STUDY ON RESIN LAYER POLISHING OF CARBON FIBER MIRROR BASED ON ION BEAM FIGURING

DING Jiao teng[1,2]，FAN Xue wu[1]，XU Liang[1]，MA Zhen[1]，XIE Yong jie[1]，
WANG Yong jie[1]，LUO Yao[3]

[1]Xi' an Institute of Optics and Precision Mechanics of CAS, Shannxi Xi' an 710119,China
[2]University of Chinese Academy of Sciences,Beijing 100049,China
[3]Xi' an Branch of China Academy of Space Technology, Shannxi Xi' an,710100,China

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ABSTRACT

Based on the advantages of stress-free and non-liquid environment, ion beam polishing is the ideal processing technology for the Resin modified layer polishing of the carbon fiber mirror. Since the glass transition temperature of the resin is low, the energy absorbed by the surface of the mirror during ion beam processing can cause localized high temperatures, which can lead to the risk of resin softening. The finite element analysis software was used to simulate the heat transfer process of Ion beam acting on the resin modified layer. The optimum process parameters of the ion beam polishing were determined. At the same time, the resin layer surface polishing test was completed. The experimental results show that the surface polishing of the resin modified layer can be achieved by ion beam processing, and it has the convergence property and the correctness of the theoretical model is Verified.

1 INTRODUCTION

In the space camera, the mirror not only directly determine the optical properties of the space camera, but also influence the mechanical properties, the thermal stability, the manufacturing difficulty and costs of the camera. Compared with the other optical materials (SIC, ULE, Zerodur), the performance of Carbon Fiber Reinforced Polymer (CFRP) is more balanced for low density, low thermal expansion coefficient and high specific stiffness characteristics. Due to use a special replication process, CFRP can be achieved at low cost and rapid manufacturing process; Compared with the conventional materials, CFRP also can greatly reduce manufacturing costs. Furthermore the manufacturing equipment of CFRP is relatively mature, you can achieve a large-diameter, lightweight mirror blank to meet the future camera and telescope which is the more growing aperture (diameter 5 ~ 20 m), the more small surface density (2 to 10 kg / m2) requirements. From the beginning of the 1990s, many foreign institutions have been studied with high precision CFRP mirrors which have been involved in passive mirror, active mirror, splicing mirror, shape memory mirrors and other application fields [1-4].

For the two-phase substrate material of Carbon fiber mirror, The smooth surface can not be directly obtained by polishing, so we can use the resin secondary replication process to complete the surface modification, then complete the surface polishing of resin layer through optical processing.

The resin surface will appear more serious mesh effect, also will cause the moisture absorption reaction by the traditional processing methods, which can not guarantee the stability of resin surface[5]. At the same time, NC polishing technology (CCOS), gasbag polishing technology (IRP) and magnetorheological polishing technology (MRF) can not solve the moisture absorption effect.

The ion beam figuring technology uses non-contact material removal mechanism, can both meet the two requirements of stress-free and non-liquid environment, is the ideal processing means of the resin layer polishing of carbon fiber mirror.

However, the glass transition temperature of the resin layer is low, and the energy absorbed by the surface of the mirror during ion beam processing causes localized high temperature, which brings about the risk of resin softening .

In this paper, the finite element analysis software was used to simulate the whole heat conduction process of Ion beam acting on the resin modified layer, and the optimum process parameters of the ion beam polishing were determined. A suitable process route of resin modified layer polishing based on Ion Beam Figuring is groped ,which can provide reference for the surface processing of resin modified layer in future.

2 HEAT GENERATION MECHANISM OF ION BEAM POLISHING

The ion beam polishing technique utilizes the ion beam emitted by the ion source to bombard the optical surface in vacuum and removes the surface material of the optical element by the physical sputtering effect , so as to achieve the purpose of correcting the surface error. Figure 1 shows the principle of ion beam processing, the physical sputtering process along with complex energy transfer and exchange, and within the workpiece caused by cascading collision, when the high-speed ions hit the optical mirror surface, and the mirror surface Of the energy transfer occurs, most of the energy of the incident ions deposited in the mirror body, kinetic energy into heat, so that the temperature of the optical mirror increased rapidly[6].

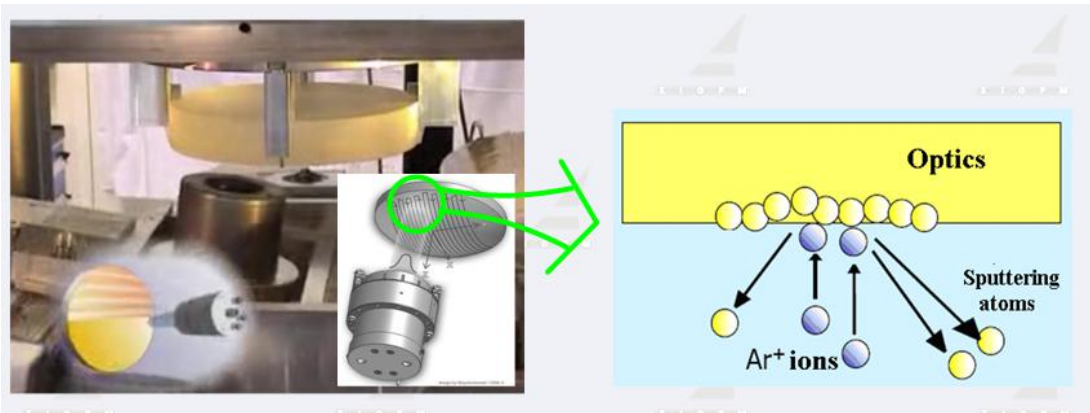
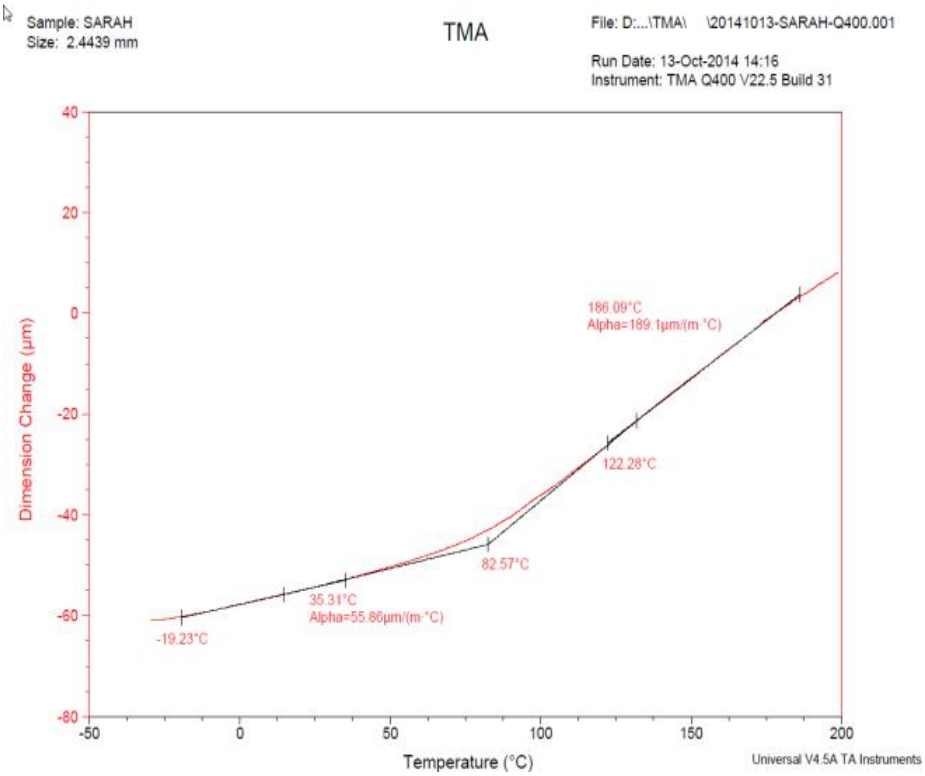


Figure 1： the principle of ion beam processing

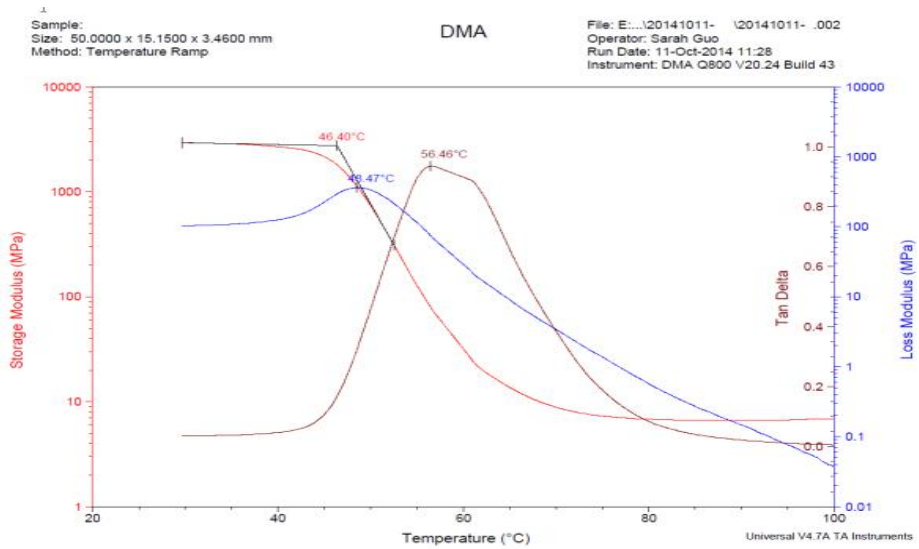
3 DETERMINATION OF GLASS TRANSITION TEMPERATURE

Resin performance has four mechanical states, including glassy, viscoelastic, high elasticity and viscous flow. When the temperature is low, the material is rigid solid, similar to the glass, under the action of external force will only occur very small deformation, this state is glass; when the temperature continues to rise to a certain range, the material significantly increased the deformation , And in the subsequent temperature range is relatively stable, this state is a high elastic state, the temperature continues to increase, the material gradually become a viscous fluid, the shape can not be restored, this state is viscous flow. The transition between the glassy state and the high elastic state is called the glass transition, and the corresponding temperature is the glass transition temperature. When the temperature of the resin is higher than the glass transition temperature, the resin surface starts to soften and thus can not guarantee the stability of the mirror, so the ion beam processing temperature must be lower than the glass transition temperature of the resin.

The glass transition temperature (TG point) of the resin can be measured by TMA or DMA equipment, as shown in Fig. 2. The TG point is 82.5℃ by TMA,and 46.4℃ by DMA,according to the test principle, the DMA test data is more accurate.



The TMA curve of the resin



The DMA curve of the resin

Figure 2： The TG point test of the resin

4 SIMULATION AND ANALYSIS OF ION BEAM FIGURING

The locally absorbed energy of the resin surface is usually determined by beam power and beam spot diameter, where the beam power is determined by the ion beam voltage and current, and the beam spot diameter is determined by the target distance. When the ion beam power is too large or the spot diameter is too small, it may cause local high temperature to be less than heat conduction, resulting in local softening of the resin layer[7-8].

The heat transfer process of resin layer by ion beam figuring was simulated and analyzed by using finite element analysis， as shown in Fig. 3. The temperature change of the local resin layer surface was simulated under different ion beam power and beam spot diameter ， And the relationship between the processing time and the temperature change of the resin layer was also simulated. Then the optimum process parameters of the ion beam polishing are determined.

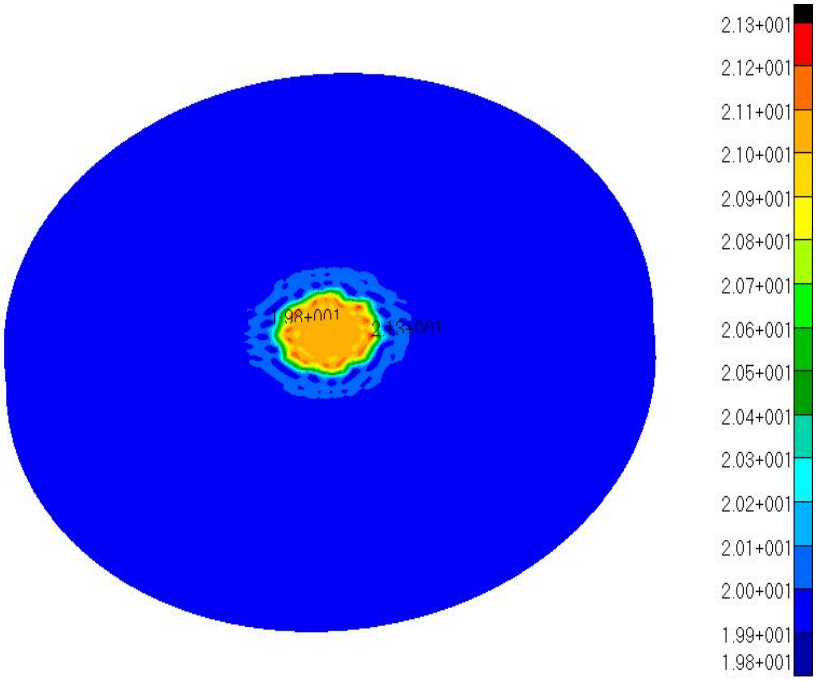
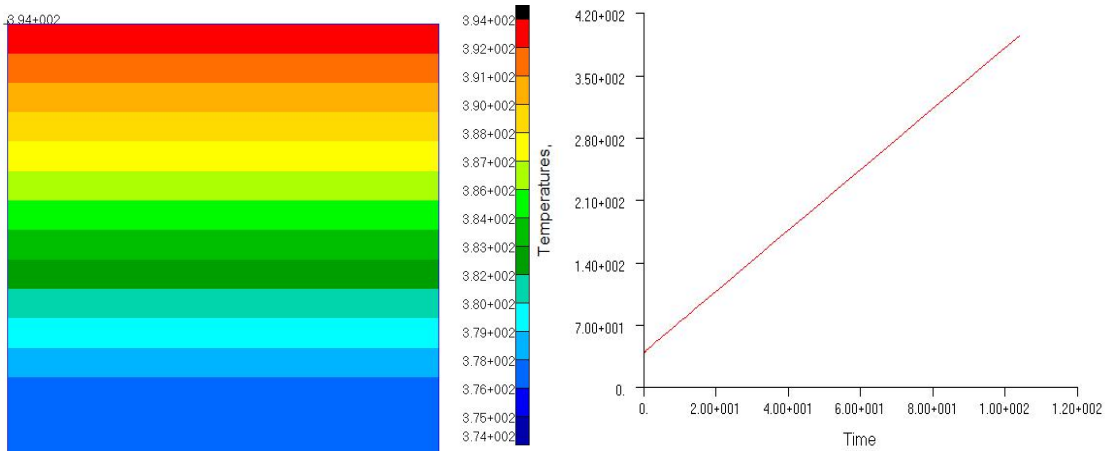


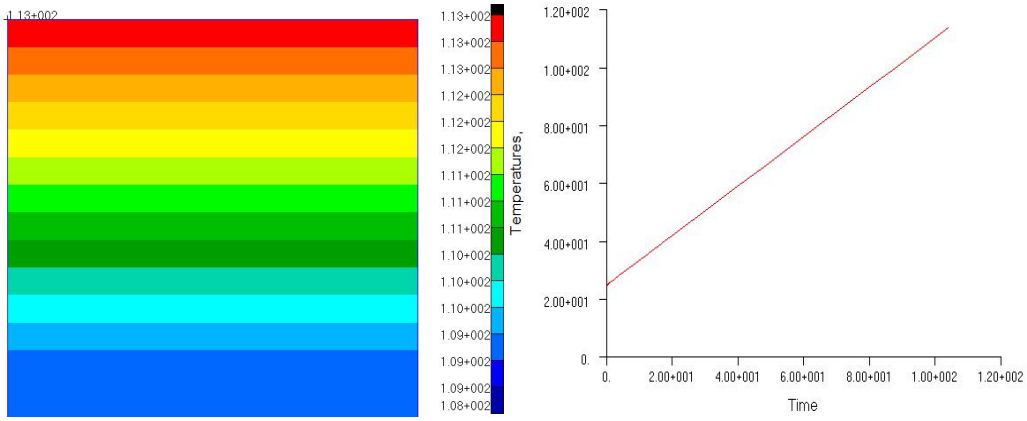
Figure 3： The heat transfer process analysis of resin layer by ion beam figuring

4.1 beam power (voltage and current)and beam spot diameter(target distance)

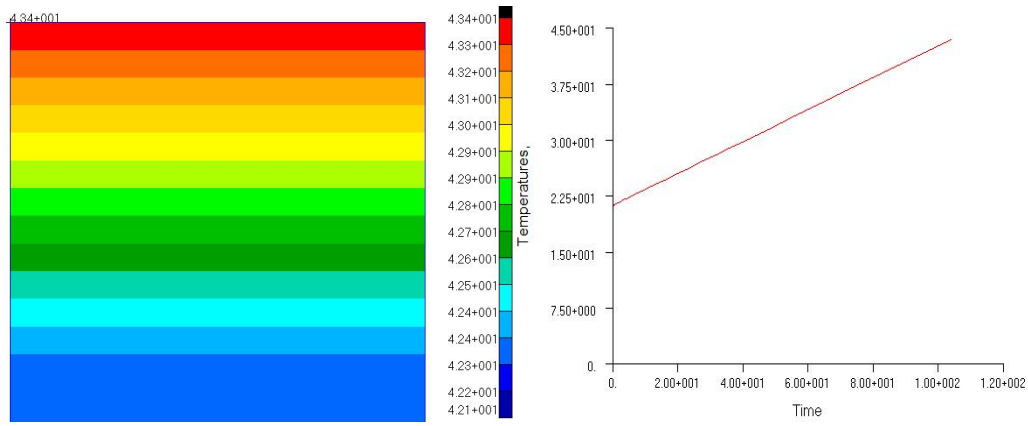
First, the temperature change process of the local resin layer is obtained by analyzing the transient heat conduction in the case of ion beam power of 1W and beam spot diameter of 5mm, 10mm, 20mm and 30mm respectively.



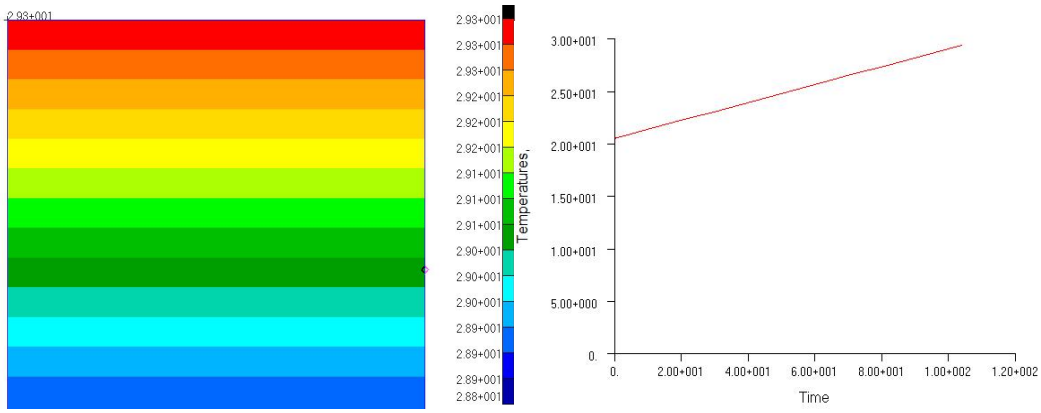
the temperature of the local resin layer changes during the spot diameter of 5mm



the temperature of the local resin layer changes during the spot diameter of 10mm



the temperature of the local resin layer changes during the spot diameter of 20mm



the temperature of the local resin layer changes during the spot diameter of 30mm

Figure 4：the temperature of the local resin layer changes during the different spot diameter

From the above analysis, it can be concluded that when the spot diameter is 5mm, the temperature of the local resin layer rises rapidly, the thickness of the whole resin layer reaches the melting zone,and all the resin is decomposed. When the spot diameter is 10mm, the temperature increases with the processing time Growth will exceed the TG point of the resin, so that the resin softens; and beam spot diameter of 20mm and 30mm, with the processing time Growth, the temperature does not exceed the TG point. However, with the increase of the beam spot diameter, the convergence efficiency of the ion beam processing will be reduced, especially the polishing efficiency will be worse during the final high-frequency stage, so choose the beam spot diameter of 20mm, corresponding the target distance of 40mm.

Next, the transient heat conduction in the case where the beam spot diameter is 20 mm and the ion beam power is 2 W is analyzed, and the temperature change process of the local resin layer is obtained.

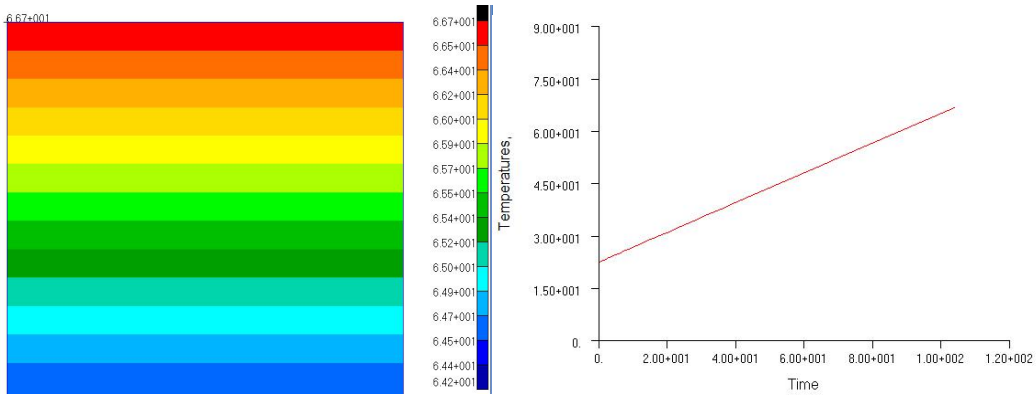


Figure 5：the local temperature of the resin layer changes with the ion beam power of 2W

As the processing time increases, the local temperature of the resin layer will also reach its TG point. Therefore, the final determination of the ion beam power is 1W, the parameters can be set to ion beam voltage of 1000V, ion beam current of 1mA.

4.2 Analysis of processing time and resin layer temperature

According to the above ion beam processing parameters, the initial finishing test is completed, the processing time is 2 hours, but the result is not ideal, the resin layer appears softening phenomenon. In order to solve this problem,it is necessary to reduce the processing time and reduce the workpiece temperature due to the long-term ion bombardment and the temperature rise of the workpiece exceeding the TG point of the resin.

The relationship between the simulation processing time and the temperature change process of the resin layer is analyzed by NASTRAN, as shown in the figure.

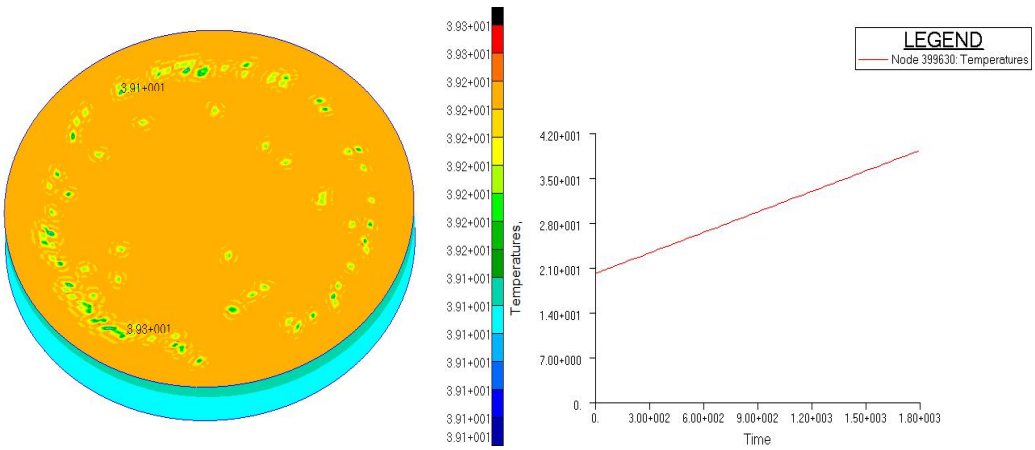


Figure 6： Relationship between ion beam processing time and resin layer temperature change

From the above analysis,it can be obtained that the resin layer temperature increases linearly with processing time Growth, when the processing time is 30 minutes, the resin layer temperature reaches about 40℃ that not reached the TG point of the resin, in order to increase the processing safety domain, we can control the time of each processing cycle within 30 minutes to improve the safety of processing.

4.3 temperature test verification during Ion beam processing process

Prepare a 150mm caliber carbon fiber mirror and place it in an ion beam vacuum chamber for 30 minutes and then immediately measure the surface temperature with an infrared thermal imager, as shown in the figure. This is consistent with the data obtained by the finite element analysis, which verifies the accuracy of the analysis.

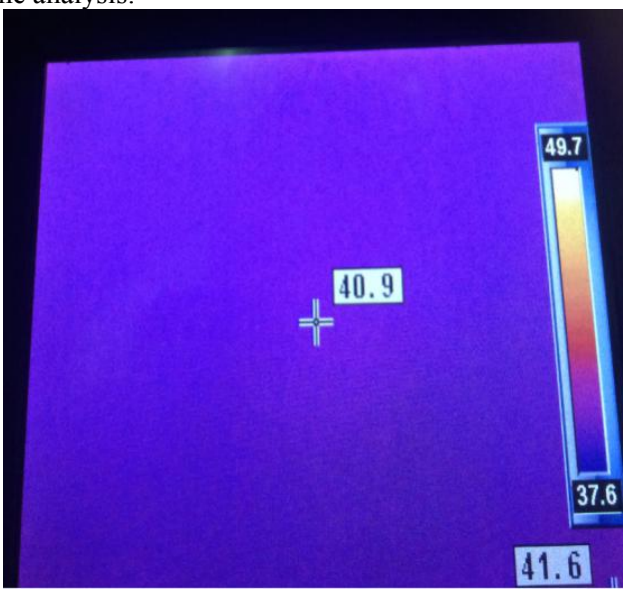
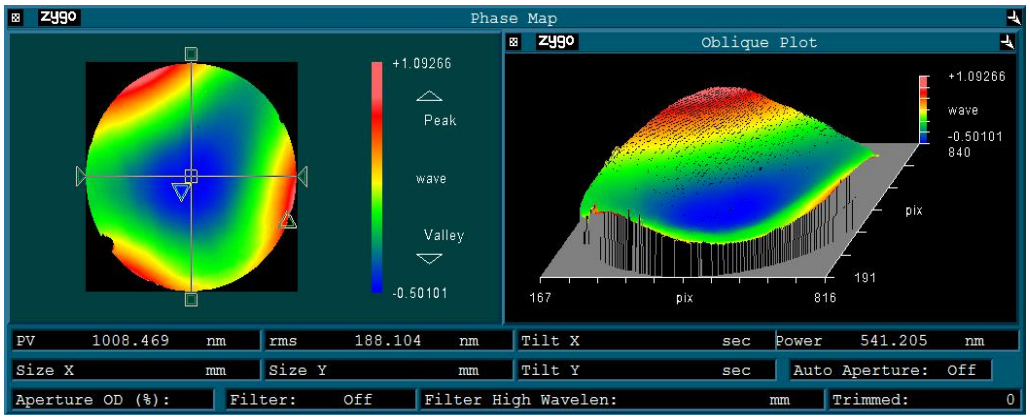


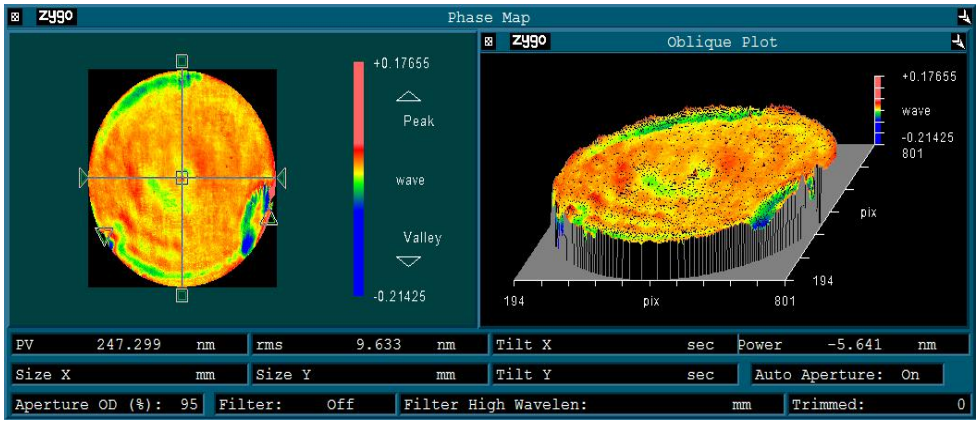
Figure 7： surface temperature after processing time of 30 minutes

5 ION BEAM PROCESSING TEST

According to the above parameters, and strictly control the processing time within 30 minutes to complete the ion beam processing test of the resin layer. After the processing cycle of 9 rounds, the resin layer is not softening,the surface accuracy of RMS is from 188nm to 10nm that can meet the surface index requirements.



Initial shape



the shape after 9 cycles

Figure8： the surface accuracy of RMS after the ion beam processing

At the same time, the surface roughness was 6.1nm, and there was no difference compared with the surface roughness before processing.

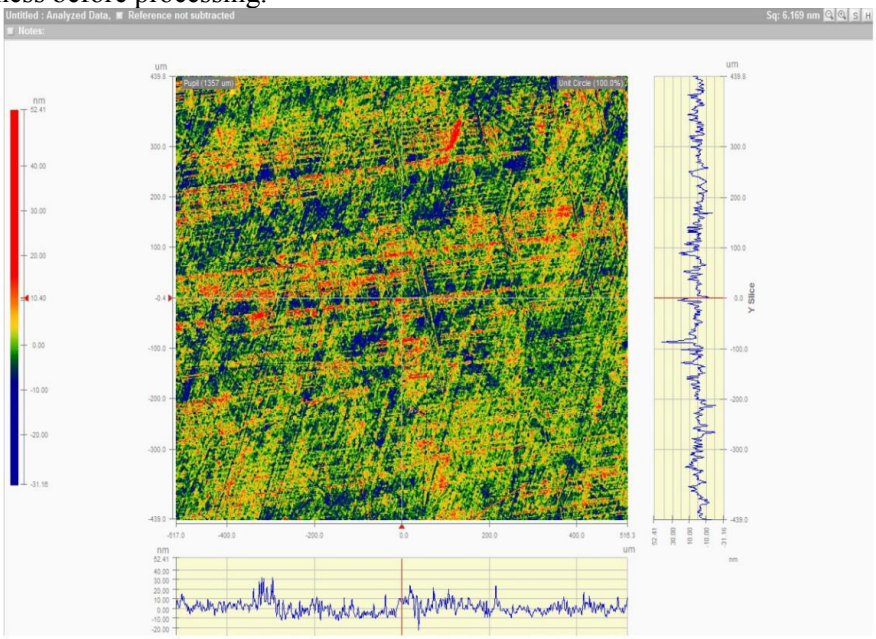


Figure 9： the surface roughness of the Resin layers

The experimental results show that the ion beam processing can realize the surface polishing of the resin layer, and it has the convergence, and also verifies the correctness of the theoretical analysis mode.

6 CONCLUSIONS

Based on the analysis and experiment of the resin layer polishing by the ion beam figuring, it can be determined that the ion beam processing can realize the surface polishing of the resin layer by the convergence of the surface modification. The correctness of the theoretical model is verified . The surface roughness of the resin layer after the ion beam bombardment does not deteriorate.

However, because of the carbon fiber composite material with Moisture absorption, if there is no dehumidification before the ion beam processing, the carbon fiber mirror have dehumidification and deflation phenomenon in vacuum cans, can not guarantee the accuracy of the surface polishing. the next step will be to solve this problem Impact.

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