MIRRORS FABRICATED BY ALL CFRP COMPOSITES AND THEIR DIMENSIONAL STABILITY IN AIR

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Summary：In this paper, a Φ150mm mirror was fabricated with carbon fiber reinforced epoxy composites. The humid stability of the mirror surface accuracy can be improved by polymer coating. The surface accuracy can be maintained for more than 200 days.

ABSTRACT

To realize ultra-lightweight ratio, a Φ150mm mirror was fabricated with all CFRP (carbon fiber reinforced plastic composites). The replication technology was applied to improve surface accuracy, meanwhile the dimensional stability was detected in this paper. As a result, 0.098 λ (λ=632.8nm, RMS) was achieved through resin replication method. The roughness was improved to 1.9 nm (Ra). The CFRP mirror presented poor dimension stability, the surface accuracy increased gradually in air. However, it can be improved by a polymer coating on mirror surface. The surface accuracy can be maintained under 0.15 λ for more than 200 days.

1. INTRODUCTION

To get higher-resolution, larger mirrors have to be adopted in space observations. However, theses mirrors are usually extremely heavy, to ensure enough stiffness. It is an indeed huge bill; many projects have to be delayed or cancelled, owning to such a giant launch pay. Therefore, how to make larger mirrors with lightweight, become an urgent problem to be solved.

Up to now, the most common mirror materials are glass (Zerodur, fused silica, ULE), metal (aluminum, beryllium) and ceramic (SiC). High surface quality can be achieved with these materials, through optical finishing. But their specific stiffness was not high enough to prevent the distortion, attributed from gravity or the environmental condition changes. These materials can not satisfy the developing requirement of ultra-lightweight large mirrors in future.

Carbon fiber reinforced plastic composites exhibited high specific stiffness and low density, can offer large amount of mass reduction. A traditional mirror weighted about hundreds of kilograms, however, the weight can be reduced to several kilograms with CFRP composites. It will make a great discount on the launch bill. Meanwhile the composites are more designable freely, the properties can be optimized through different material design. Researchers have done great amount of works in this field. CMA(Composites mirror Applications, Inc. America), COI(composites optics, Inc. America) and JAXA(Japan aerospace exploration agency, Japan) have done lots of works on the fabrication of CFRP laminates and mirrors, especially the resin replication technology. Other institutions like UCL (university college London, UK) focus their effort on the deformable mirrors, through electroplating Ni coating on the CFRP laminate plates. Compared with the Ni electroplating technology, resin replicating can reduce the optic finishing time and realize high surface accuracy in a short time; meanwhile, it is more suitable for fabrication of enormous same structure mirrors in the huge joint mirror system.

But, there are still some problems. The resin expanded when absorbed moisture, which threatened the stability of mirror surface accuracy. Therefore, mirror dimension stability in humid environment must be well studied and improved. In this paper, a Φ150mm mirror was fabricated by CFRP with M40 carbon fiber and epoxy resin; the surface accuracy was improved through resin replication method. The surface accuracy varieties were investigated for long time in air by ZYGO interferometer. Meanwhile, in order to improve its humidity tolerance, a polymer coating was applied on the mirror surface through painting. With the polymer coating, the CFRP mirror can be isolated with outer water vapor; the surface accuracy was hoped to be controlled stable in air.

2. EXPERIMENTAL

2.1 Fabrication of all CFRP mirror body

As shown in Fig.1, the mirror was made of two surface skins and core. The skins laminate was fabricated of high modulus carbon fiber (M40) and epoxy matrix resin. 16 thin compliant prepreg layers were arranged in a quasi-isotropic configuration ([0/22.5/45/67.5/90/-67.5/-45/-22.5/0]2s) onto a layup tool made of low expansion steel. 8 layers with same configuration order was applied in the core laminate. Therefore, the thickness of core ribs was 1mm and half of the surface skins. The stacked laminates were cured at 120℃ for 2h in an autoclave. The low expansion steel tool was selected to reduce thermal distortion of the laminates in cooling from curing temperature to room temperature.

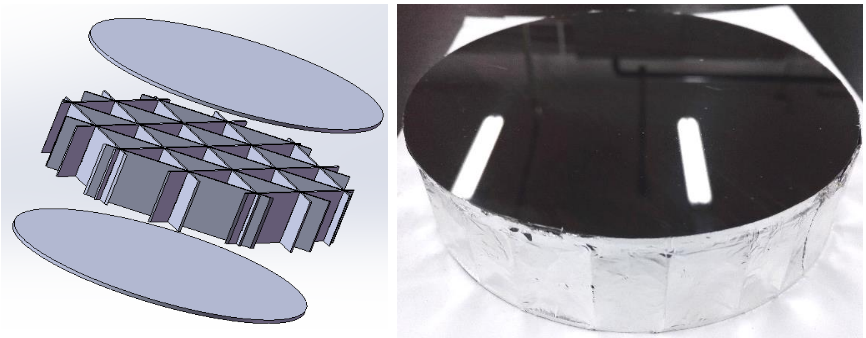

Fig.1 the structure and macroscopic picture of all CFRP mirror

The core structure was prepared with a novel method. Firstly, the CFRP laminate was cut into small strips with indentations. Then, the strips inserted into each other, according to the indentations. Finally, an inlaying triangle honeycomb was formed. More details can be found in the ref [7].

At the last step, the skins and the core was stick together with adhesive of low cure shrinkage. All CFRP mirror body can be obtained, after the adhesive cured completely.

2.2 surface accuracy improvement and detection

After mirror body was prepared, replication technique was applied to improve the surface accuracy. Mold release reagent was painted on a glass mandrel firstly, which have a high surface accuracy of 0.02λ. Degassed epoxy resin was poured on mandrel surface, then the mirror body was placed on the resin coated mandrel. Residual air bubbles were forced out in a careful manner. After cured for 5-7 days at room temperature, the mirror can be removed from the tool.

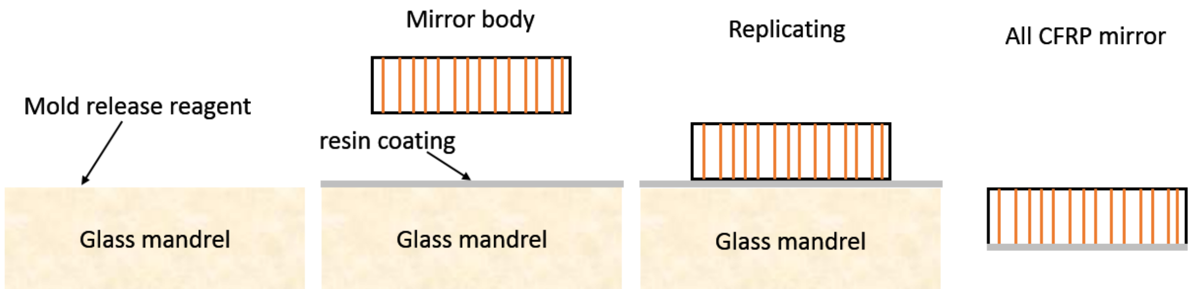

Fig.3 Replication process of CFRP mirror

The surface accuracy was investigated by a ZYGO interferometer after replication. In order to study the effects of humidity on surface accuracy, longtime detection was operated. To assure the reliability of the test data, the test was carried on at stable temperature with a tolerance of ±2 ℃. The roughness was tested by 4D digital rough meter.

3. Discussion

3.1 Surface accuracy of all-CFRP mirror

Ideally the resulting CFRP laminate surface will replicate the optical quality surface of the mandrel, reducing the costs of polishing and correcting of the mirror's surface figure after autoclaving. However, the final surface replicated accuracy was affected by lots of factors: the glass mandrel accuracy, the initial accuracy of CFRP mirror body, cure shrinkage of resin, environmental condition.

(1) The mandrel must have high accuracy, low roughness and well dimensional stability. It is because that heat released during the copy resin cure, which might attributed to increase of the mandrel surface accuracy. Mandrel roughness can be copied on the mirror surface. It is because that the roughness was not changed with the temperature; however, mold release reagent and its painting manners do affect the roughness much. The painting marks will do harm to mandrel surface smoothness. Solid content of mold release reagent should be low enough, otherwise a smooth surface could hardly be obtained.

(2) To realize high accuracy, the initial surface should have a certain flatness. The flatness of glass mirror can be improved through optical-polished to an acceptable value. Therefore, surface accuracy can always reach λ/50 RMS in the glass mirror replication, if the mandrel have high enough surface accuracy. However, CFRP mirror was difficult to be polished. The carbon fiber and resin were the phases with so different hardness; the resin expanded when absorbed water, which cannot be avoided in the traditional optical grinding process. In addition, the thermal dimensional stability will be decreased if the symmetry of fibers layup was damage. So the initial flatness of CFRP mirror can only be improved through optimizing cure craft in autoclave; such as using low cure temperature, enhancing the spreading accuracy of the prepreg tapes.

(3) During the cure, the polymerization reactions happened to the molecules of epoxy resin. The molecule coherence changed from hydrogen bond (van der Waals force) into covalent bond. The bond length become shorter. Therefore, the shrinkage was unavoidable during cure process. The mirror dimensional changed because of the residual stress, which attributed from the resin shrinkage. Therefore, the mirror cannot copy the same high accuracy of the mandrel. So to figure out the problem, epoxy resin with low cure shrinkage should be applied and reduce the residual stress as much as possible in the replication.

(4) The environmental condition should be carefully controlled. Surface accuracy especially high accuracy of mandrel changes greatly if the temperature changes; the CFRP mirror dimensional will also change because of humid absorption expansion, if it is so wet around. So a stable and well controlled environment was very significant to get an excellent copy accuracy.

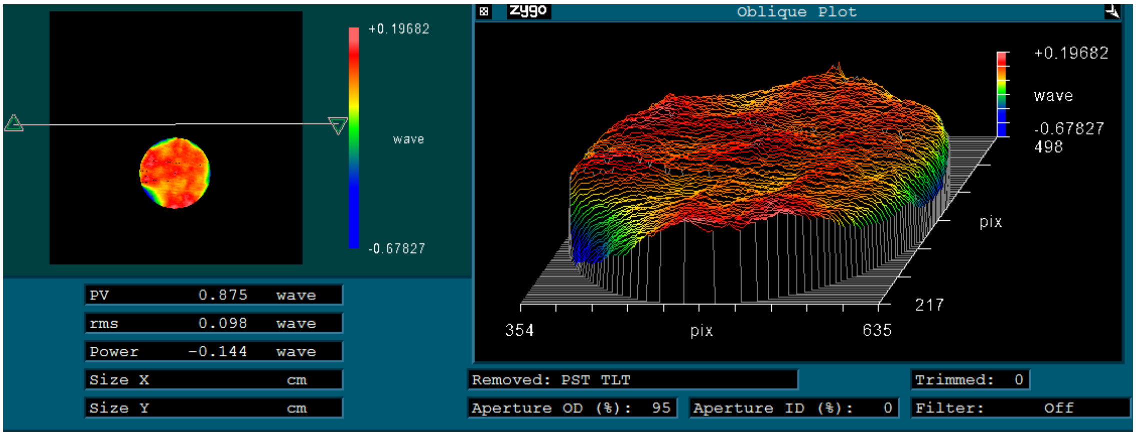

Fig. 4 Surface accuracy of all-CFRP mirror

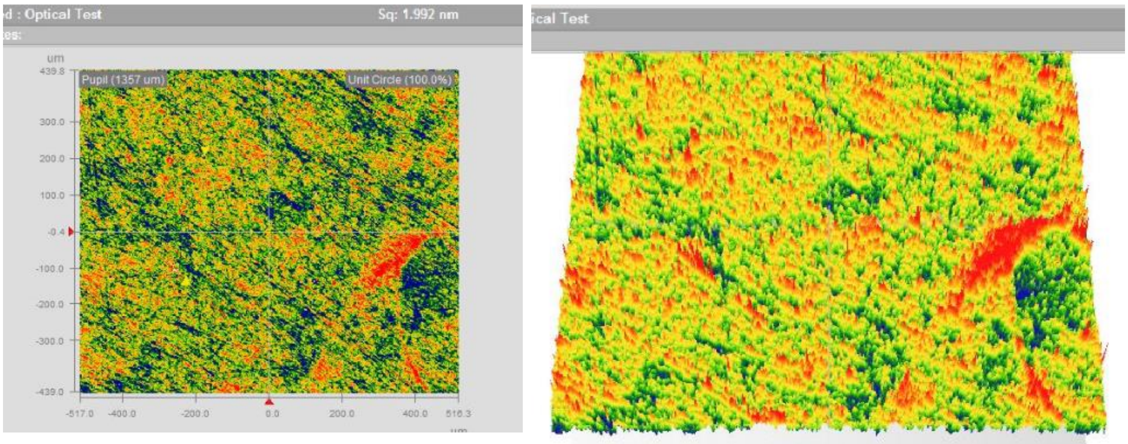

Fig. 5 the surface roughness of all-CFRP mirror

In our experimental, great efforts have been made on above factors. Finally, the surface accuracy can be improved greatly. Up to now, 0.098λ (RMS, λ=632.8nm) was realized on Φ150mm CFRP mirror. Surface roughness was 1.9nm (Ra) and almost the same as the roughness of glass mandrel.

3.2 surface accuracy stability of all-CFRP mirror

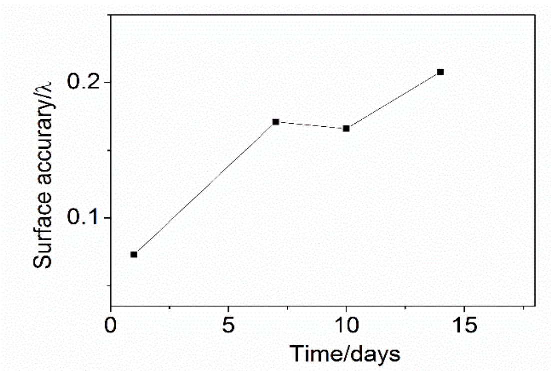

Fig.6 Surface accuracy variety of CFRP mirror in air

Although accuracy can be improved with replicated method, there was another problem to be solved. The surface accuracy was unstable, resulted from the moisture expansion of CFRP. As shown in the Fig.6, surface accuracy of as-prepared sample was 0.073λ. However, the value increased gradually to 0.2 λ in 14 days. It mainly attributed to the moisture expansion of CFRP. When the mirror was exposed in air, the copy and matrix epoxy resins began to absorb the water vapor in air. The different moisture expansion properties of core and faceplate CFRP resulted in the anisotropy dimensional change. Consequently, the surface accuracy increased with the exposed time.

In order to solve this problem, the authors do a lot works on the waterproof films. Many films like fusible metal and their alloys (such as Bi, Sn), polymer (such as PET, PP, PE, polyurea) can isolated CFRP mirrors out of water vapor in air. Polymer coating was more suitable for this purpose, because of convenient operation process and more firmly coherence with the plastic composites. In this paper, the author prepared a polymer coating through painting method on mirror surface. Then the accuracy stability after replicated was detected in the air.

From Fig.7, it can be found that the coated CFRP mirror behaved more stable accuracy. The accuracy can be controlled under 0.15λ for more than 200 days (from October to June next year). It obvious that the accuracy was closely related with the air moisture. At the first several days, the accuracy became better with the decrease of the air moisture. Then the accuracy was stable for about 20 days, when air moisture was not changed much. The surface accuracy became worse with the moisture decrease after winter coming. Then, the accuracy changed better again along with the moisture increase.

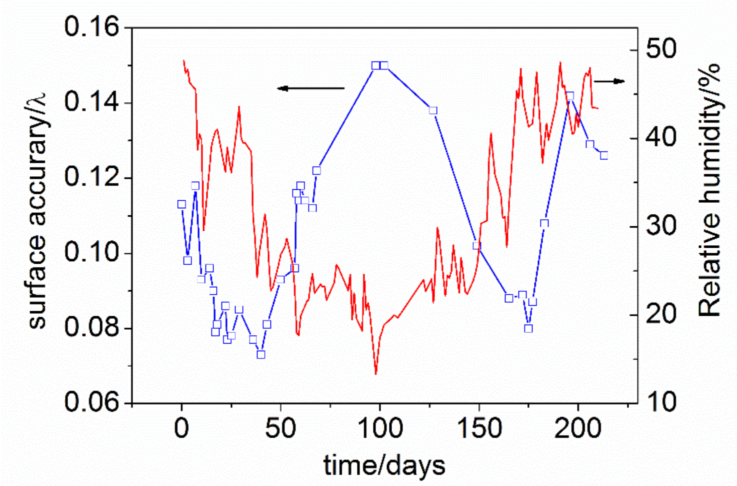

Fig.7 Surface accuracy variety of coated CFRP mirror in air

Form Fig.8, the change details can be found at different time. At initial, the interior surface was quite flat. The accuracy error was mainly come from the uneven spot at the edge. Then, a lot of high strip line appeared in the interior region, which were correspondent with the core ribs. Along with the exposed time, the high lines were more and more obvious on the surface. It is because that the core rib expansion direction was different with the faceplate. The core CFRP ribs expanded or shrinkage resulted in the surface accuracy changes, during the moisture absorption or release.

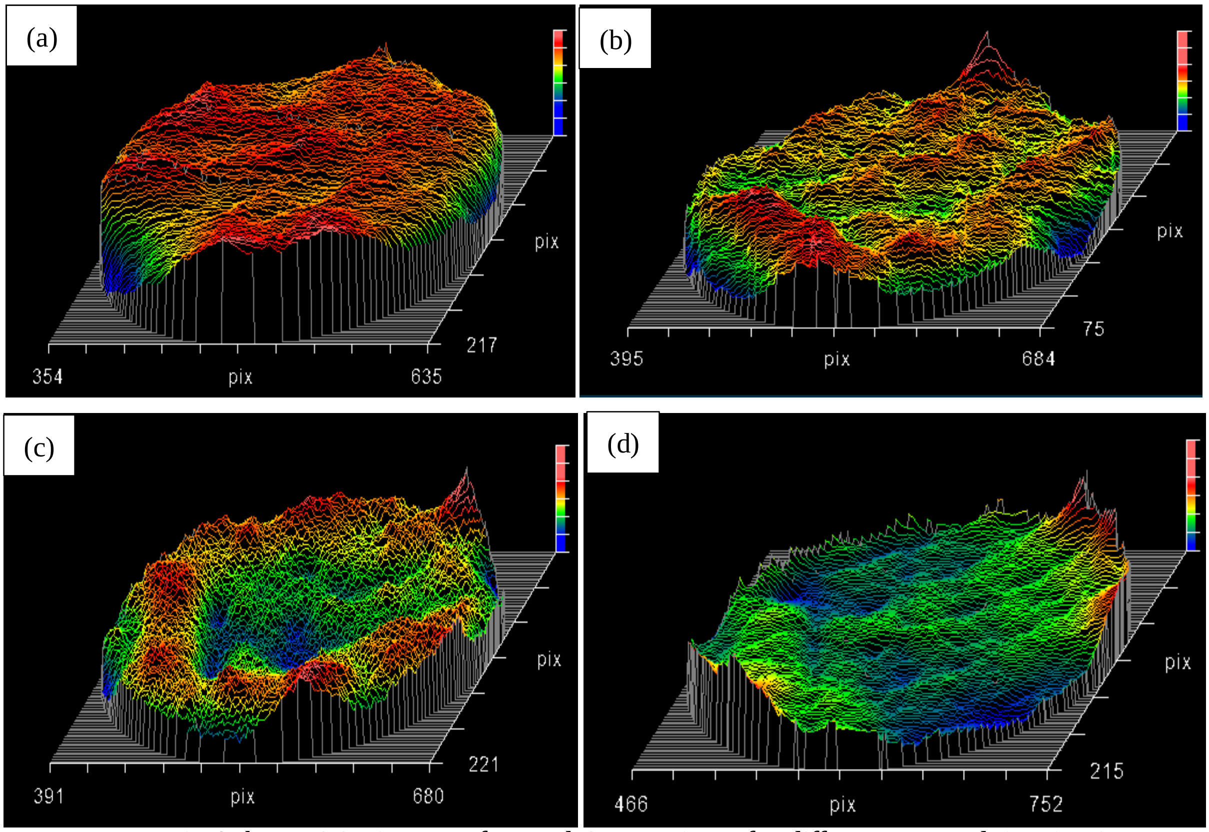

Fig.8 the ZYGO pictures of coated CFRP mirror for different exposed time in air
(a)3days, 0.098λ (b)40days, 0.073λ (c)68 days.0.122λ (d)196days,0.142λ

4. CONCLUSIONS

A Φ150mm all CFRP mirror was fabricated with carbon fiber reinforced epoxy composites successfully. Through replication technique, the surface accuracy can be improved to 0.098λ, the surface roughness of 1.9nm (Ra) can be achieved. The surface accuracy gradually increased when exposed in wet air. However, the stability can be improved by polymer coating. The surface accuracy can be maintained under 0.15λ for more than 200 days.

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