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A Novel Method for Curing Carbon Fiber Reinforced Plastics by High-pressure Microwave

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Abstract: Traditional autoclave molding process is energy-consuming and time-consuming. To deal with this issue, a novel method for curing the high performance carbon fiber reinforced plastics (CFRP) by high-pressure microwave is presented. The high-pressure microwave curing equipment has been developed, which enables the microwave energy be imported into the autoclave under high pressure, and the temperature of the component could be real-time monitored and controlled. A series of tests have been carried out to study the curing effects of this equipment. The results show that, comparing with traditional autoclave curing, the high-pressure microwave curing save energy and time significantly. Furthermore, the properties of the CFRP irradiated by microwave under the high-pressure outweigh those cured by autoclave. Specifically, there are no obvious defects in the CFRP components cured by high-pressure microwave; the CFRP exhibits more ductile behavior which cured by high-pressure microwave. The mechanical properties of the specimens are enhanced. The failure of the CFRP mainly occur in the inner of the resin matrix, which indicate that the interfacial strength is stronger. In conclusion, it is promising to improve the interfacial properties and mechanical property of CFRP in an efficient and economical way by high-pressure microwave curing.

Keywords: Carbon fiber reinforced plastics, Microwave, High-pressure microwave, Curing

Introduction

Carbon fiber reinforced plastics (CFRP) is widely used in the aerospace industry due to its characteristics of high specific strength, high specific stiffness, designable, etc. The main method of producing CFRP parts is autoclave molding process, of which the molding quality is relatively stable, and the resulting part exhibits low porosity, uniform resin content and stable mechanical properties [1,2]. Despite of the advantages above, autoclave molding process is energy-consuming and time-consuming. The autoclave molding process applies high temperature and pressure gas inside the autoclave to heat and press the CFRP pre-impregnated material, so as to complete the curing process of the CFRP [3]. The transfer and convection of heat in the CFRP component are the inherent disadvantages of autoclave curing [4]. In particular, when producing the variable thickness and complex structure components, curing exothermic reaction will easily occur at the weak part of the component, while at the thick wall part it will delay, thus the temperature of the component couldn't reach a balance on the whole, which leads to the curing deformation and other defects [5].

The microwave curing of thermoset plastics had many potential advantages over thermal curing: Heat energy was transferred electromagnetically and quickly and relatively evenly throughout the component, but not as a thermal heat flux. This enabled better process temperature control and more uniform curing, lower cure-induced strains, increased throughput, especially for curing the thick laminates [4,6-9].

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In order to cure composite materials in cost-effective way, many researchers have studied on microwave curing of CFRP. However, most of the studies were carried out under normal pressure or vacuum condition in a common microwave oven. Moreover, the temperature of the components could not be real-time monitored and controlled during the curing process [4,6,9-16]. So that abnormalities can easily result, such as over curing, low curing temperature or non-uniform curing, which would affect the quality and mechanical properties of the component.

At present, with the development of the CFRP, the curing process of the high-performance CFRP requires relatively high temperature and pressure, such as T800 carbon fiber reinforced epoxy resin pre-impregnated material used in aviation [17,18]. If the curing pressure is too low, the material would have plenty of voids, which reduce the mechanical properties of the material greatly [17]. Since the microwave generator can't tolerate high-pressure and high-temperature, it is necessary to import the microwave energy into the autoclave and configure a set of real-time temperature measurement and microwave input power real-time control system to realize the microwave curing of the CFRP under high pressure. However, it is costly and time-consuming to modify the autoclave, so there is few study reported on microwave curing of CFRP under high pressure.

In order to apply the pressure to the component during the microwave curing, a clamping unit made of polypropylene was designed to clamp the CFRP laminate component [14], as shown in Figure 1. When the CFRP cured in the microwave oven, the screw bolts of the clamping unit used the polypropylene, which can only provide a very small

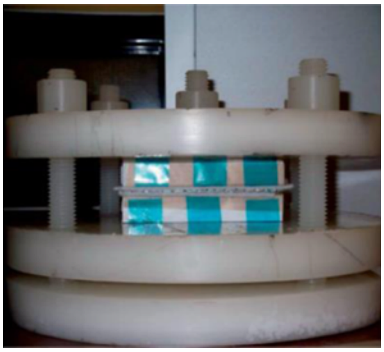


Figure 1. Clamp unit made of polypropylene.

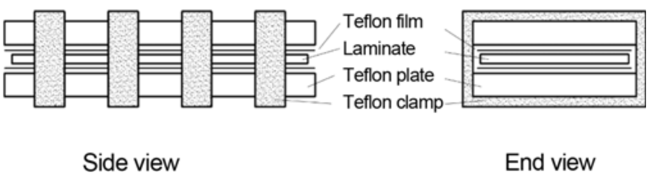


Figure 2. Schematic diagram of the Teflon clamping arrangement.

pressure. So, the curing pressure would be much less than the 0.1 MPa, which was obtained from the vacuum. Another Teflon clamping unit was made to increase the pressure on the component for curing [13], as shown in Figure 2. However, the size of the CFRP pre-impregnated material reduced after been cured. The Teflon material is not elastic material, so the clamping unit could not provide sustained pressure to the laminate during curing. In another paper, the title of which involved high-pressure microwave curing, however, there was no specific description about the principle of the experimental equipment, neither a photo of the equipment. The content of this paper was mainly about curing the glass fiber reinforced composites by microwave. What's more, the device was not equipped with the temperature measurement and feedback control system [19]. A cure-control system for the monitoring and controlling of the microwave curing process of polymer composite was developed. The whole system was placed whole inside the autoclave. When the system worked, the autoclave provided pressure, but didn't provide heating [20], as shown in Figure 3. Although the microwave curing under high-pressure was done. The thermocouple used to measure the temperature in this system was so easily been disturbed that it may result in incorrect measurement. Moreover, in this paper, only the glass fiber reinforced composites was cured by microwave, nor did the CFRP been studied. Aerospace GKN claimed on its web site that it successfully produced a high-pressure microwave equipment, and the pressure in the oven was about 0.689 MPa. But, from Figure 4, which was shown in the site, the door of the microwave oven was furnace door lock buckle device, which obviously could not withstand the pressure of 0.689 MPa (refer to Figure 6, the tank door of the

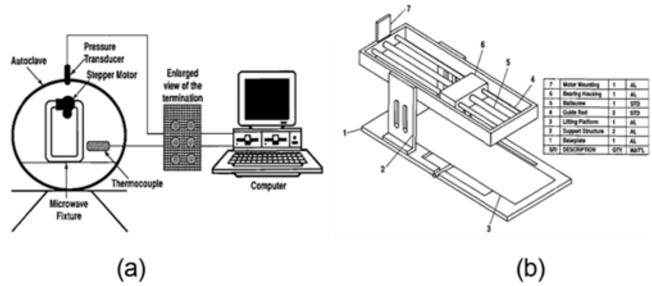


Figure 3. Schematics of the curing process and equipment; (a) schematics of the curing process and (b) key components of the microwave radiation mechanism.

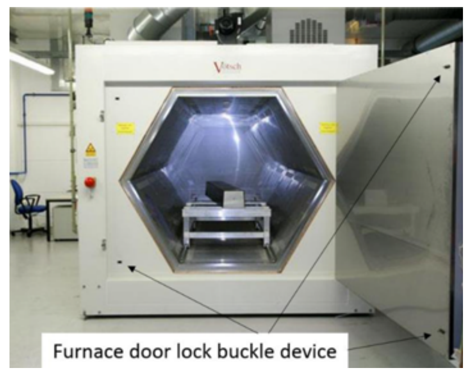


Figure 4. Microwave oven of GKN Aerospace.

autoclave adopts fast open pressure structure with tooth, and the maximum working pressure was 3.0 MPa). Therefore, whether the microwave oven curing pressure could reached 0.689 MPa was still in doubt, nor could it be confirmed that whether the high-pressure gas was inject into the microwave oven or the compression method was used to pressure the component to mold . In summary, to our knowledge, there is no literature about curing the high-performance CFRP by microwave under high pressure, which requires high pressure and uniform temperature field during curing.

In this paper, a set of devices was made, which enabled the microwave been import into the autoclave under high pressure, and a real-time temperature measurement and real-time control system of the microwave input power were equipped. A comparative study on curing the T800 carbon fiber reinforced epoxy resin pre-impregnated material specimens by the high-pressure microwave and the conventional autoclave were carried out.

Experimental

Materials

The material for the experiment was the T800 carbon fiber reinforced epoxy resin pre-impregnated material. The pre-impregnated material was stored at -12 ^{o}C, in a sealed contain, the laminate physical properties was shown in Table 1.

Table 1. Laminate physical properties

Name	Ply thickness (mm)	Laminate density (g/cm^3)	Fiber volume (%)	Glass transition, dry (^{o}C)
Nominal value	0.191	1.570	57.55	180

Table 2. Parameters of the tensile test specimens

Name	Dimension	No. of piles	Orientation
Tension test specimen	200 mm×25 mm	10	Unidirectional

In order to compare the difference of the curing quality, two unidirectional CFRP laminates were prepared by manual paving. The designed CFRP laminates dimension were 300 mm (length)×400 mm (width)×1.91 mm (thickness), the laminate physical properties was shown in Table 2. And the final thickness were approximately 1.82-1.85 mm after curing.

High-pressure Microwave Curing Test

High-pressure Microwave Curing Equipment

When the traditional autoclave working, the temperature could reach 200 ^{o}C, the pressure could reach 1.5 MPa, the magnetrons of the microwave equipment could not withstand such high temperature and high pressure. So, the autoclave needed to be modified, in order to import the microwave from outside of the autoclave to the inside. Moreover, the system of temperature measurement and the automatic control system of microwave power were also equipped, so as to realize the microwave curing of the CFRP under high pressure according to the pre-set cure cycle.

The equipment was shown in Figure 5 and Figure 6. The high-pressure gas of autoclave 10 got into the microwave shielding porous cavity 19 through the small holes of the cavity, then it was applied to the component 14, which was put into the vacuum bag 11 after the vacuum bag 11 be vacuumed by vacuum tube 15. After setting the cure cycle of the component 14 in the Programmable Logic Controller (PLC) 2, microwave generator 5 launched the microwave, it pass the confined glass 6 which fixed in the coupling flange 7 into the slot antennas 8, the slot antennas 8 fixed in the microwave shielding cavity 19. Then, the microwave entered the microwave shielding porous cavity 19 to heat the components 14 (The frequency of microwave was 2450 MHz). The temperature value of the component 14 is measured by the optical fiber 9 in real time, which was embedded in component 14, and transmitted to the data acquisition instrument 1, then to the PLC 2. After comparing the data collected by the temperature measurement optical fiber 9 with the cure cycle of the component 14, the PLC 2 continuously controlled the microwave power control module 4 to output microwave power, then, on line monitoring and

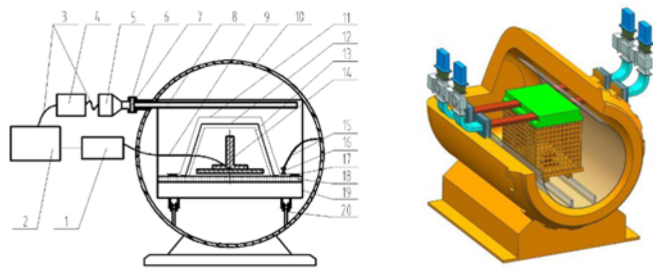


Figure 5. Schematic diagram of the structure of high-pressure microwave curing equipment; (1) data acquisition instrument, (2) PLC, (3) connects cables, (4) microwave power control module, (5) microwave generator, (6) coupling flange, (7) confined glass, (8) slot antenna, (9) temperature measurement optical fiber, (10) autoclave, (11) vacuum bag, (12) air felt, (13) peel ply, (14) composite component, (15) vacuum tube, (16) quick connect, (17) sealing adhesive tape, (18) through wave shelf plate, (19) microwave shielding porous cavity, (20) guide.

Figure 6. High-pressure microwave curing equipment.

closed-loop control system applied to adjust the temperature of the component were realized.

The component 14 could be heated and kept the heating insulation according to the pre-set cure cycle, by the microwave power emitted by the microwave generators 5. Then the high-pressure microwave curing process was realized. To get even more uniform heating than regular oven, the round robin mode was used by the microwave power control module to control the four microwave sources to work in turn (it is equivalent to moving the microwave

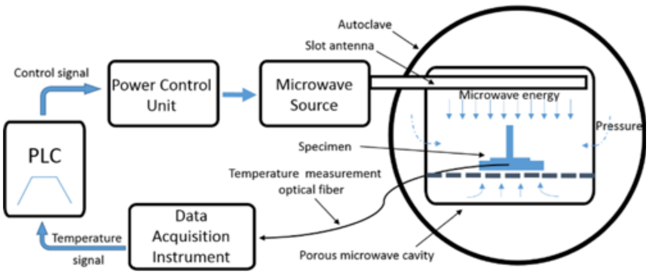


Figure 7. Schematics of the curing process.

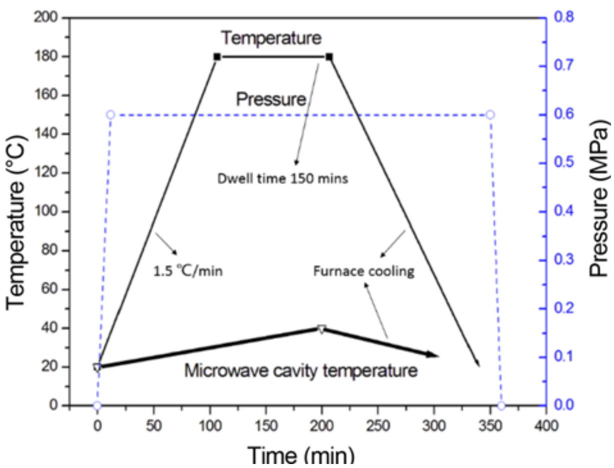


Figure 8. Cure cycle of the specimen of the high-pressure microwave curing.

source). The working principle of the device was shown in Figure 7.

High-pressure Microwave Curing

In order to prevent the arcing between the carbon fibers in microwave field, edging with aluminum foil around the component. Components of the T800 carbon fiber reinforced epoxy resin pre-impregnated material according to 0^{o} unidirectional layered, covered with air felt and peel ply, sealed with vacuum bag (Figure 5). After these, put it into the microwave cavity for high-pressure microwave curing. The pressures was set as 0.6±0.05 MPa. The power of microwave was controlled by the PLC automatically. The cure cycle of the component was shown specifically in Figure 8. Due to the characteristics of microwave selective heating, the temperature inside the microwave cavity was only increased by 20 ^{o}C after the experiment.

Conventional Autoclave Molding Curing

Components of the T800 carbon fiber reinforced epoxy resin pre-impregnated material according to 00 unidirectional layered covered with air felt and peel ply, sealed with vacuum bag (Figure 5). Then, put into the autoclave by heating curing. The cure cycle of the component was shown in Figure 9.

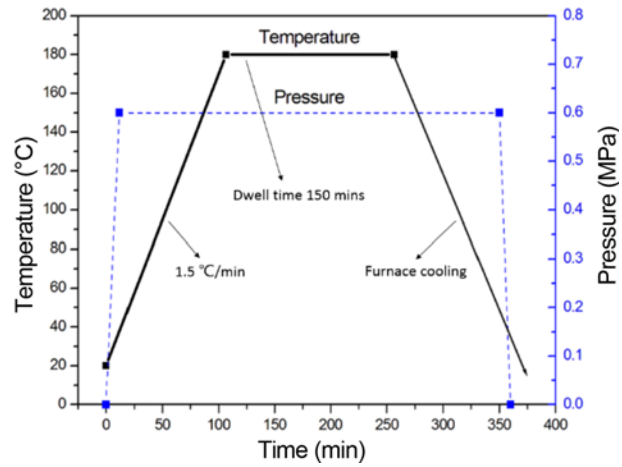


Figure 9. Cure cycle of the specimen of the autoclave curing.

Test and Comparison of the Properties of the Cured Components

Performance Comparison of the Components by Conventional Autoclave Curing and High-pressure Microwave Curing

Ultrasonic Phased Array Flaw Detection (UPAFD)

The defects of the voids, delamination had great influence on the mechanical properties of the CFRP. In order to find out whether there was defects in the components after high-pressure microwave curing, the UPAFD (Omni Scan MX2) was used. The frequency of probe (5L64-A2) was 5 Hz, using 64 chips arranged in a one-dimensional style, the wedge (SA2-AL) material was plexiglass. C-scan display mode was employed in the test. The depth of focus was 2.5 mm, and the longitudinal wave sonic speed was 3000 m s^{-1}. Water was used as the coupling agent, which coupled together with the probe and the CFRP laminates.

Optical Digital Microscopy (ODM)

For each piece of composite laminates cured by different curing methods, samples were taken from them of 10×10 mm, respectively. According to the national standard GB3365-82, the samples were mosaic, polished, polishing and anhydrous alcohol cleaning. The optical digital microscope (ODM, model: OLYMPUS DS×500) was employed to study the microscopic structure of composite laminates.

Mechanical Performance Test

The mechanical properties of the CFRP were the most important, the most common and the most concerned by the people. To assess the effects of microwave on the mechanical properties of the composite laminates during the curing process, the resin tensile strength test (GB/T 3354-2014) and the inter-laminar shear properties test (JC/T 773—2010) were employed for mechanical performance evaluation. These tests were carried out on the CMT5105 tensile testing apparatus (produced by Sansi Taijie Co., Ltd., China), and these mechanical performance tests were carried out in room temperature. The same performance test with the same

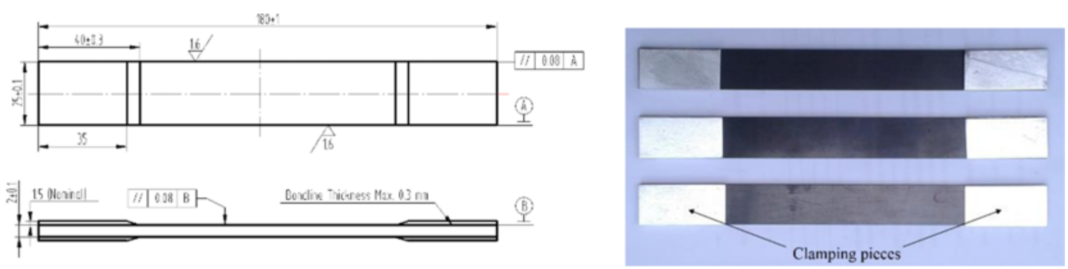


Figure 10. Tensile test specimens.

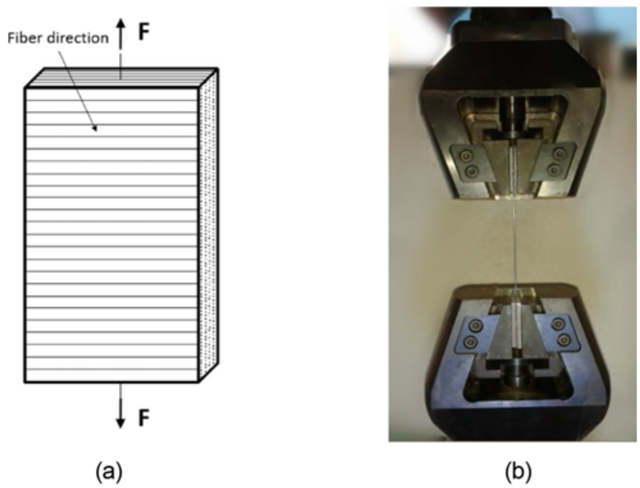


Figure 11. Schematic diagram and actual drawing of the resin tensile strength test.

geometry of the specimen. In order to avoid premature rupture due to the stress concentration caused by machining scratches, the specimen edges were polished before testing.

The tensile specimen geometry was shown in Figure 10, the thickness of specimens were the full thickness of the CFRP laminates (about 2 mm), respectively. The stretching rate was 0.5 mm/min. Select 2 mm thick aluminum plates as the clamping pieces, and a team of typical tensile specimens, and the internal carbon fiber orientation and drawing mode were shown in Figure 11.

The tensile strength σ_t (MPa) of the CFRP samples was determined according to equation (1):

$$\sigma_t = F_{\max}/(ab) \tag{1}$$

where $F_{\max}$ was the yield load, a breaking load or the maximum load (N), b was the sample width (mm) and d was the sample thickness (mm).

The inter-laminar shear specimen size as Table 3. The fillet radius of the loaded head was 5 mm, the fillet radius of the bearing was 2 mm, the pivot span was 12.5 mm.

The inter-laminar shear properties τ_m (MPa) of the composite samples was determined according to equation (2):

Table 3. The size of inter-laminar shear specimen (Unit: mm)

Thickness h	Length l	Width b
2±0.2	20±1	10±0.2

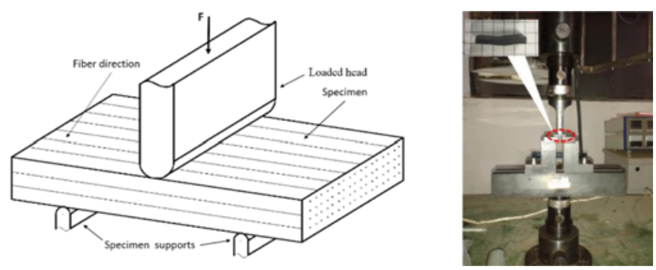


Figure 12. Schematic diagram and actual drawing of the inter-laminar shear properties test.

$$\tau_m = \frac{3}{4} \times \frac{F}{bh} \tag{2}$$

where F was the failure load or maximum load (N), b was the sample width (mm) and h was the specimen thickness (mm).

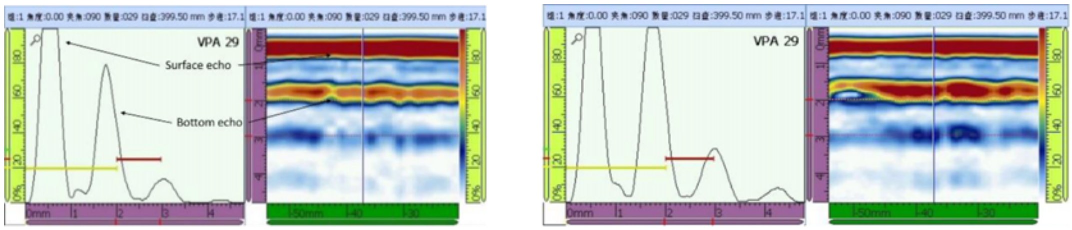
Microscopic Morphology Study

To study the bonding condition between the fiber and the resin in each specimen, after resin tensile strength and inter-laminar shear properties test. The scanning electron microscope (SEM) (Model: TESCAN MIRA3 LUM, USA) was employed to study the surface microstructure of the specimens.

Results and Discussion

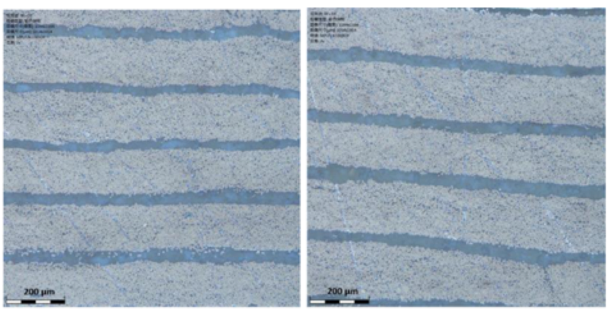
Internal Defects Analysis

The presence and location of possible defects in the CFRP laminates could be assessed accurately without damage by the UPAFD. The principle of the technology bases on the defects such as delamination and voids, which absorbed the ultrasonic and cause ultrasonic attenuation. In different curing process, the ultrasonic testing results were shown in Figure 13. If there were defects, such as delamination, voids, etc. So in the detection of the corresponding position in the map, where there would be a clear source of ultrasonic attenuation (namely defects) appeared between surface echo and bottom wave. The defects absorbed and reflected partial



(a) (b)

Figure 13. Ultrasonic flaw detection with different curing process; (a) high-pressure microwave curing and (b) conventional autoclave curing.



(a) (b)

Figure 14. The ODM morphology of the CFRP with different curing process; (a) high-pressure microwave curing and (b) conventional autoclave curing.

sonic wave, made the amplitude of inter-laminar echo increased as well as make the bottom wave seemed to be not obvious. Compared with the UPAFD of the components cured by high-pressure microwave curing, the internal situation of the microwave curing of the component was the same as that of the autoclave. The intensity of bottom waves and surface waves were almost unanimous from the Figure 13.

Based on the ultrasonic flaw detection, the microscopic morphology of the CFRP laminates could be observed intuitively by the ODM. The microscopic morphology of different cure way applied on CFRP laminates was shown in Figure 14. Tight binding between layers and the voids and the delamination in the CFRP laminates were not found as shown in Figure 14(a), which was the main types of defect. The phenomenon of resin rich or lean fat was not found, too. There was little difference between the two small graphs in Figure 14.

Mechanical Performance Analysis

In order to analyze the changes of the mechanical properties of the resin of the high performance CFRP laminates, which were curing by the high-pressure microwave. By comparing the tensile strength of the CFRP specimens cured with high-pressure microwave curing and autoclave curing, with the same curing pressure. The experimental results showed that the specimens' average tensile strength was 68.70 MPa by high microwave curing, and the specimens' average tensile strength was 62.90 MPa by autoclave curing, the detail number as shown in Table 4. The tensile strength value of the specimens cured by high-pressure microwave was about 9.2 % higher than the average of the tensile strength of the autoclave curing, as shown in Figure 15.

The size of the inter-laminar shear strength could be characterized by the properties of the adhesive property between the layers. It was an important way to characterize the macroscopic mechanical properties of the high performance

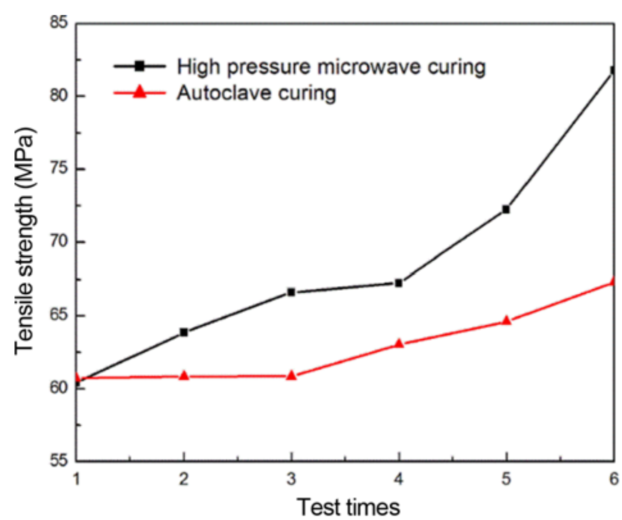


Figure 15. Comparison of resin's tensile strength of high-pressure microwave and autoclave curing.

Table 4. Resin's tensile strength test of high-pressure microwave and autoclave curing

Test times	Test piece 1	Test piece 2	Test piece 3	Test piece 4	Test piece 5	Test piece 6	Average value
High-pressure Microwave curing (MPa)	60.43	63.86	66.62	67.26	72.24	81.79	68.70
Autoclave curing (MPa)	60.73	60.84	60.86	63.05	64.62	67.31	62.90

Table 5. Specimens' inter-laminar shear strength of high-pressure microwave and autoclave curing

Test times	Test piece 1	Test piece 2	Test piece 3	Test piece 4	Test piece 5	Test piece 6	Average value
High-pressure Microwave curing (MPa)	104.17	104.98	105.20	110.80	112.02	114.64	108.64
Autoclave curing (MPa)	90.34	99.89	105.42	106.38	108.60	114.91	104.26

CFRP laminates, that determination of apparent inter-laminar shear strength by short beam method. The higher the shear strength of the CFRP, the better the interfacial properties of the CFRP laminates. Through the short beam shear test, compared the inter-laminar shear numerical value of the specimens cured by high microwave and autoclave, with the same curing pressure.

As shown in Table 5, it could be known that the specimens' average shear strength between layers was 108.64 MPa, which were cured by high-pressure microwave, the specimens' average shear strength between layers was 104.26 MPa, which were cured by autoclave. The shear strength value of the specimens cured by high-pressure microwave was about 4.2 % higher than the average of the shear strength of the autoclave curing, as shown in Figure 16.

The variation of load and displacement curve of the specimen during the shear test was shown in the Figure 17. It could be seen from the Figure 17 that the specimens' inter-laminar shear load displacement curve shape of high-pressure microwave and autoclave curing were basically the same. All specimens exhibited three stages: firstly, the specimen showed elastic deformation after loading. During the elastic deformation stage, elastic deformation was only occurred in the specimen, the fibers and resin of the specimen bear the load together. And the failure modes of composite laminates, such as matrix cracking, delamination, fiber breakage and de-bonding would not happen. Secondly, when the load to the A (A') point, the elastic deformation stage come to the end and the failure stage begun, adhesive failure took place along the interface and low interfacial adhesion strength between carbon fibers' surface and the resin resulted in failure in the process of increasing load. Then, the delamination began to happen with the load increasing, and some of the carbon fibers broken and pulled out from the resin with the load increasing, and the slope of the curve was decreased during this stage. When the load reached the B (B') point, under the action of the load, the delamination and most of the carbon fibers were broken or pulled-out or de-bonding were over. The ODM morphology of the specimens after the inter-laminar shear test was shown in Figure 18. Thirdly, after the B (B') point, the load that the specimen could bear was straight down. It could be seen that all specimens exhibited a brittle fracture during the inter-laminar shear test.

From Figure 17, we could see that during the elastic deformation stage, the slope curves of the specimen by the high-pressure microwave curing was lower than the specimen

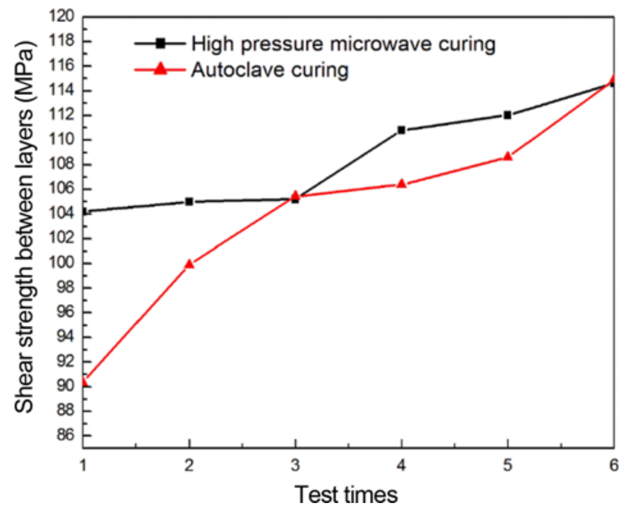


Figure 16. The inter-laminar shear strength of high-pressure microwave and autoclave curing.

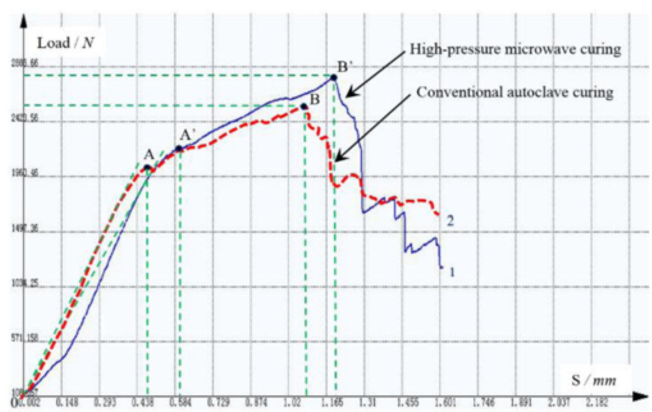


Figure 17. The inter-laminar shear load-displacement curve diagram.

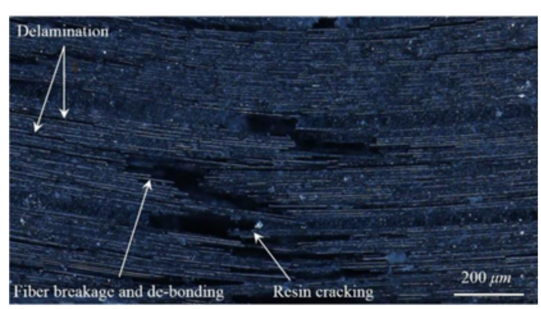


Figure 18. The ODM morphology of the specimen after the inter-laminar shear test.

by the autoclave curing. The horizontal distance between point A and A' was 0.123 mm, which indicated that the CFRP cured by the high-pressure microwave exhibited more ductile behavior than cured by autoclave. The difference between the maximum load of the specimens cured by the high-pressure microwave curing and autoclave was 188.6 N. To withstand the load, the matrix had to transfer the strength to the reinforcing carbon fibers via the interface between the carbon fibers and matrix. It indicated that the interface between the carbon fiber and resin of the CFRP cured by the high-pressure microwave was stronger than the CFRP cured by the autoclave. When shear failure happened, the CFRP cured by the high-pressure microwave required more energy.

From the above illustration, it could be known that, after the high-pressure microwave curing, the tensile strength of the resin in laminates increased by 9.2 % than the laminates cured by autoclave. The inter-laminar shear strength of the laminates after high-pressure microwave curing was enhanced by 4.2 % than the laminates cured by autoclave. It indicated the irradiation of the high pressure microwave curing not only resulted in better interfacial between the carbon fibers and resin, but also enhanced the mechanical property notably than the autoclave curing.

Fracture Morphology Microscopic Structural Analysis

The fracture surfaces of the CFRP specimens subjected to tensile strength and three-point bend test were examined by using SEM. Because the carbon fiber itself had electrical conductivity, did not need the surface spray treatment. 2000 times and 5000 times of the microstructure of the specimen section were amplified respectively, to analysis of the failure mechanism of laminates' resin and fiber bonding interface.

According to the microscopic images of the fracture surfaces by SEM (Figure 19, 20), the fibers arrangement in the section of the high-pressure microwave curing tensile test specimens was in close order, and the resin was evenly filled with the space between the fibers. From Figure 19, the specimens cured by the high-pressure microwave and autoclave showed the typical fracture surface of brittle epoxy resins, which displayed the same type of mechanical tensile behavior. Comparing a, c with and b, d (Figure 19), it could be found that on the surface of the carbon fiber cured by high-pressure microwave, a layer of resin was coated. While on the surface of the carbon fibers cured by autoclave, there was only a fraction of resins remains adhered, and interfacial de-bonding appeared mostly. It can be concluded that the interface strength of the carbon fiber produced by two curing methods were different. The difference of the tensile strength value could be attributed to the different interface strength between the carbon fiber and the matrix, which explained the reason why the average tensile strength was different of the specimens cured by the high-pressure

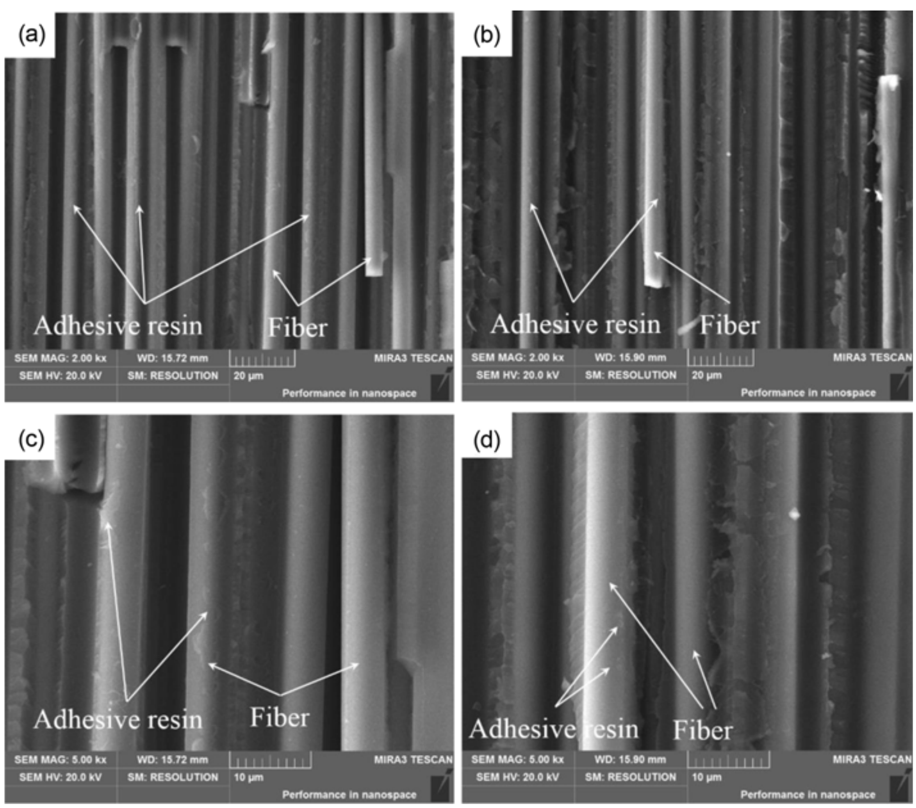


Figure 19. The section SEM images of the resin tensile strength test; (a, c) high-pressure microwave cured specimen and (b, d) autoclave cured specimen.

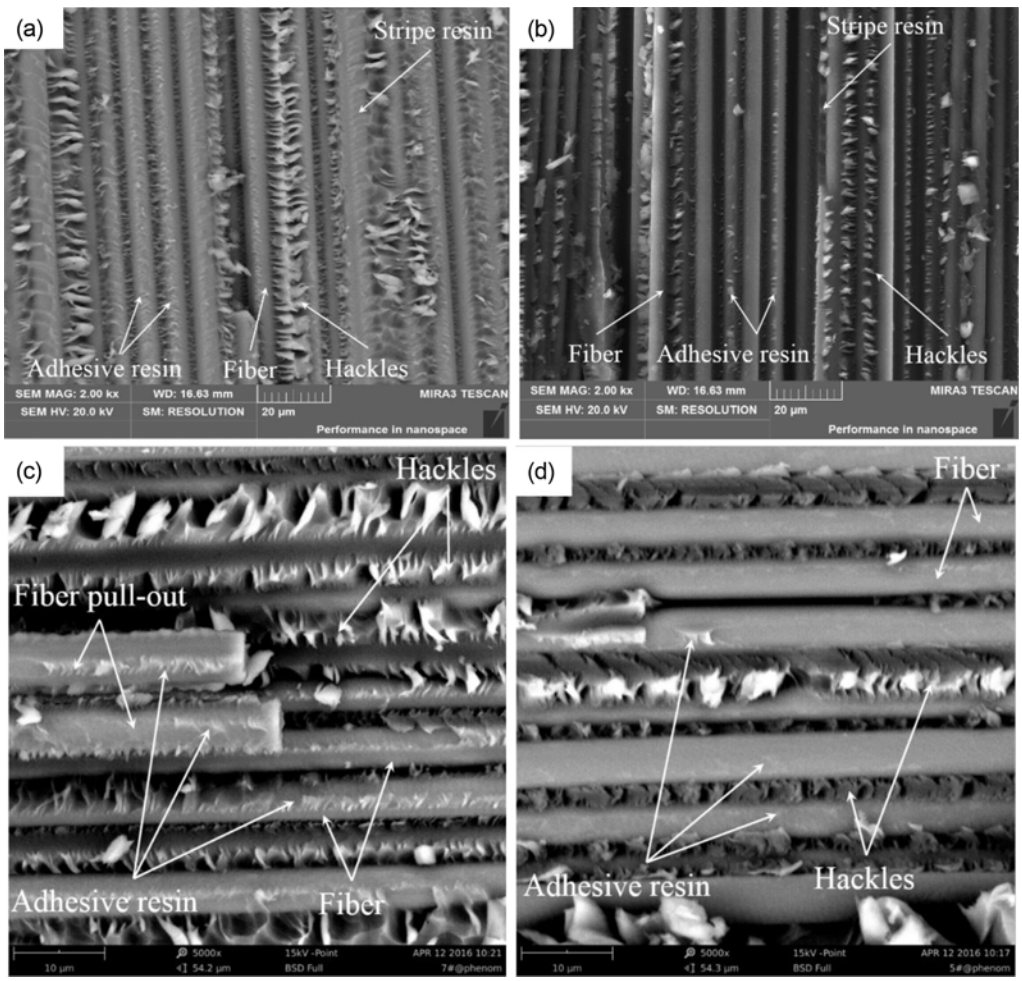


Figure 20. The section SEM images of the specimen after shear test; (a, c) high-pressure microwave cured specimen and (b, d) autoclave cured specimen.

microwave and autoclave (Figure 15).

When the amplification factor reaches 5000 times, there was still no observed voids, delamination and other defects, which affected the mechanical properties of the CFRP indirectly. These conclusions were consistent with the observations of the previous UPAFD and the ODM.

From Figure 20, the section SEM images of the specimens after shear test all showed the same shear fracture surface of brittle epoxy resins, which indicated the mechanisms of shear rupture are identical for the specimens cured by the high-pressure microwave and autoclave. The resin of the layer failure surface showed the hackles, which evenly distributed in the space between the carbon fibers were all present.

The difference was that (Figure 20):

The inter-laminar shear failure surfaces of the high-pressure microwave-cured CFRP showed a considerable layer of resin wrapped to the fibers surface, whereas the inter-laminar shear failure surface of the autoclave cured composites were small pieces of resin adhered to the surface of the fibers. The failure of the former occurred in the interior of the resin matrix, and the latter occurred was mostly interfacial.

Even the fibers was pulled-out from the resin, the surface of the carbon fibers was wrapped with a layer of resin (Figure 20(c)). The better interface bonding of the fiber by the resin occurred in the high-pressure microwave curing than the autoclave curing. There are some major reasons of the stronger interface strength: firstly, it most likely to be attributed to the volume heating and the greater homogeneity of the high-pressure microwave cured resin. Secondly, considered to be the excellent heat transfer from each carbon fiber to the resin. Thirdly, it seemed that the local thermal energy transferred from carbon fibers to the resin due to microwave irradiation modified the physico-chemical linking at the carbon-resin interface. It explained that the interface strength was stronger result that the specimens' mechanical property of the high-pressure microwave cured was better than the autoclave cured.

Conclusion

This research is a valuable exploration of curing the high-performance CFRP by high-pressure microwave technologies. The working principle of high-pressure microwave equipment was introduced. And the high-pressure microwave curing of T800 carbon fiber reinforced epoxy resin pre-impregnated material was carried out by using the equipment under 0.6 MPa pressure.

In terms of the production efficiency, the results showed that compared with the traditional autoclave molding process, high-pressure microwave curing could not only reduced the energy consumption significantly, but also saved 1/3 of the curing time.

Microwave radiation under high-pressure environment resulted in the mechanical property of the CFRP was improved. The comparative analysis was carried out on the specimens which were cured by high-pressure microwave and autoclave curing respectively, under the same curing temperature and pressure, with the UPAFD, the ODM, mechanical properties testing, fracture morphology microscopic structural analysis of SEM. The analysis showed that, compared with the specimens cured by autoclave, there was no obvious difference in quality in the specimens cured by high-pressure microwave; the CFRP exhibited more ductile behavior, and the mechanical properties were enhanced. Specifically, the tensile strength of the components increase by 9.2 % in the direction perpendicular to the fiber; and the inter-laminar shear strength increase by 4.2 %. The failure of the CFRP mainly occur in the inner of the resin matrix, it indicated that the radiation of the microwave under the high-pressure environment enhanced the interfacial strength between the carbon fibers and resin.

In conclusion, the novel method opens the door for improving the curing efficiency and reduce the energy consumption for processing the CFRP in aerospace applications, and provide a new way for improving the interfacial properties by high-pressure microwave curing.

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