Experimental Study of Laser - enhanced 5A03 Aluminum Alloy and Its Stress Corrosion Resistance

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Abstract. Based on the study of improving the stress corrosion resistance of 5A03 aluminum alloy for ship, this paper mainly studied the tensile test, surface morphology and residual stress under laser shock, high temperature and stress corrosion. It is found that the residual compressive stress and the grain refinement on the surface of the material during the heat strengthening process increase the breaking strength of the sample in the stress corrosion environment. Appropriate high temperature maintenance helps to enhance the effect of deformation strengthening. In the 300℃ environment insulation, due to recrystallization of the material, the performance decreased significantly. This study provides an experimental basis for effectively improving the stress corrosion resistance of 5A03 aluminum alloy.

1. Introduction
Aluminum and aluminum alloys have lower density, good mechanical properties, processability, thermal conductivity, electrical conductivity and corrosion resistance, which have been widely used in marine and marine equipment [1,2]. Marine 5A03 aluminum alloy is a typical Al-Mg series ship can welded aluminum alloy, which commonly used in shipbuilding parts, rivets, fuel tanks and pipes and other key components. Studies have shown that corrosion of marine aluminum alloy in the marine environment mainly pitting and stress corrosion, corrosion resistance of aluminum alloy is affecting application in the marine environment, one of the important indicators [3-5]. Therefore, the rolling shot peening [8,9], laser shock [10-12] and other surface strengthening process has been widely used. As one of the main forms of failure, stress corrosion resistance of materials is more and more by scholars both at home and abroad.

So far, no papers and data have been found on the experimental study on the improvement of stress corrosion resistance of marine 5A03 aluminum alloy laser. In this paper, the effects of laser thermal compounding on the stress corrosion resistance of marine 5A03 aluminum alloy are studied, and the mechanism of laser shock on improving metal anti-stress corrosion is discussed in depth.

2. Experimental conditions and testing methods

2.1 Sample preparation and thermal compound strengthening experiment
The experiment uses 5A03 aluminum alloy, which used in commercial marine. Its chemical shown in Tab 1. The specimen, shown in Figure 1, is obtained by wire cutting. After the sample processing is completed, it is polished with 400 to 1200 sandpaper and then polished mechanically. Then the sample was cleaned by ultrasonic cleaning in acetone, dried by a blower, which
prepared for subsequent thermal compounding and stress corrosion testing.

### Tab 1. 5A03-H112 aluminum alloy chemical composition

| Element | Mg  | Si  | Mn  | Fe  | Cu  | Zn  | Ti  | Al  |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|
| (Wt%)   | 3.2-3.8 | 0.5-0.8 | 0.3 | 0.5 | 0.1 | 0.2 | 0.15 | Remainder |

![Fig 1. Specimen size after laser shock and stress corrosion](image1.png)

In this paper, the experimental process of the thermal compound to strengthen is to maintain the high temperature after the laser shock. The laser impact experiment was carried out by Shanghai Jiao Tong University laser impact enhanced integrated system. The main process parameters were as follows: the laser pulse width was 10ns, but the pulsed laser energy was 4J, the spot diameter was 2.5mm, the spot overlap rate was 75% , double-sided impact. High temperature maintenance test is to place the sample in a high temperature box, set the temperature to maintain high temperature and holding time.

#### 2.2 Test of stress corrosion

Stress corrosion tests were performed at room temperature, using a stress corrosion tester as shown. The experiment is divided into 6 groups, the specific process parameters of each group are shown in Table 2. Samples were immersed in 3.5% NaCl solution for stretching. The tensile strain rate was $2 \times 10^{-5}$ s$^{-1}$. After the specimen was broken, the fracture time was recorded. The fracture was cleaned by ultrasonic cleaning with acetone. The appearance of the fracture surface was observed with a scanning electron microscope after the blower was blown dry.

![Fig 2. Stress corrosion testing machine](image2.png)

### Tab 2. Sample grouping and stress corrosion experimental parameters

![Tab 2. Sample grouping and stress corrosion experimental parameters](image3.png)
| Group | Treatment | High temperature to maintain temperature (℃) | High temperature to maintain time (h) |
|-------|-----------|---------------------------------------------|--------------------------------------|
| A     | Untreated | ——                                          | ——                                   |
| B     | LSP       | ——                                          | ——                                   |
| C     | LSP+HT    | 200                                         | 2                                    |
| D     | LSP+HT    | 200                                         | 6                                    |
| E     | LSP+HT    | 300                                         | 2                                    |
| F     | LSP+HT    | 300                                         | 6                                    |

2.3 Observation and test of residual stress and microstructure
The samples were polished with 400 #, 800 #, 1200 # and 1500 # sandpaper in sequence, then polished and cleaned. The Keller reagent (formula: 1.0% HF + 1.5% HCl + 2.5% HNO₃ + 95% H₂O) for 30-60s and rinsing with plenty of water. Finally, the morphology was observed with light microscope. Residual stress test uses X350-type X-ray stress meter. During measurement, the impact area by the middle of the point as the measuring point.

3. Experimental results and discussion
3.1 Residual stress induced by laser
Deformation strengthening can induce residual compressive stress on the material surface. As shown in Fig 3, the residual compressive stress on the surface of 5A03 aluminum alloy is up to -100MPa for laser shock treatment. The residual compressive stress on the surface of the material can counteract the tensile stress of the specimen during the stress corrosion stretching. To a certain extent, it can prevent the occurrence of stress corrosion cracking and improve the resistance to the expansion of stress corrosion cracking [15]. However, due to the complexity of marine 5A03 aluminum alloy working conditions, the residual stress will relax during service, which seriously reduces the stress corrosion resistance. Some studies have shown that the heat treatment will not only cause a certain degree of relaxation of the residual stress induced by the deformation strengthening on the one hand, but also enhance the pinning effect by strengthening the relative dislocation due to the dislocation movement during the heat preservation Residual stress in the ensuing service stability.
Fig 3. 5A03 aluminum alloy surface residual stress after different treatment

As can be seen from Fig 3, at 200°C for 2h, the sample residual stress relaxation occurred, was about -88MPa. Further incubated to 6h, the residual stress was basically stable. While at 300°C, after incubated 6h, the sample surface residual stress serious release occurred, which only -30MPa. Obviously, laser shock treatment can produce a certain residual compressive stress on the surface of the material. During high temperature holding stage, due to laser shock generated residual stress relaxation occurs, the specific amount of relaxation and holding temperature and holding time. It is initially judged that the residual stress induced by deformation strengthening can be kept basically stable below the recrystallization temperature of the material.

3.2 Surface morphology and microstructure comparison before and after laser shock
After the laser shock, the macroscopic surface morphology of the sample is shown in Fig 4. It can be found that the laser shock treatment causes macroscopic plastic deformation on the surface of the material. The surface morphology of single point impingement pits is shown in Fig 5. The diameter of the pits is about 2500μm, which is basically the same as that of the laser spot used in laser impingement processing.

Figure 4. Stress samples after laser shock stress corrosion
Fig 5. 5A03 aluminum alloy surface after the laser pits

The microstructure of 5A03 aluminum alloy before and after laser shock is shown in Fig 6. It can be seen from the comparison of Fig 6 (a) and Fig 6 (b) that the laser shock caused the surface of the sample to undergo some grain refinement and the grains became more uniform. For the grain refinement behavior, some scholars point out that this is related to the dislocation and agglomeration in the deformation process. Numerous studies have shown that grain refinement induced by deformation strengthening can effectively improve the material fatigue resistance, stress corrosion resistance and other properties.

Fig 6. Metallography: (a) untreated sample; (b) laser shock

3.3 Test of stress corrosion tensile

| Group | Breaking strength (MPa) | Sensitivity coefficient (%) | Elongation (%) |
|-------|------------------------|-----------------------------|----------------|
| A     | 210                    | 12.48                       | 12             |
| B     | 230                    | 10.57                       | 8              |
| C     | 234                    | 10.28                       | 9              |
| D     | 237                    | 9.96                        | 15             |
| E     | 112                    | 27.81                       | 23             |
The samples before and after the thermal compound strengthening were placed respectively in a 3.5% NaCl solution in a corrosive medium and subjected to a slow strain rate tensile-stress corrosion test. The test results are shown in Table 3. We can see that in the stress corrosion environment, the rupture strength of the marine 5A03 aluminum is about 210MPa, and the rupture strength after laser shock strengthening is increased to 230MPa. After heat preservation at 200°C for 6h, the breaking strength of the sample is 237MPa, reaching the maximum value. At the same time, the corrosion sensitivity index of the sample to 3.5% NaCl solution is 9.96% under the condition of 200°C for 6h after laser shock, which is 20.2% less than that of the untreated sample (12.48%). In view of this, thermal compound strengthening effectively improves the shipboard 5A03 aluminum alloy stress corrosion resistance. The sample was heat-treated at 300°C. The recrystallization of the sample resulted in a significant decrease in the breaking strength and stress corrosion susceptibility of the sample, and the laser shock-strengthening effect basically disappeared.

3.4 Analysis of stress corrosion tensile fracture

![Fig 7. Stress corrosion fracture morphology](image)

(A) Untreated; (b) Thermal Compound Hardening

In order to further study the effect of thermal compound strengthening on the stress corrosion resistance of marine 5A03 aluminum alloy, SEM was used to observe the stress corrosion fracture. Figure 7 (a) shows the untreated sample in 3.5% NaCl solution stress corrosion tensile fracture morphology. It can be seen from Figure 7 (a) that less dimples on the fracture and more pores. Corrosion pits. The fault mode is quasi-cleavage. The stress-corrosion tensile fracture morphology of the samples, shown on Fig 7 (b), exposed to laser shock and incubated at 200°C for 6h in 3.5% NaCl solution. It can be seen from the figure that the corrosion pits and pores are significantly reduced, a considerable number of dimples appear in the fracture, and the dimples are relatively uniform in size. There are a few tearing zones around the dimples. The fault patterns are ductile and locally cleavage faults. Thus, after laser shock, 5A03 aluminum alloy stress corrosion resistance improved significantly, the material in the stress corrosion cracking plasticity is improved.

4. Conclusion

Through the experimental study of laser impact and anti-stress corrosion of 5A03 aluminum alloy, the
main conclusions are as follows:

- Laser shock strengthening can introduce residual compressive stress on the surface of marine 5A03 aluminum alloy material with the maximum amplitude of -100MPa. At the same time, the laser shock treatment causes the grain refinement on the sample surface to be refined.
- For marine 5A03 aluminum alloy, heat treatment at 200°C after deformation strengthening helps to enhance the effect of deformation strengthening. However, when the holding temperature is higher than the recrystallization temperature of the material, the strengthening effect will disappear due to recrystallization behavior of the material.
- Compared with the untreated sample, the 5A03 aluminum alloy has a significant improvement in stress corrosion resistance after being laser shocked, which opening up a new path for effectively improving the stress corrosion resistance of 5A03 aluminum alloy.

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