Experimental research on flexible coating used for online repairment of damaged aircraft parts by laser shock peening

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Introduction

The corrosion damage of aircraft parts is one of the major damage forms of the ageing aircraft [1], shot peening on the corroded surface is a common method of repairing the damaged aircraft parts. While, the damaged aircraft parts have to be disassembled from the aircraft firstly and then send to the repairment shops when shot peening by solid projectile. The aircrafts have to be parked on ground for a long time, which leads to large economic losses for the airline companies. In order to solve this problem, the method of online shot peening for the repairment of the damaged aircraft parts is proposed. However the solid projectile can't be used in online repairment since its scattering in a wide range during shot peening. Due to laser has a good reachability [2] and laser shock peening does not produce projectile fragment or dirt, which is especially suitable for online repairment of the damaged aircraft parts.

Objectives

In order to apply the laser shock peening process to the online repairment of the damaged aircraft parts, it is necessary to research the selection of coating materials and the corresponding parameters. Correa [3] conducted a laser shock peening experiment on 2024 aluminum alloy without coating (or with gas confinement layer). The result shows that serious ablation exists on the surface of the target material, which will decrease the fatigue life of the peened parts. The strengthening effect of laser shock peening is affected directly by the properties of the coating material. Water is the commonly used confinement layer [4], and the black paint is the mainstream absorbent layer [5]. However, as a kind of liquid confinement layer, water is not suitable for online laser shock peening.

The surface shape of the damaged aircraft parts after grinding is complex (as shown in Fig.1), where, area I is the original surface, areas II~V are the generating surfaces after grinding[6]. Therefore, the coating material used for the online laser shock peening should not only be the solid one, but also be confirmed well with the complex surfaces of the ground part.

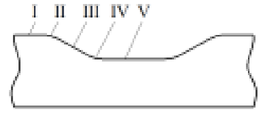


Fig.1 Diagram of surface shape of the damaged aircraft part after grinding

Methodology

Development of the flexible coating material

The coating material includes the energy confinement layer and the energy absorbent layer [7]. K9 optical glass is the commonly used solid confinement layer material, by which large peak pressure can be obtained during laser shock peening [8]. But, it can't be adapted to the complex surface of the damaged aircraft parts due to the simplex plane shape. Silicone also has large acoustic impedance, however, large elastic deformation occurs easily under the shock wave due to the low elastic modulus [9], which will lead to the phenomenon of pressure relief. The colloidal material consisted of the bisphenol A-epichlorohydrin epoxy resin and the cycloaliphatic amine curing agent has good flexibility before completely curing, which can be well fitted to the complex surface of the ground specimen, therefore, it is proposed as the energy confinement layer of online laser shock peening, and named as the flexible confinement layer (FCL) material.

The black electrical tape and black double-sided adhesive tape were combined as the energy absorbent layer. The glue surface of the electrical tape is bonded with the target material, which is easy to be separated from the specimen after laser shock peening. The non-viscous surface of the electrical tape is bonded with one side of the double-sided adhesive tape, and the other side of the double-sided adhesive tape is bonded with the energy confinement layer. Therefore, the energy confinement layer is tightly adhered to the absorbent layer. The structure of the proposed flexible coating is shown in Fig.2.

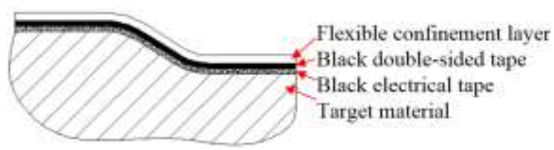


Fig.2 Diagram of structure of the proposed flexible coating material

Determination of the composition ratio of the flexible confinement layer material

According to the composition ratio provided by the raw material suppliers, the volume of the composition ratio *r* of bisphenol A-epichlorohydrin epoxy resin and cycloaliphatic amine is 2: 1. After expanded the scope of the composition ratio, the experiment results show that the range of the effective volume ratio *r* of the FCL material is 1.5:1~3:1.

The physical properties of the FCL material were measured under different *r* by the high-precision ultrasonic thickness gauge, and the acoustic impedance was obtained by multiplying the density and the wave velocity (as listed in table 1). From table 1, the maximum acoustic impedance Z_i can be obtained when *r* is 1.5.

Table 1. Physical properties of the FCL material under different volume ratios *r*

Volume ratio	Density ρ_i /(g/cm^3)	Wave velocity v_i /(m/s)	Acoustic impedance Z_i /(g·cm^{-2}·s^{-1})
r=1.5	1.25	2523	0.3154×10^6
r=2.0	1.24	2506	0.3107×10^6
r=2.5	1.22	2488	0.3035×10^6
r=3.0	1.19	2465	0.2933×10^6

Manufacturing method of the flexible confinement layer material

Fig.3 shows the mold used for manufacturing the FCL material. Firstly, the thickness and the cavity dimensions of the intermediate metal plate are determined according to the repaired dimensions of the ground specimen. Secondly, the metal plate after caving is placed onto the bottom silica gel plate, and the colloidal material prepared at a ratio of 1.5 is poured into the cavity of the metal plate, then put the upper silica gel plate onto the intermediate metal plate. Finally, curing process is carried out at room temperature. Fig.4 shows the manufactured FCL material, and the main mechanical and optical properties of the FCL material was measured by the universal testing machine and spectrometer, respectively, which are listed in table 2.

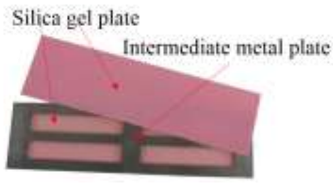


Fig.3 Mold used for manufacturing the FCL material

Fig.4 FCL matrial made from bisphenol A-epichlorohydrin epoxy resin and cycloaliphatic amine

Table 2. Mechanical and optical properties of the manufactured FCL material

Shear strength /MPa	Microhardness /HD	Tensile strength /MPa	Impact toughness /(KJ/m^2)	Elastic modulus /GPa	Transmissivity /%
16	75	24	8.52	5.1	99.3

Determination of curing time of the flexible confinement layer material

The curing time and curing degree of the FCL material were measured by the differential scanning calorimeter. Table 3 shows the curing time for reaching the required curing degree, the ratio of the heat released in a certain time to the total heat released during whole curing process, under the different temperatures when r is 1.5. Table 3 shows that the higher the curing temperature, the shorter the curing time, however the internal stress of the solidified confinement layer is big and bending defect occurs easily [10].

In order to improve the curing efficiency and reduce the internal stress of the final solidified confinement layer, the two-stage curing method was put forward. Firstly, the curing process is carried out at a high temperature until reaching a certain curing degree; then stop heating when the temperature is suitable for the confinement layer being modeled and coated on the complex surface of the ground specimen. Secondly, continue the curing process at a low temperature until the FCL material being suitable for laser shock peening.

Table 3. Curing time of reaching a certain curing degree under different temperatures (min)

Temperature /℃	Curing degree α /%						
	40	50	60	70	80	90	100
60	69.6	82.1	93.2	102.3	116.7	128.6	136.3
70	55.8	62.7	73.4	80.5	91.6	99.7	106.2
80	45.8	51.6	59.0	66.1	73.4	78.2	84
100	28.3	32.9	37.2	41.1	46.3	49.6	52

The FCL material is a kind of colloidal material consisted of the epoxy resin and curing agent. The researches [11] showed that the toughness and strength of the epoxy resin colloid increases rapidly after the curing degree reaches 60% and has a high mechanical properties when the curing degree reaches 70%; however, the strength increases little when further increasing the curing degree. The impact toughness reaches the maximum when the curing degree is 80% and then begins to decrease with the increasing of the curing degree. Therefore, the suitable range of curing degree for the FCL coating on the target material is 50%~60%, and the suitable range for laser shock peening is 80%~100%.

According to table 3, the reasonable curing process is determined as follows: 1) Partially curing the colloidal material for 32~37mins at 100℃; 2) Removing the partially cured colloidal material from the mold and coating the colloid on the complex surface of the ground specimen; 3) Continue the curing process for 24~35mins at 60℃. Laser shock peening should be carried out immediately after curing. Fig.5 shows the flexible coating on the complex surface of the ground specimen. It proves that the developed FCL material can be tightly adhered to the complex curved surface of the damaged aircraft specimen.

Fig.5 Flexible coating on the complex surface of the ground specimen

Results and analysis

Experimental conditions

The 7075 aluminum alloy was selected as target material. The surface shape of the specimens used for the single-impact laser shock peening (SI LSP) was simplex plane, and the dimension was 100mm × 25mm × 10mm. The surface shape of the specimen used for the continuous-impact laser shock peening (CI LSP) was complex curve, and the dimension was shown in Fig.6. The laser parameters were as follows: the spot diameter was 2.0mm, the pulse energy was 1.6 J, the pulse width was 10 ns and the wavelength was 1064 nm. The surface microhardness was measured by the automatic location table typed digital microhardness tester.

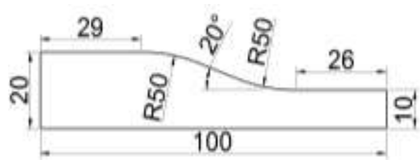


Fig.6 Curved specimen used for the continuous-impact laser shock peening

Influence of the thickness of FCL material on strengthening effect.

Fig.7 shows the influence of the thickness of FCL material on the strengthening effect of the specimen after the SI LSP. It shows that the surface microhardness of the specimen is the maximum when the thickness of the FCL material is 2.0mm, and it indicates that the strengthening effect is the best. Fig.7 shows also that the strengthening effect of the laser shock peening would reduce whether increasing or decreasing the thickness of the FCL material.

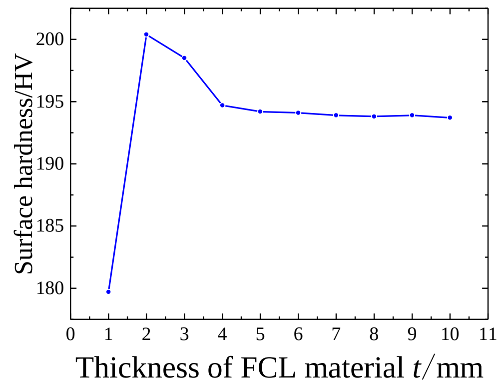


Fig.7 Strengthening effect under different thickness of FCL material

Comparison of the strengthening effect between FCL material and water

Table 4 shows the surface microhardness of the specimen obtained after SI LSP by water and 2mm FCL material, respectively; where, Δ refers to the percentage of microhardness increasing. It shows that the surface microhardness improves more obviously by using the FCL material, and it indicates that the strengthening effect of the developed FCL material is better than that by using water as the confinement layer material.

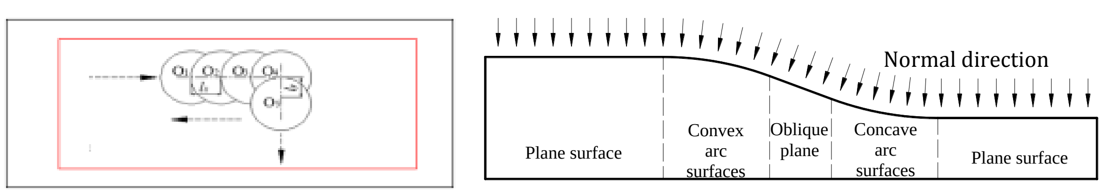
Table 4. Surface microhardness under different FCL material after single-impact laser shock peening (HV)

Measured area	1st measured	2nd measured	3rd measured	Average	Δ /%
Original microhardness	171.7	171.2	171.0	171.3	7.82
Water layer	185.3	184.5	184.3	184.7	
Original microhardness	173.1	171.1	175.1	173.1	11.55
Flexible layer	193.7	195.3	190.2	193.1	

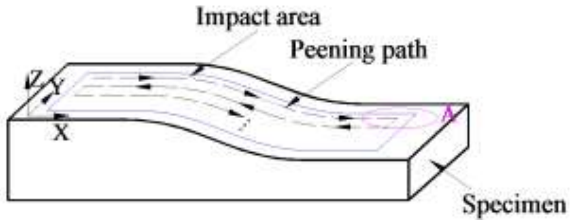
Strengthening effect under the continuous-impact laser shock peening

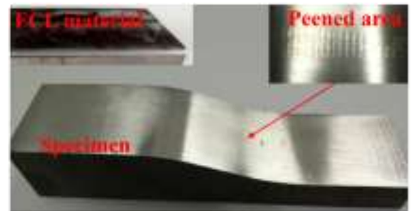
Taking the specimen with complex curved surface shape as the reseraching object (as shown in Fig.6), and the continuous-impact laser shock peening experiment was crrier out under the 50% overlap rate, an important parameter used to describe the coincidence degree of two adjacent laser spot in the two-dimensional direction (as shown in Fig.8 (a)).

The direction of the laser impact was along the normal direction of the target material surface (as shown in Fig.8 (b)), and the movement path of the laser spot was shown in Fig.8 (c). The experiment resutls show that the FCL material is still kept unbroken after three times impacts (as shown in Fig.8 (d)). Besides, the surface microhardness of the convex and concave arc surfaces increases by 18.68% and 20.43%, respectively. It proves that the developed FCL material can be used for online repairment of the damaged aircraft parts effectively.



(a) Diagram of the overlap rate(50%) (b) Direction of the laser impact





(c) Moving route of laser spot (d) Specimen obtained by the continuous-impact

Fig.8 Diagram of the continuous-impact laser shock peening

Conclusion

The Experimental research on flexible coating used for online repairment of the damaged aircraft parts by laser shock peening were studied and the conclusions are as follows:

1. The colloidal material consisted of the bisphenol A-epichlorohydrin epoxy resin and the cycloaliphatic amine curing agent is proposed as the flexible confinement layer (FCL) material of the ground complex curved surface of the damaged aircraft parts during online repairment through the laser shock peening.
2. The black electrical tape and the black double-sided adhesive tape are proposed as the energy absorbed layer material of the ground complex curved surface of the damaged aircraft parts during online repairment through the laser shock peening.
3. The optimum ratio of the bisphenol A-epichlorohydrin epoxy resin and the cycloaliphatic amine curing agent is 1.5: 1, and the optimum thickness of the FCL material is 2.0 mm.
4. The reasonable curing process is that after partially curing the colloidal material for 32~37mins at 100℃, removing the partially cured colloidal material from the mold and coating the colloid on the ground surface of the damaged aircraft parts, and then continue the curing process for 24~35mins at 60℃.

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