

Compressive Strength of 3-D Heat-Resistant Composites

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SUMMARY: The effect of through-the-thickness fiber arrangement on the compressive strength of heat-resistant polymer matrix composites were studied for several conditions of elevated temperatures. Composite plates of a carbon fiber with bismaleimide, cyanate ester , and TGDDM type epoxy were prepared in this research. A series of in-plane compression and interlaminar shear strength tests was run to characterize the 3-D and also 2-D composites comprising pi-by-four orientation carbon fiber reinforcement with and without orthogonal z-direction carbon fibers. All dry fabric preforms of 3-D and 2-D plates were produced and prepared by the same thrusting apparatus and procedures. Specimens were fabricated by a resin transfer molding(RTM) process following to the manufacturer's instructions respectively. In this study, bismaleimide resins were observed to be more durable than TGDDM type epoxy especially for higher temperature exposures and the 3-D MR50/5250 composite showed higher strength and stable characteristics including in elevated temperature compression and interlaminar shear strengths.

KEYWORDS: 3-D, three-dimensional textile, resin transfer molding, compression test, CAI strength, heat-resistant resin, carbon/bismaleimide

INTRODUCTION

The use of three-dimensional(3-D)fiber architecture is one of the most promising methods to improve low out-of-plane properties of laminated composite structures. Our previous studies showed the 3-D composites had more than 40% higher compressive strength after severe out-of-plane impact damages than that of 2-D ones[1]. On the other hand, the in-plane properties are known to be inferior to 2-D ones. Quantitative understanding of both properties including higher temperature environments will be necessary to expand the application fields of polymeric composites structures more.

After more than twenty years of scheduled flights of Concorde, there is considerable interest around the world in developing a new generation of supersonic commercial transport[2].

One of the conceptual design study which was supported by the Japanese government indicates that the airplane should be required to have the payload of 300 passengers, the range of more than 10,000 km and the cruise speed of Mach 2.2 with maximum takeoff weight of less than 400 ton. In order to produce an economically viable and environmentally acceptable supersonic transport, it is required to develop and apply high performance polymeric composite materials which will be durable for long term high temperature adverse environments and more tolerable against impact damages with promising cost-effective manufacturing processes[3,4].

Laminated plates of fiber reinforced plastics have been widely adopted to the composite structures as load bearing components. However, increased use of advanced composite materials has required that processes other than traditional prepreg lay-ups and autoclave cure be developed to meet design properties and damage tolerance requirements of structures[5-7]. The 3-D composites offer potential improvements in the ability of a composite structure to survive a high energy impact with minimal decrease of strength[8-10].

In this work, effects of through-the-thickness fibers(z-fibers) in the several heat-resistant resin material systems on the compressive and compressive interlaminar shear strengths were investigated for several conditions of elevated temperatures which include high temperature test of 170 degree C, and isothermal exposures in atmosphere of 24 hours at the temperature of 150, 205, and 260 degree C respectively. Candidate resin systems which are applicable to resin transfer molding(RTM) process include bismaleimide, cyanoester, and TGDDM type epoxy.

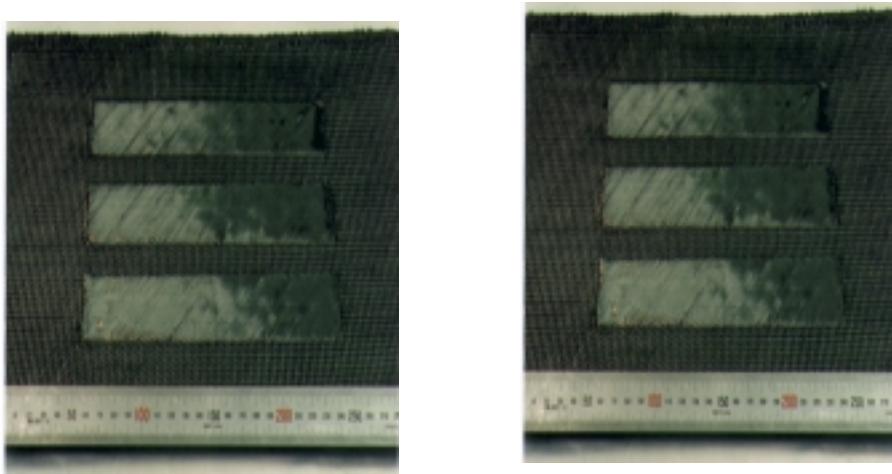


Fig. 1 3-D dry fabric preform without z-yarn

1. Specimen configurations and testing method

The 5 axes 3 dimensional (with 4 in-plane axes directions in 0, -45, +45, 90 and additional one axis in thickness direction) composite (3-D) was prepared. A high modulus carbon fiber, MR50-4.5kf from Mitsubishi Rayon was used for all of four direction of in-plane fibers, and T900-3kf from TORAY for through-the-thickness one. All dry fabric preforms of 3-D and 2-D plates were produced by the same thrusting apparatus which was developed by Toyoda Automatic Loom Works and by the same procedures, but the only difference was with/without z-fibers. As is shown in Fig. 1, a large plate of dry fiber preform with out-of orthogonal z-direction fiber areas in the center of it was fabricated. The ratio of in-plane

fiber orientations in 3-D specimen is 45%, 19%, 19%, and 17% respectively. the weight ratio of z-fiber to the total fiber weight was about 1.5%. After RTM process, this plate was cut out to 2-D specimens using area and without z-fibers, and 3-D ones using with z-fiber area respectively shown in Fig. 2.

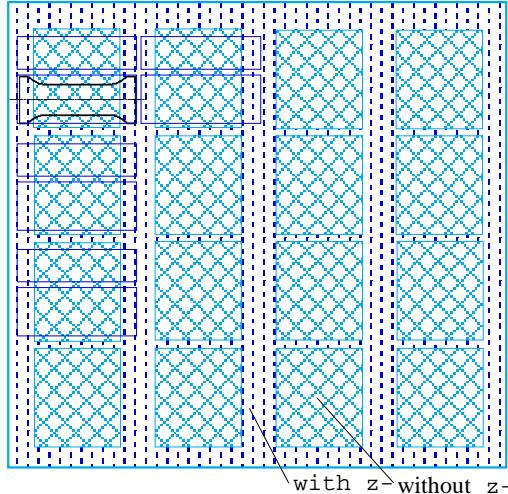


Fig. 2 Motherboard of specimen without z-yarn

Heat resistant systems studied here include bismaleimide 5250-4RTM from Cytec/Fiberlight, cyanate ester AROCY-B30, and TGDDM type epoxy MY-9512/DDS from CIBA-GEIGY. A series of in-plane compression and interlaminar shear strength tests was run to characterize the 3-D and also 2-D composites comprising pi-by-four orientation carbon fiber reinforcement with and without orthogonal z-direction carbon fibers. The effect of z-fibers on the in-plane compressive stiffness after isothermal exposures of several temperatures was investigated and summarized in Table 1 for these three material systems. Any significant degradation was not observed after isothermal exposures of 24 hours. The stiffness was measured for each material under high temperature environment of 170 degree C, and all these three material systems showed a slightly higher values in the higher temperature.

2. Compressive strength after isothermal exposure

In-plane compression tests were carried out based on ASTM D-695 recommendations for 2-D and 3-D composites using these candidate resins. The specimen configuration is shown at Fig. 3. Compression strengths were investigated and compared under room temperature dry (RTD) condition after several adverse environments including 24 hours exposure at 150, 205, and 260 degree C.

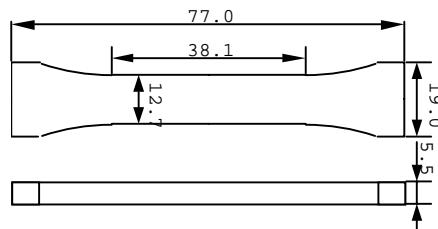


Fig.3 Compressive test specimen

High temperature compression(HTC) test was also carried out under 170 deg. C. Compressive strength properties are summarized in Fig. 4. As is shown in this figure, the strength of epoxy resin(MY-9512) composites were observed less than half after exposure of higher than 200 deg C. The effect of resin system on the compressive strength was less sensitive for 3-D composites than 2-D.

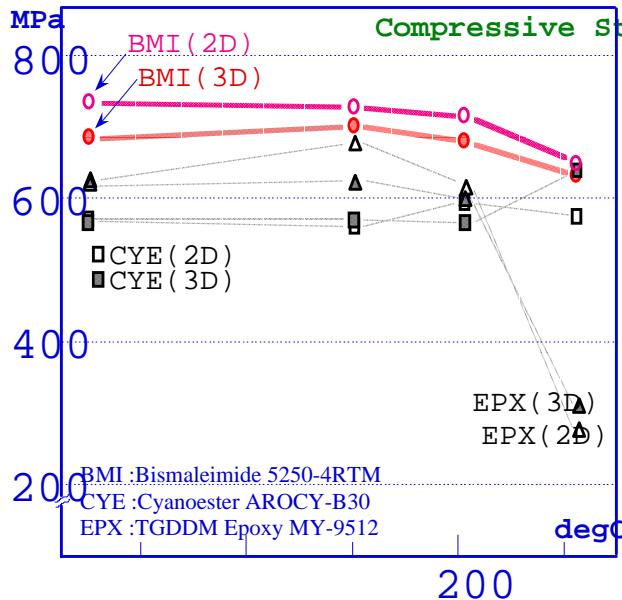


Fig. 4 In-Plane Compressive Strengths after Isothermal Exposures

3. Interlaminar shear strength after isothermal exposure

Interlaminar shear strength tests were carried out based on ASTM D-3846 recommendations for 2-D and 3-D composites using these candidate resins. The specimen configuration is shown at Fig.5. Similar to the compressive tests, interlaminar shear strengths of 2-D and 3-D composites were investigated and compared under room temperature dry(RTD) condition after several adverse environments including 24 hours exposure at 150, 205, and 260 degree C.

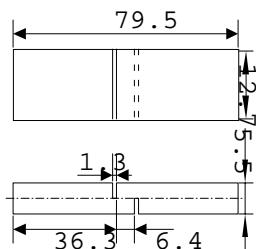


Fig. 5 Interlaminar shear specimen

Test results are summarized in Fig. 6. As is shown in this figure, the strength of epoxy resin(MY-9512) composites were observed less than half after exposure of higher than 200 deg C. Composites with bismaleimide systems were observed to be durable for up to the 200 degree C exposure. Thermal cycles did not give any additional adverse effects on the composites for this testing condition. The effect of resin system on the interlaminar shear strength was less sensitive for 3-D composites than that of 2-D.

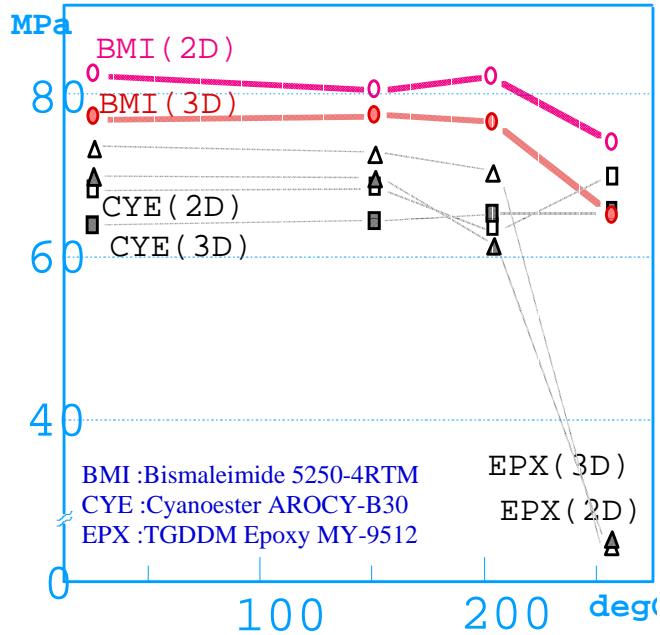


Fig . 6 Compressive interlaminar shear strength after isothermal exposures

4. Concluding remarks

A comprehensive investigation into the strength properties of 2-D and 3-D composites for higher temperature applications were carried out, using plate type specimens of carbon fiber/bismaleimide, cyanate ester, and TGDDM type epoxy resin matrix composite made with RTM process. A series of in-plane compression and interlaminar shear strength tests was run to characterize the 3-D textile composites comprising pi-by-four orientation carbon fibers reinforced with orthogonal z-direction carbon fibers.

As is seen in Fig.4 and Fig.6, bismaleimide resins were more durable than TGDDM type epoxy especially for higher temperature exposure in such a range as 200 degree C. Our limited experimental results show the bismaleimide matrix composite is expected to be durable up to 250 deg C for limited time duration. It is also important that 3-D composites showed more stable strength characteristics than that of 2-D. Not only compressive strength but interlaminar shear strength of 3-D composites scatters in the narrower band which indicate z-direction fibers in the 3-D composites functions to maintain the strength after high temperature exposures.

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