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Influence of braided angles on mechanical properties of three-dimensional full five-direction braided composites

Abstract

E-Glass fibers (1200tex) were used as raw materials in the paper to prepare three-dimensional five-direction (3D5D) and three-dimensional full five-direction (3D-full-5D) braided fabrics by using 3DB-J100-8 modular braided machine. Resin system composed of epoxy resin E51 and polyethenoxyamines H023 were combined with above three-dimensional braided fabrics to prepare three-dimensional (3D) braided composites. Tensile and compressive properties of 3D braided composites were tested by using Instron 3385H universal testing machine, and tensile and compressive characteristics of 3D braided composites were observed. What's more, influence of braided angles on tensile and compressive properties was studied. The results show that tensile and compressive properties of 3D-full-5D braided composites were better than that of 3D5D braided composites. Tensile and compressive properties of 3D braided composites decreased with the increase of braided angles. The results will lay a foundation of further study on 3D braided composite's designing optimization and property analysis.

Keywords: three-dimensional five-direction braided composite, three-dimensional full five-direction braided composite, braided angle, mechanical characteristics, strength property, compressive property, axial-direction, braided composites, flying temperature, tensile property, tensile characteristics, dense part, fiber breakage, resin crack, france isojet corporation

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Introduction

As a new type of textile materials, Three-dimensional (3D) braided composites can overcome traditional lamination composites' defect of weak interlamination properties and impact resistance, which have been widely used in aerospace and civilian fields for their excellent properties, like integrity, lightweight and design ability.[1–5] The 3D braided composites can be divided into three-dimensional four-direction (3D4D) braided composites, three-dimensional five-direction (3D5D) braided composites and three-dimensional full five-direction (3D-full-5D) braided composites. Particularly, the 3D5D braided composites were developed from basis of traditional 3D4D braided composites, which were prepared by adding axial-direction yarns (the fifth yarns) into part braided interspace of 3D4D braided composites along axial-direction. The 3D5D braided structures could obviously increase fiber volume fraction and axis-direction mechanical properties of 3D5D braided composites, which provide possibility for 3D braided composites as main structures in some degrees.[6–10] In recent years, many home and abroad scholars have found that 3D5D braided composites still remained many braided interspaces without axial-direction yarns and resin were easy to enrich in the interspaces during molding process, which might limit greatly raising of mechanical properties on 3D5D braided composites. Therefore, Liu Zhenguo[11] etc. proposed that axial-direction yarns could be added to all braided interspaces to farthest improve fiber volume fraction and mechanical properties of 3D braided composites, and the 3D braided composites could be called 3D-full-5D braided composites.

In the paper, E-Glass fibers were used as raw materials to prepare 3D braided fabrics by using modular braided machine, and resin system were combined with above 3D braided fabrics to prepare 3D braided composites. Instron 3385H universal testing machine was used to test mechanical properties of 3D braided composites, and influence of braided angles on tensile and compressive properties was studied too. The results will lay a foundation of further study on 3D braided composites' designing optimization and property analysis.

Experiment

Materials and equipment

In the paper, E-Glass fibers (1200tex) were used as raw materials, which were provided by Taishan Fiberglass Inc. Resin system including Epoxy resin E51, provided by Nantong Xingchen Synthetic Material Co. Ltd.; polyether amine H023, provided by Wuxi Renze Chemical Co. Ltd.; Release agent XTEND807, provided by Sino Composite.

Apparatus including 3DB-J100-8 modular combination three-dimensional braided machine, provided by Beijing 3D Braiding Co. Ltd.; RTM injection system, provided by France Isojet Corporation; Instron 3385H universal testing machine, provided by Instron Corporation; 101A-4S electrical heating drying oven, provided by Nanjing Wohuan Science &Technology Industrial Co. Ltd.; JA2003 electronic balance, provided by Shanghai Jinghai instrument Co. Ltd.; S212 constant speed agitator, provided by Shanghai Shenshun Biological Science & Technology Co. Ltd.

Preparation of 3D braided composites

Preparation processing of 3D braided composite perform (3D braided fabrics) could be seen in literature.[3] Preparation processing of 3D braided composites was shown as below.[12] (1) 3D braided fabrics were pretreated. The 3D braided fabrics were placed into drying oven to dry and heat, then net weight was weighed after drying. (2) Mould surface was treated. Cleaning cloth impregnated of ethyl acetate was used to clean release agent and oil contamination on the mould surface. (3) 3D braided fabrics were placed into mould. 3D braided fabrics were placed into mould, and then the mould was placed into oven at 60˚C for 30min. At the same time, processing parameters, like injection speed, injection joint temperature, pipeline temperature, resin tank temperature, and injection pressure were set. (4) 3D braided fabrics were molded. Resin system was injected into the mould when the mould could not be moved freely during injection processing, then resin transport pipeline was cut off after injection ended, and mould injection entrance and resin reflux export were sealed, finally flying oven was closed and flying temperature was kept at 80˚C for 3h. Thus 3D braided composites could be prepared.

Testing of tensile property

Tensile property was tested in accordance with relevant provisions of national standard GB/T 1447-2005 "Tensile property testing method of fiber reinforced plastics". Four groups of samples with different technology parameters were prepared in order to effectively analyze the influence of braided angles on tensile properties of 3D braided composites. Five valid testing values were selected for each group samples, and sample size is: length*width*thickness=250mm*25mm*4mm, and testing speed is 5 mm/min. Processing parameters and testing results of tensile samples were shown as Table 1.

Testing of compressive property

Compressive property was tested in accordance with relevant provisions of national standard GB/T 1448-2005 "Compressive property testing method of fiber reinforced plastics". In order to effectively analyze influence of braided angles on compressive properties of 3D braided composites, four groups of samples with different processing parameters were prepared. Five valid testing values were selected for each group samples, and sample size is: width*thickness*height =10mm*10mm*30mm, and testing speed is 2 mm/min. Processing parameters and testing results of compressive specimen was shown as Table 1.

Table 1 Technology parameters and testing results of tensile samples

Sample	Braided angles /°	Ratio of axial-direction yarns /%	Tensile strength /Mpa	Compression strength / Mpa
3D5D (1#)	20	39	372	199
3D5D (2#)	30	39	285	118
3D-full-5D (3#)	20	49	835	385
3D-full-5D (4#)	30	49	465	194

Results and discussion

Tensile characteristics

Tensile characteristics of 3D-full5D braided composites were shown in Figure1. At the initial stage of tension, failure mode of 3D-full-5D braided composites was mainly resin crack. What's more, the crack were regularly distributed in both sides of centerline when braided angle was smaller (α=20°), as shown in Figure 1(a). Failure mode of 3D-full-5D braided composites was mainly resin crack too, while the crack were distributed in the entire samples, and the most dense part is the middle center when braided angle was smaller (α=30°), as shown in Figure 1(b).

In the process of tensile testing, sound of resin crack and fiber breakage could be heard continuously with the increase of tensile loads. The 3D-full5D braided composites fractured sharply as the value of tensile stress reached the maximum, at the same time, severe sounds were heard and bigger shock were seen, and chunks of resin began to break down nearby the samples, as shown in Figure1c & d.

It can be seen that the fracture appearance of 3D-full-5D braided composites was relatively flat and fibers were pull out less when braided angles were smaller (α=20°), and the 3D braided composites showed obviously brittle fracture characteristics, as shown in Figure 1c. The fracture appearance of 3D-full-5D braided composites was irregularly when braided angles were larger (α=30°). What's more, the flatness of fibers' fracture appearance decreased obviously, and phenomenon of fibers' pulling-out was seen too, as shown in Figure 1d.

Compressive characteristics

Compressive characteristics of 3D-full-5D braided composites were shown in Figure 2. To standard 3D-full-5D braided composites, it could be seen that failure angles between the fracture appearance and the direction of the load were 45°, and 3D-full-5D braided composites appeared obviously failure characteristics of flexural and shear properties. In addition, the upper and lower surface of 3D-full-5D braided composites still remained smoothly and fiber bundle had no phenomenon of dispersing, as shown in Figure 2a.

There would be many weaker regions of loads for 3D-full-5D braided composites existing composite molding defect, such as bad impregnating and interspace, as shown in Figure 2b. The phenomenon of resin cracking and debonding would appear easily in the weaker region of loads, and then gradually extends up to resulting in early failure.

There would be uneven loads and stress concentration for 3D-full-5D braided composites with raised upper and lower surface, as shown in Figure 2c. Raised section would contact with compressive fixtures firstly when compressive loads were loaded to the 3D composites, and the 3D composites would appear cracks from an angle, and finally the 3D composites failed for part compressive failure.

Influence of braided angles on tensile properties

Influence of braided angles on tensile properties of the 3D braided composites was shown in Figure 3. It can be seen that tensile properties of 3D-full-5D braided composites are better obviously than that of 3D5D ones. Tensile strength of 3D-full-5D braided composites (3#) is

835 MPa, while tensile strength of 3D5D braided composites (1#) is 372 MPa when a braided angle is 20°. Tensile strength of 3D-full-5D braided composites (4#) is 465 MPa, while tensile strength of 3D5D braided composites (2#) is 285 MPa when a braided angle is 30°. The reason is that the 3D-full-5D braided composites have more axial-direction yarns than 3D5D ones, which could greatly increase axial-direction tensile property of the 3D-full-5D braided composites.

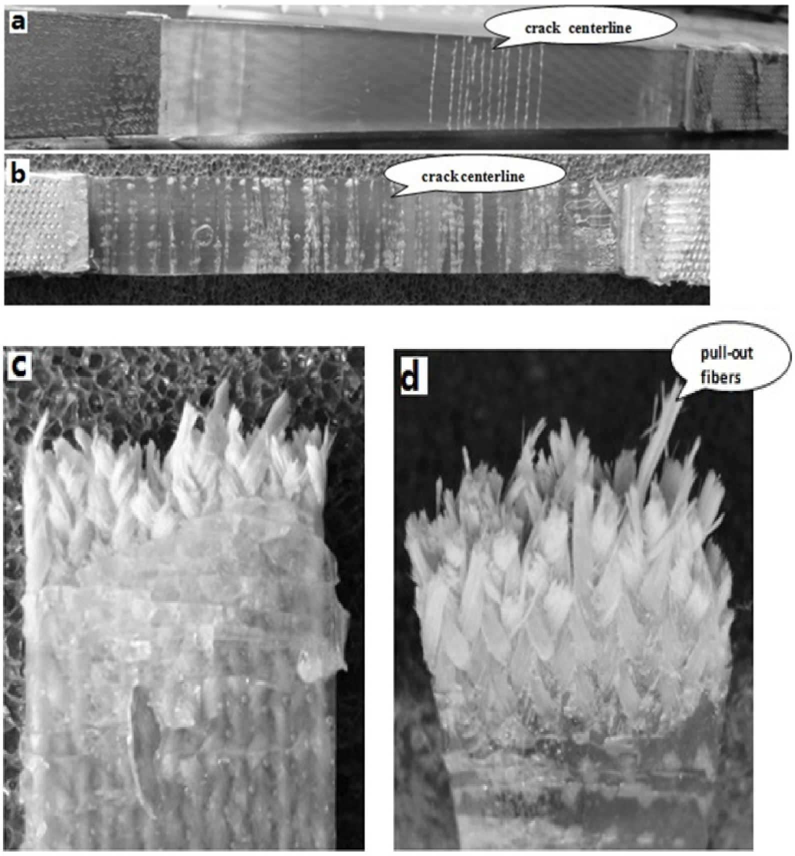

Figure 1 Tensile characteristics of 3D-full-5D braided composites

Failure appearance of sample 3# during initial process of tension (α=20°); (b) Failure appearance of sample 4# during initial process of tension (α=30°); (c) Failure appearance of testing sample 3#; (d) Failure appearance of testing sample 4#.

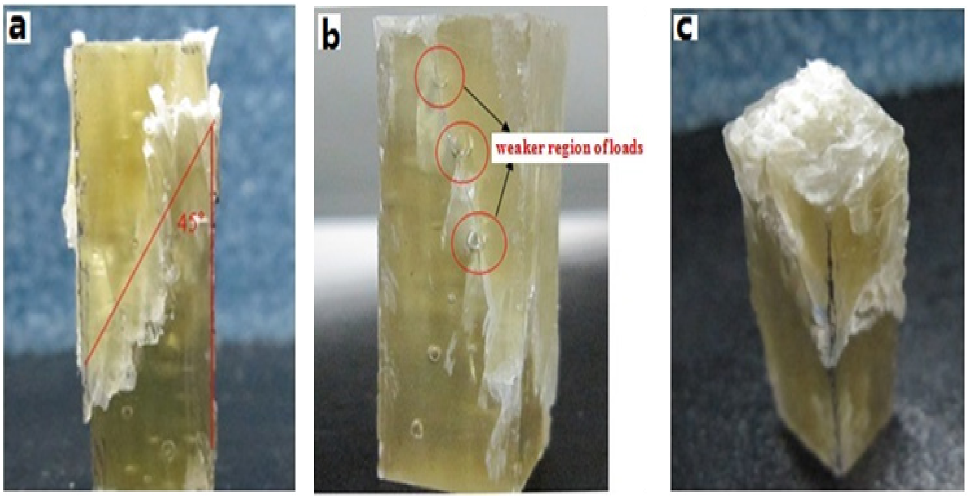

Figure 2 Compressive characteristics of 3D-full-5D braided composites

Failure appearance of standard samples; (b) Failure appearance of samples existing composite molding defects; (c) Failure appearance of samples existing unevenness upper and lower face-sheet.

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Tensile properties of the 3D braided composites decreased obviously with the increase of braided angles. To 3D-full-5D braided composites, tensile strength is 835 MPa when braided angle is 20°, while tensile strength is 465 MPa when braided angle is 30°, and the tensile strength decreased 44.3%. To 3D5D braided composites, tensile strength is 372 MPa when braided angle is 20°, while tensile strength is 285 MPa when braided angle is 30°, the tensile strength decreased 23.4%. The reason is that braided yarns tended to be more lateral when braided angles increased, which resulted in braided yarns contributed declining to axial-direction mechanical properties, and overall tensile properties of the 3D braided composites declined.[13–15]

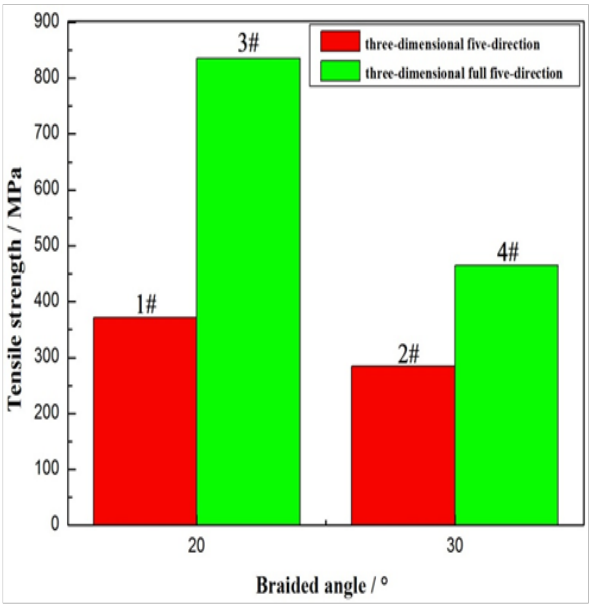

Figure 3 Influence of braided angles on tensile properties of 3D braided composites.

Influence of braided angles on compressive properties

Influence of braided angles on compressive properties of the 3D braided composites was shown in Figure 4. It can be seen that compressive properties of 3D-full-5D braided composites are better obviously than that of 3D5D ones. Compressive strength of 3D-full-5D braided composites (3#) is 385 MPa, while compressive strength of 3D5D braided composites (1#) is 199 MPa when a braided angle is 20°. Compressive strength of 3D-full-5D braided composites (4#) is 194 MPa, while compressive strength of 3D5D braided composites (2#) is 118 MPa when a braided angle is 30°. The reason is that the 3D-full-5D braided composites have more axial-direction yarns than 3D5D braided composites, which could greatly increase axial-direction compressive property.

Compressive properties of the 3D braided composites decreased obviously with the increase of braided angles. To 3D-full-5D braided composites, compressive strength is 385 MPa when braided angle is 20°, while compressive strength is 194 MPa when braided angle is 30°, and the compressive strength decreased 49.6%. To 3D5D braided composites, compressive strength is 199 MPa when braided angle is 20°, while compressive strength is 118 MPa when braided angle is 30°, the compressive strength decreased 40.7%. The reason is that braided yarns tended to be more lateral when braided angles increased, which resulted in braided yarns contributed declining to axial-direction compressive properties.[13–15]

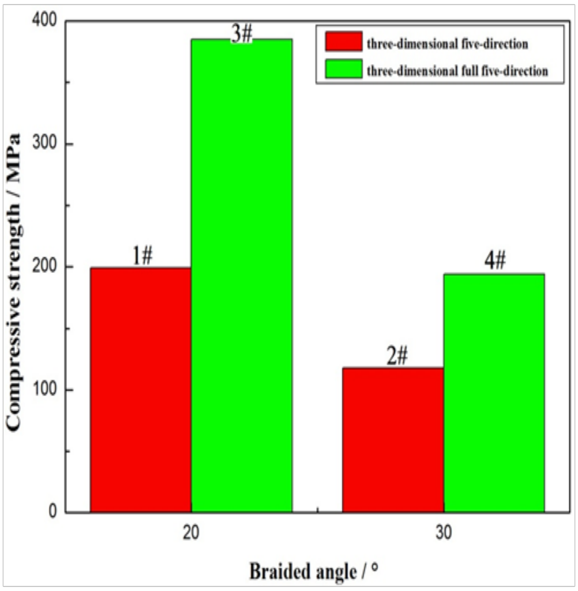

Figure 4 Influence of braided angles on compressive properties of 3D braided composites.

Conclusion

Tensile characteristics of 3D-full-5D braided composites: tensile fracture appearance was relatively flat and fibers were pulling out less when braided angles were smaller, and the composites showed obviously brittle fracture characteristics. While tensile fracture appearance was irregular when braided angles was larger, and more fibers were pulled out. What's more, failure modes of the composites are mainly resin fracture, fibers breakage and interface debonding between fibers and resin.

Compressive characteristics of 3D-full-5D braided composites: To standard braided composites, fracture appearance and the direction of the loads were 45°, and the composites appeared obviously failure characterization of flexural and shear properties. Too bad impregnating and existing interspace braided composites, phenomenon of resin cracking and debonding would appear easily in the weaker region of loads, which would result in early failure. To the composites with raised upper and lower surface, stress concentration is easily occurred to result in the composites failure for part compressive loads.

Tensile and compressive properties of the 3D-full-5D braided composites are obviously better than that of 3D5D ones when braided angles are same. For 3D-full-5D and 3D5D braided composites, tensile and compressive properties both decreased with the increase of braided angles.

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Conflict of interest

Author declares there is no conflict of interest in publishing the article.

References

1. Zhang MZ, Li HJ, Li KZ. Progressing in the study on mechanical properties of the 3D braided composites. *J Materials Eng*, 2004;(2):44–48.

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2. Liu Q, Li JL, Li XM. Influence of 3D braiding technology parameters on tensile properties of composites. *Aerospace Materials & Technology.* 2000;30(1):55–58.

3. Byun JH, Chou TW. Process-microstructure relationship of 2-step and 4-step braided composites. *Composites Science and Technology*. 1996;56(2):235–251.

4. Cao HJ, Qian K, Xu WX, et al. Compressive properties of three-dimensional full five-directional braided composites. *Journal of Textile Research*. 2013;34(8):68–71.

5. Ayranci C, Carey JP. Predicting the longitudinal elastic modulus of braided tubular composites using a curved unit-cell geometry. *Composites Part B: Engineering*. 2010;41(3):229–235.

6. Li XM, Li JL, Wang Z. Effect of 3-D & 5-D braiding structure on mechanical properties of the composites. *J Tianjin Institute of Tex Sci & Tech.* 1997;16(5):7–12.

7. Li JL, Yang HN, Kou CH. Fatigue properties of three dimensional braiding composites. *Acta Materiae Compositae Sinica*. 2005;22(4):172–176.

8. Wu DL. Three-cell model and 5D braided structural composites. *Composites Science and Technology.* 1996;56(3):225–233.

9. Wang YQ, Wang ASD. On the topological yarn structure of 3D rectangular and tubular braided performs. *Composites Science and Technology.* 1994;51(4):575–586.

10. Norman T, Anglin C, Gaskin D. Strength and damage mechanisms of notched two-dimensional triaxial braided textile composites and tape equivalents undertension. *J Composites Technol & Res.* 1996;18(1):38–46.

11. Liu ZG. Concept of three-dimensional all five-directional braided performs. *Journal of Materials Engineering.* 2008;S1:305–312.

12. Pi XB, Qian K, Cao HJ, et al. Microstructure analysis of 3D full 5-directional braided composites. *Aerospace Materials & Technology*. 2011;(6):39–43.

13. Li ZP, Lu ZX, Feng ZH, et al. Investigation of the tensile properties and failure mechanism of integrally-braided 5D carbon/phenolic composites. *Acta Aeronautica et Astronautica Sinica*. 2007;28(4):869–873.

14. Chen L, Liang ZQ, Ma ZJ, et al. Experimental investigation on longitudinal properties of 3-D 5-Directional braided composites. *Journal of Materials Engineering*. 2005;(8):3–6.

15. Lu ZX, Hu Q. Experimental investigation into the compressive mechanical properties of three dimensional braided composites. *Acta Materiae Compositae Sinica*. 2003;20(6):67–72.

Citation: Cao H, Chen H. Influence of braided angles on mechanical properties of three-dimensional full five-direction braided composites. *J Textile Eng Fashion Techno.* 2017;1(3):101–105. DOI: 10.15406/jteft.2017.01.00017