanium Oxide Metal Matrix Composites, 5th National Conference on Materials and Manufacturing Processes, Hyderabad, pp: 144-148, 2006.

13. A. C. Reddy, Simulation of MgO/AA6061 Particulate-Reinforced Composites Taking Account of CTE Mismatch Effects and Interphase Separation, 3rd National Conference on Materials and Manufacturing Processes, Hyderabad, pp: 184-187, 2002.

14. A. C. Reddy, Reckoning of Micro-stresses and interfacial Tractions in Titanium Boride/AA2024 Alloy Metal Matrix Composites, 1st International Conference on Composite Materials and Characterization, Bangalore, pp: 195-197, 1997.

15. B. Kotiveerachari, A. C. Reddy, Interfacial effect on the fracture mechanism in GFRP composites, CEMILAC Conference, India, pp: 85-87, 1999.

16. S. Pichi Reddy, P. V. Chandra Sekhar Rao, A. C. Reddy, G. Parmeswari, Tensile and flexural strength of glass fiber epoxy composites, International Conference on Advanced Materials and Manufacturing Technologies, Hyderabad, pp: 98-102, 2014.

17. A. C. Reddy, Prediction of CTE of Al/TiB2 Metal Matrix Composites, 3rd International Conference on Composite Materials and Characterization, 3rd International Conference on Composite Materials and Characterization, Chennai, pp: 270-275, 2001.

18. C. R. Alavala, Comparison of Experimental and Theoretical CTE of Al/h-BN Metal Matrix Composites, International Journal of Material Sciences and Technology, vol: 6, No: 1, pp: 13-20, 2016.

19. C. R. Alavala, Influence of Temperature on Particulate Fracture of AA2024 Alloy/Titanium Oxide nanoparticulate Metal Matrix Composites, International Journal of Scientific Engineering and Applied Science, vol: 2, No: 4, pp: 1-6, 2016.

20. C. R. Alavala, Effect of Thermoelastic Behavior on interfacial debonding and Particulate Fracture in AA1100/TiN Nanoparticulate Metal Matrix Composites, International Journal of Science and Research, vol: 5, No: 3, pp. 1295-1300, 2016.

21. C. R. Alavala, International Journal of Engineering and Advanced Research Technology, Thermoelastic Behavior of Nanoparticulate BN/AA5050 Alloy Metal Matrix Composites, International Journal of Engineering and Advanced Research Technology, vol: 2, No: 1, pp. 6-8, 2016.

22. C. R. Alavala, Nano-mechanical modeling of thermoelastic behavior of AA6061/silicon oxide nanoparticulate metal matrix composites, vol. 5, No. 1, pp. 550-553, 2016.

23. P. Laxminarayana, A. Chennakesava Reddy, Influence of heat treatment on mechanical behavior of aluminium- 7075/Silicon carbide composites manufactured by squeeze casting process, International Conference on Advanced Materials and Manufacturing Technologies, Hyderabad, pp. 182-193, 2014.

24. G. Satish Babu, A. Chennakesava Reddy, Fracture behavior of alumina particles reinforced with different matrix aluminium alloys, International Conference on Advanced Materials and Manufacturing Technologies, Hyderabad, pp. 72-80, 2014.

25. V. K. Reddy, A. C. Reddy, Role of Reinforcing Particle Size in the Wear Behavior of AA6061-Titanium Nitride Composites, 5th International Conference on Modern Materials and Manufacturing, Bangalore, pp. 394-398, 2013.

26. V. K. Reddy, A. C. Reddy, Mathematical Models for Dry Wear of H18 Heat Treated AA1100/TiB2 Composites, pp. 341-346, 2011.

27. G. V. R. Kumar, A. C. Reddy, Tribological Analogy of Cast AA2024/TiB2 Composites, 2nd International Conference on Modern Materials and Manufacturing, Pune, pp. 287-291, 2010.

28. H. B. Niranjan, A. C. Reddy, Determination of Micro-stresses and interfacial Tractions in Titanium Boride/AA1100 Alloy Metal Matrix Composites, 1st International Conference on Composite Materials and Characterization, Bangalore, pp. 192-194, 1997.

29. A. C. Reddy, Influence of Stiffeners on Strength of E-Glass/Epoxy Composite Submergible Hull Subjected to Shock Pressure Load using Finite Element Method, International Conference on Advancements in Materials for Manufacturing, Hyderabad, pp. 7507–7518, 2016.

30. C. R. Alavala, Weight Loss Functions for Tolerable Wear Rate of AA1100/BN Metal Matrix Composites, International Journal of Mechanical Engineering and Technology, vol. 7, no. 5, pp. 9-17, 2016.

31. C. R. Alavala, Thermal Expansion Behavior of Al/Magnesia Metal Matrix Composites, vol. 5, no. 8, 1817-1821, 2016.

32. C. R. Alavala, Micromechanical Modelling of Thermoelastic Behavior of AA7020/TiC Metal Matrix Composites, International Journal of Scientific Engineering and Research, vol. 4, no. 2, pp. 1-5, 2016.

33. C. R. Alavala, Adhesive and Abrasive Wear Behavior of AA4015 Alloy/Si3N4 Metal Matrix Composites, Indian Journal of Engineering, vol.13, no. 34, pp. 625-633, 2016.

34. V. K. Reddy, A. C. Reddy, Wear performance of AA4015/Boron Carbide Metal Matrix Composites, 5th International Conference on Modern Materials and Manufacturing, Bangalore, pp. 384-388, 2013.

35. A. C. Reddy, Application of Factorial Techniques to Validate Wear Model of AA2024-Graphite Microcomposites, 4th International Conference on Modern Materials and Manufacturing, Chennai, pp. 344-348, 2012.

36. V. K. Reddy, A. C. Reddy, Tribological Investigation of Particle Size Effect on Wear Rate of Zirconium Oxide Microcomposites, 4th International Conference on Modern Materials and Manufacturing, Chennai, pp. 339-343, 2012.

37. M. Mastanaih, A. C. Reddy, Implication of Macro-sized Silicon Oxide Particles on Wear Rate of AA2024Alloy Metal Matrix Composites, 4th International Conference on Modern Materials and Manufacturing, Chennai, pp. 334-338, 2012.

38. M. Mastanaih, A. C. Reddy, Three-Body Wear Behavior of AA1100/ZrC Metal Matrix Composites, 4th International Conference on Modern Materials and Manufacturing, Chennai, pp. 319-323, 2012.

39. R. G. Math, A. C. Reddy, Tribological Performance of AA3003/B4C Metal Matrix Composites, International Conference on Modern Materials and Manufacturing, Chennai, pp. 314-318, 2012.
40. Y. S. A. Kumar, A. Chennakesava Reddy, Interfacial Criterion for Debonding of Titanium Boride/AA4015 Metal Matrix Composites, 2nd International Conference on Modern Materials and Manufacturing, Pune, pp. 265-268, 2010.

41. A. C. Reddy, Strength and fracture mechanisms in carbon-carbon composites, International symposium on Advanced Materials and Processing, Bagalkot, pp. 138-144, 2007.

42. S. Satyanarayana, A. C. Reddy, High pressure Die Casting of AA7020/Zirconium Carbide Particulate Metal matrix Composites, 6th International Conference on Composite Materials and Characterization, Hyderabad, pp. 155-159, 2007.

43. A. C. S. Kumar, A. C. Reddy, Processing of AA4015-Silicon Oxide Particulate Metal Matrix Composites by Stir Casting Technology, 6th International Conference on Composite Materials and Characterization, Hyderabad, pp. 139-143, 2007.

44. P. Rami Reddy, A. C. Reddy, Structure and Properties of Liquid Metal Processed Zirconium Oxide Reinforced AA3003 Alloy, 6th International Conference on Composite Materials and Characterization, Hyderabad, pp. 133-138, 2007.

45. T. Prasad, A. C. Reddy, Sliding Wear of AA6061/Carbon Black Metal Matrix Composites, Vol.8, No. 2, pp. 203–209, 2017.

46. C. R. Alavala, Synthesis and Tribological Characterization of Cast AA1100-B4C Composites, International Journal of Science and Research, Vol.5, No. 6, pp. 2404-2407, 2016.

47. C. R. Alavala, Influence of CTE Mismatch on Debonding and Particulate Damage in AA1100 Alloy/ZrC Nanoparticulate Metal Matrix Composites, International Journal of Innovative Research in Science, Engineering and Technology, Vol.5, No. 3, pp. 3489-3495, 2016.

48. C. R. Alavala, Nanomodeling of nonlinear thermoelastic behavior of AA5454/ silicon nitride nanoparticulate metal matrix composites, International Journal of Engineering Research and Application, Vol.6, No. 1, pp. 104-109, 2016.

49. A. C. Reddy, Reduction of Vibrations and Noise using Nylon-66/SiC Nanocomposite Gear Box in Lathe, International Journal of Science and Research, Vol.4, No. 9, pp. 1485-1489, 2015.

50. A. C. Reddy, Effects of Adhesive and Interphase Characteristics between Matrix and Reinforced Nanoparticle of AA4032/AlN Nanocomposites, International journal of research in mechanical engineering, Vol.3, No. 6, pp. 13-21, 2015.

51. A. C. Reddy, Design and Finite Element Analysis of E-glass Fiber Reinforced Epoxy Composite Air Bottle used in Missile System: Experimental Validation, International Journal of Scientific & Engineering Research, Vol.6, No. 8, pp. 157-165, 2015.

52. A. C. Reddy, Evaluation of Curing Process for Bi-directional S-Glass (5HS)/Epoxy (780E +782H) Composites Fabricated by Vacuum Infusion Process for Wind Energy Blades, International Journal of Advanced Research, Vol.3, No. 4, pp. 667-675, 2015.

53. A. C. Reddy, Evaluation of Curing Process for Carbon-Epoxy Composites by Mechanical Characterization for Re-entry Vehicle Structure, International Journal of Scientific & Engineering Research, Vol.6, No. 3, pp. 65-70, 2015.

54. Essa Zitoun, A. C. Reddy, Metallurgical characteristics of fracture behaviour in Al/SiC metal matrix composite, International Conference on Advanced Materials and Manufacturing Technologies, Hyderabad, pp. 62-71, 2014.

55. T. K. K. Reddy, A. C. Reddy, Wear Performance of Magnesia as Reinforcement of AA2024 Metal Matrix Composites, 5th International Conference on Modern Materials and Manufacturing, Bangalore, pp. 404-408, 2013.

56. V. B. Reddy, A. C. Reddy, Sliding Wear by Hard and Micro-Particles of AA2024-Zirconium Carbide Metal Matrix Composites, 5th International Conference on Modern Materials and Manufacturing, Bangalore, pp. 399-403, 2013.

57. M. Mastanaih, A. C. Reddy, Influence of Reinforcing Particle Size on Tri¬bological Properties of AA6061-Titanium Carbide Microcomposites, 5th International Conference on Modern Materials and Manufacturing, Bangalore, pp. 389-393, 2013.

58. M. Mastanaih, A. C. Reddy, Exploitation of Reinforcement in Revision of Wear Behavior of AA1100/Si3N4 Metal Matrix Composites, 5th International Conference on Modern Materials and Manufacturing, Bangalore, pp. 379-383, 2013.

59. A. C. S. Kumar, A. C. Reddy, Microstructural and Numerical Evaluation of Porosity and Clustering Control over Micromechanical Properties of Cast Titanium Nitride Reinforced AA5050 Alloy, 6th International Conference on Composite Materials and Characterization, Hyderabad, pp. 144-148, 2007.

60. P. Rami Reddy, A. C. Reddy, Formation of Gas Porosity and Clustering in Stir Cast AA2024/Titanium Diboride Particle-Reinforced Metal Matrix Composites and Influence on Micromechanical Properties, 6th International Conference on Composite Materials and Characterization, Hyderabad, pp. 128-132, 2007.

61. Essa Zitoun, A. C. Reddy, Unit Cell Models for Clustering of Particles embedded in MgO Particle/AA8090 Alloy Metal Matrix Composites, 4th International Conference on Composite Materials and Characterization, Hyderabad, pp. 211-215, 2003.

62. Essa Zitoun, A. C. Reddy, Agglomeration of Nanoparticles into Network Aggregates in Zirconium Carbide/AA6061 Alloy Particle Reinforced Composites, 4th International Conference on Composite Materials and Characterization, Hyderabad, pp. 202-205, 2003.

63. P. Laxminarayana, A. C. Reddy, Effect of Particle Spatial Distribution and Clustering on Tensile Behavior of Titanium Oxide/AA5050 Alloy Particle Reinforced Composites, 4th International Conference on Composite Materials and Characterization, Hyderabad, pp. 197-201, 2003.

64. P. Laxminarayana, A. C. Reddy, Numerical Investigation of the Effect of Particle Clustering on the Micromechanical Properties of Titanium Nitride/AA4015 Alloy Particle-Reinforced Metal Matrix Composites, 4th International Conference on Composite Materials and Characterization, Hyderabad, pp. 193-196, 2003.

65. S. Madhav Reddy, A. C. Reddy, Effect of Particle Clustering on Micromechanical Properties of Boron Nitride/AA3003 Alloy Particle-Reinforced Metal Matrix Composites, 4th International Conference on Composite Materials and Characterization, Hyderabad, pp. 188-192, 2003.

66. S. Madhav Reddy, A. C. Reddy, Clustering in Zirconium Oxide/AA1100 Alloy Particle-Reinforced Metal Matrix Composites, 4th International Conference on Composite Materials and Characterization, Hyderabad, pp. 182-186, 2003.

67. T. Prasad, A. C. Reddy, Micro-Tensile Behavior of AA7020/Carbon Black Nanoparticle Metal Matrix Composites, International Journal of Engineering and Science, VOl.6, No.8, pp. 36-40, 2016.

68. A. C. Reddy, Consequences of Interphase between Matrix and Reinforced Nanoparticle on Behavior of AA6262/AlN Nanocomposites, International Journal of Science and Research, Vol.4, No.9, pp. 1045-1049, 2015.

69. T. Prasad, A. C. Reddy, Effects of Adhesive Characteristics between Matrix and Reinforced Nanoparticle of AA6061/Carbon Black Nanocomposites, International Journal of Scientific & Engineering Research, Vol.6, No.7, pp. 40-45, 2015.

70. A. C. Reddy, Combined Loading and Micromechanical Analysis of AA5050 Alloy-Silicon Oxide Particle-Reinforced Metal Matrix Composites, 5th International Conference on Modern Materials and Manufacturing, Bangalore, pp. 373-378, 2013.

71. C. R. Alavala, Influence of Debris on Wear Rate of Metal Matrix Composites, Journal of Materials Science & Surface Engineering, Vol.4, No.6, pp. 458-462, 2016.

72. C. R. Alavala, Tribological Investigation of the Effects of Particle Volume Fraction, Applied Load and Sliding Distance on AA4015/Titania Nanocomposites, IPASJ International Journal of Mechanical Engineering, Vol.4, No.10, pp. 9-15, 2016.

73. A. C. Reddy, Shock Analysis of E-Glass/Epoxy Composite Submersible Hull Subjected to Pressure Loads of Underwater Explosion using Finite Element Method - Experimental Validation, International Journal of Scientific & Engineering Research, Vol.6, No.9, pp. 1461-1468, 2015.

74. A. C. Reddy, Effect of Phase Transformation from h-BN to c-BN on Nanoparticle Fracture Tendency in AA8090/h-BN Particle-Reinforced Metal Matrix Composites, 5th International Conference on Modern Materials and Manufacturing, Bangalore, pp. 365-372, 2013.