Asian Journal of Chemistry; Vol. 24, No. 11 (2012), 5145-5147

ASIAN JOURNAL OF CHEMISTRY

www.asianjournalofchemistry.co.in

Micro-Geometry Model of 2.5D Braided SiO_2/SiO_2 Composites

TIANRU GUAN[1], ZHAOFENG CHEN[1], JIANXUN ZHU[2,*] and YONG LIU[1]

[1]College of Material Science and Technology, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, P.R. China
[2]Sinoma Science and Technology Co. Ltd., Nanjing 210012, P.R. China

*Corresponding author: E-mail: linlong@nuaa.edu.cn; guantianru@163.com

(*Received*: 24 September 2011; *Accepted*: 12 June 2012) AJC-11582

Based on the hypothesis of the rectangle and lenticular section shape of the yarn and a new process of SiO_2/SiO_2 composites being considered especially, a geometric cell model for 2. 5D braided structures are developed. This model can be used to calculate the configuration of each yarn system, including the orientation angle of the constituent yarns and the fiber volume fraction. To verify the geometric model, the fiber volume fractions with three kinds of various structures are measured. The experimental results are in good agreement with the outcomes of the model.

Key Words: 2.5D SiO_2/SiO_2, Composites, Geometric model.

INTRODUCTION

Continuous fiber-reinforced SiO_2/SiO_2 ceramic matrix composites (CMCs) can be widely used in RF window and warhead of a missile for the combination properties of stable dielectric at high temperature[1,2]. In 3D braiding technology, fabric is constructed by the intertwining or orthogonal interlacing of two sets of yarns (braiders and axials) to form an integral structure[3]. Inevitably, the distribution of the reinforcement fibers in 3D braids is not uniform in all three dimensions. In recent years 2.5D braiding, a new braiding technology, has been developed. It can improve this problem in processing and produce composites with more layers and thicker preforms than weaving. Nowadays, the application of 3D composites is wider than before. 2.5D braided composites as an important branch of 3D composites have a very favourable application perspective in engineering, due to simple and rapid processing and acceptable mechanical properties. 2.5D braided composites can be used in the aerospace, automobile and marine industries.

The elastic properties such as elastic moduli are governed by the properties of constituent phases, shape orientation and volume fraction. Moreover, the shape and orientation of the fibers have a major effect on the anisotropy of the elastic properties of these composites[4]. Thus, it is important to analyze geometry structures and characterize the elastic properties through building the micro-geometry.

Up to now, a lot of micro-geometry models have been developed to analyze resin matrix composites[5]. However, limited attention has been focused towards understanding the micro-geometry models of braided-fiber-reinforced ceramic matrix composites like 2.5D SiO_2/SiO_2. Due to the differences on structure, the traditional geometry model does not fit 2.5D SiO_2/SiO_2 ceramic matrix composites, but it can be borrowed ideas.

The aim of this work is to build micro-geometry models of 2.5D SiO_2/SiO_2 CMCs through experiment and analysis of the geometry quantitative, which can provide theoretical basis for designability of this material and analysis of elastic properties.

EXPERIMENTAL

2.5D braided SiO_2/SiO_2 composite

2.5D braided structure: The 2.5D braided silica reinforcements were provided by Nanjing Fiberglass Research and Design Institute. Fig.1 shows various 2.5D SiO_2/SiO_2 composite architectures. In 2.5D braided preforms, threads are interlaced in a manner similar to that of 2-D woven preforms, except that the warp threads interlace several weft threads in the thickness direction. The warp direction coincides with the machine direction, whereas the weft threads are filled in the transverse direction[6].

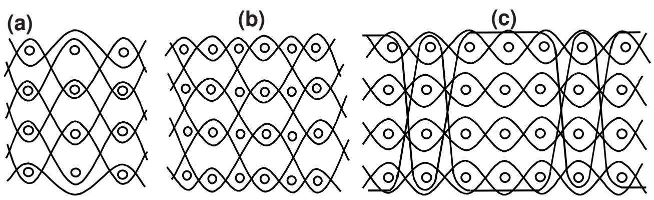
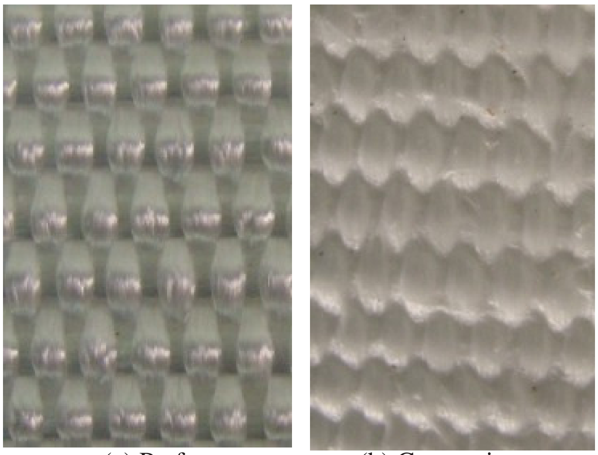


Fig. 1. Various 2.5D SiO_2/SiO_2 composite architectures (a: shallow curve link structure; b: shallow straight-link structure; c: sunk structure)

2.5D braided SiO_2/SiO_2 composites preparation: In this paper, 2.5D braided reinforced silica composites had been prepared by silica sol infiltration and sintering. Firstly, the braided silica reinforcement was put into a closed container. Then, the pure silica sol (35 vol %) was sucked into the container meanwhile the pressure was maintained at 0.01 MPa. After 0.5 h, the pressure was raised to 10 atm for 1 h. Next, the wet reinforcement was dried at 80 ºC for 1 h and 110 ºC for 1 h. Then the dried reinforcement was calcined at 450 ºC for 2 h. The above processes were repeated for 10 times to obtain SiO_2/SiO_2 composites.

RESULTS AND DISCUSSION

Fig. 2 shows the photographs of the preform and the composite. The preform is a kind of shallow curve-link structure. The good wettability between silica sol and quartz fibers led to large surface tension and yarn shrinkage. The width of the warp yarn reduced after infiltration and calcination. Thus, a geometric model about shrinkage or extrusion would be more exactly to understand inner yarns of composite.



(a) Preform (b) Composite

Fig. 2. Photographs of the preform and the composite

Fig. 3 shows the cross-section of the 2.5D SiO_2/SiO_2 composites with shallow curve-link structure. The weft yarns were lenticular. According to the lenticular section shape, we can build model closely to the fact.

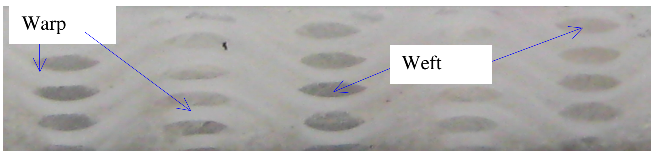


Fig. 3. Cross-section of the 2.5D braided CMCs

Assumptions: It is understood that warp and weft threads interlace differently (Figs.1-3). In order to build the geometry model more exactly, we may do the assumptions as follows: (1) The cross-section shape of weft yarn is lenticular approximately, as for the warp yarn, cross-section shape is rectangle; (2) Fiber interlocking and crimping are ignored. Laminate intersection at the center of the unit cell is also neglected; (3) Laminates have the same thickness. The fiber volume fraction of each laminate is assumed to be the same as that of the composite. This assumption is made to take into account the pure matrix regions between the laminates by reducing the contribution of the fiber to the calculation.

Geometry model

Analysis of geometric parameter: A lenticular and rectangle geometric model, more in line with the facts, was proposed by Hearle *et al.*[7]. The model represents the thread-flattening. It is suitable for the 2.5D braided SiO_2/SiO_2 CMCs manufactured by a new process, as its generality. The geometric models for the warp/weft threads in the x-z cross-section of the 2.5D braided preform are proposed in Fig. 4. The X- and Z-axes in Fig. 4 correspond to the warp (machine) direction and the thickness direction, respectively. The geometrical parameters are defined as follows: S, b = the distances between two warp threads in the x- and z-directions, respectively; D = the cross-sectional dimensions of weft yarn; L_f = the lengths of straight thread segments of warp threads; r_f= the radii of the lenticular shape of warp and weft threads; a_f = the ratio of long axis and short axis.

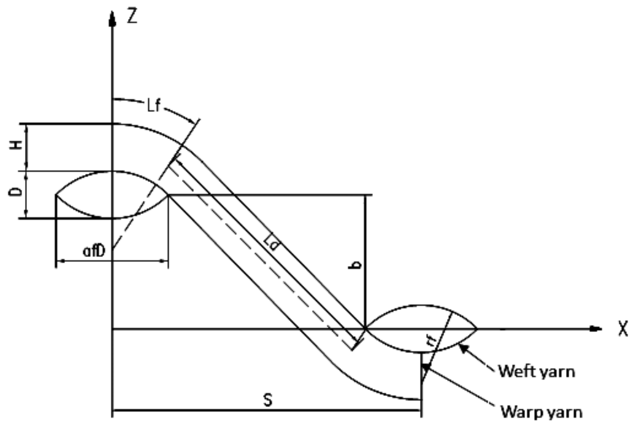


Fig. 4. Geometric model for x-z cross-section of the 2.5D braided perform

As yarns arranged closely, b = D + H. According to geometric model for x-z cross section, we have[8]:

$$r_f = \frac{D}{4}(1 + a_f^2)$$

$$L_d^2 = S^2 + (a + D - 2r_f)^2 - (2r_f + H)^2$$

$$\sin\theta = \frac{L_d(b + D - 2r_f) + S(2r_f + H)}{L_d^2 + (2r_f + H)^2}$$

$$L_f = (r_f + \frac{H}{2})\theta$$

$$V_f - V_f^j + V_f^w$$

where, V_f^j, V_f^w = volume of warp threads and weft threads, respectively. The volume of warp yarn and weft yarn can be calculated as follows:

$$V_f^j = \frac{2(L_d + 2L_f)S_j}{V}$$

$$V_f^w = \frac{CS_W}{V}$$

TABLE-1
CONTRAST OF THE PREDICTION RESULTS AND EXPERIMENTAL RESULTS OF 2. 5D BRAIDED COMPOSITES IN FIBER VOLUME FRACTION

Sample	Shallow curve-link structure		Shallow straight-link structure		Sunk structure	
	1	2	1	2	1	2
Experiment (%)	50.5	49.8	47.5	47.9	51.1	49.8
Prediction of model (%)	49.7	49.7	46.4	46.4	48.8	48.8
Error of model (%)	1.6	0.02	2.3	3.1	4.5	2.0

where, V refers to volume of unit cell. It can be defined as V = abc/2. For this assumptions, we can calculate the cross-section area of warp threads: $S_j = W \times U$. The cross-section area of weft threads can be defined as:

$$S_w = r_f(2r_f \arcsin(\frac{a_f D}{2r_f}) - a_f D) + \frac{a_f D^2}{2}$$

(1) Calculation method of parameter α, P_w refers to the density of single layer of weft yarn. Thus, we have: $\alpha = 2\frac{10}{P_w}$

(2) Calculation method of parameter b; Obviously, $b = D + H$

(3) Calculation method of parameter c; P_j refers to the number of warp threads in unit cell. Thus, we have: $c = 2\frac{10}{P_j}$

(4) Calculation method of cross-section area of threads; Tex is defined as numeral of 1000 meters thread. δ Refers to density of threads. The relationship between S_1 and Tex is $S_1 = \frac{Tex}{1000\delta} mm^2$.

According to the theory of Hearle[8], filling fraction of fibers (ϕ) is 0.9. Thus,

$$\phi = \frac{S_1}{S_y}$$

where, S_1, S_y refer to cross-section area of fibers and threads, respectively.

$$S_y = S_j = S_w = \frac{S_1}{\phi} = \frac{Tex}{900\delta}$$

(5) Calculation method of parameters H and U

H, U are length and width of warp yarn, respectively. Because of the closely arrangement, we have:

$$U = \frac{10}{P_j}$$

$$H = \frac{S_y}{U} = \frac{Tex}{900\delta U}$$

(6) Calculation method of parameters a_f

On the condition of certain materials and process, we can calculate according to experience:

$$a_f = \frac{44}{P_j + P_w}$$

Test of model: In this paper, 2.5 D braided reinforced silica composites had been prepared by silica sol infiltration and sintering. We select two samples from every structure to test fiber volume fraction. The density of wrap yarn used in this study is 10 cm and the weft yarn is 4 cm. Density of threads is 195 Tex and volume density is 2.2 g/cm^3. Table-1 shows contrast of the prediction results and experimental results of 2.5D braided composites in fiber volume fraction. It can be saw that error of model of each structure is controlled fewer than 5 %. Thus, this model can satisfy applications of engineering. It states the geometric model built in this paper is coincided with the fact.

Conclusion

Based on the hypothesis of the rectangle and lenticular section shape of the yarn and a new process of SiO_2/SiO_2 composites being considered especially, a geometric cell model for 2. 5D braided structures are developed. It can be used to predict fiber volume fraction of preform, warp yarn and weft yarn and fiber orientation angle. Through the contrast of the prediction results and experimental results of 2.5D braided composites in fiber volume fraction, we can see the maximum error of model is 4.5 %. The model can reflect inner threads exactly.

ACKNOWLEDGEMENTS

The authors thank the Basic Research Project of Science and Technology of Jiangsu province, China (No. BK2009002).

REFERENCES

1. Z.F. Chen, L.T. Zhang, L.F. Cheng and Y.D. Xu, *Ceramics Int.*, **31**, 573 (2005).
2. J.S. Lyons and T.L. Starr, *J. Am. Ceram. Soc.*, **77**, 1673 (1994).
3. G.-W. Du and F.K. Ko, *J. Reinforc. Plast. Comp.*, **12**, 752 (1993).
4. A. Dalmaz, D. Ducret, R. El Guerjouma, P. Reynaud, P. Franciosi, D. Rouby, G. Fantozzi and J.C. Baboux *Comp. Sci. Technol.*, **60**, 913 (2000).
5. M. Karahan, S.V. Lomov, A.E. Bogdanovich, D. Mungalov and I. Verpoest, *Composites Part A*, **41**, 1301 (2010).
6. J.H. Byun and T.W. Chou, *J. Text. Inst.*, **81**, 538 (1990).
7. J.W.S. Hearle, P. Grosberg and S. Backer, Structural Mechanics of Fibers, Yams and Fabrics, New York, Vol. 1, p. 323 (1969).
8. Y. Caiyun and L. Jialu, *Acta Mater. Comp. Sinica*, **22**, 178 (2005).