Investigation for Different Peening Techniques on Residual Stress Field of SiCw/Al Composite

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Abstract: In order to improve the residual stress field of SiCw/Al composite after conventional shot peening, modified warm peening, stress peening, compound peening as well as conventional peening were carried out on SiCw/Al composite specimens and residual stress fields of those specimens were investigated via X-ray measurement. Results show that conventional shot peening can improve residual stress field of SiC_w/Al composite but the improvement has a limit. Comparing with conventional peening, modified warm peening can increase the maximum residual stress, the depth of compressive residual stress layer and improve stability of residual stress field meanwhile stress peening can increase all characteristic parameters of residual stress field efficiently. Compound peening combines the positive effects of modified warm peening and stress peening, and has the most strengthening effects.
Keywords: modified warm peening, stress peening, compound peening, residual stress distribution

1. Introduction

Metal matrix composites have received considerable attention because of their good combination of excellent properties such as high specific strength, modulus and hardness, etc. Many metal matrix composites components are subjected to cyclic loading during their service so improving metal matrix composite fatigue life and strength is very important for the behavior of components[1-3]. Shot peening (SP) is an effective surface treatment process widely used in industry with the purpose of introducing compressive residual stresses on the surface in order to prevent the micro-crack initiation and growth, which can considerably improve fatigue strength and fatigue life of cyclically loaded metallic components [4-6]. Many studies deal with optimizing peening parameters, but the increase of fatigue life and strength obtained by conventional shot peening are limited[7], which leads to modification of shot peening process. There are some modified shot peening process such as stress peening and warm peening proposed by former researchers[8-10]. Comparing with conventional shot peening, warm peening can increase residual stress stability and the depth of residual stress layer meanwhile stress peening can increase the value of residual stress. In this report, the investigation of warm peening and stress peening were carried out on SiCw/Al composite. Furthermore, the compound peening, which included warm peening and stress peening, was proposed to improve the residual stress field of SiCw/Al composite.

2. Experiment

The SiCw/Al composite (in situ, 15 vol.% SiCw) used in this paper was synthesized according to Refs [11]. The reinforcement in composite was SiCw whisker. The diameter of whisker was about 1μm and the length of whisker was about 15 μm. Before SP, heat treatments were conducted: solution treatment at 530°C for 120min, then quenched in water, and finally aging at 170°C for 6h. The mechanical properties of SiCw/Al are listed in Tab. 1. The SP treatments were carried out according to the conditions: 0.4-0.6 MPa jet pressure, 0.2 mm mean diameter of ceramic beads, 100mm distance between nozzle and specimen, 30s-60s shot times and 0.15 mmA-0.5 mmA peening intensities. For warm peening treatment, as former method was heating

specimen during shot peening, which might lead to stress relaxation and decrease of peening effect, a modified warm peening method were carried out via preheat specimens before shot peening. Two specimens were kept at 120°C and 170°C respectively for 5min before SP and then peened at the room temperature (RT). The cooling curves during the shot peening are shown in Fig. 1. For stress peening treatment, two specimens were pre-stressed by three-point bending method along the longitudinal direction during shot peeinng treatment and the magnitudes of the pre-stress were 100 MPa and 150 MPa, respectively. For compound peening, one specimen was warmed with 120°C before SP as well as pre-stress with 100 MPa during shot peening treatment.

Tab. 1 Mechanical properties of SiC_w/Al

Material	$\sigma_{0.1}$ / MPa	$\sigma_{0.2}$ / MPa	σ_b / MPa	E / GPa
SiC_w/Al	421．12	451.21	584.14	102.15

The measurements of the depth distribution of residual stresses were performed by iterative electrolytical removal of thin surface layers and subsequent X-ray measurements. Residual stresses were determined using the $\sin^2\psi$-method with CrKα radiation with voltage 30 kV and current 25 mA and the Al (311) diffraction profiles were detected.

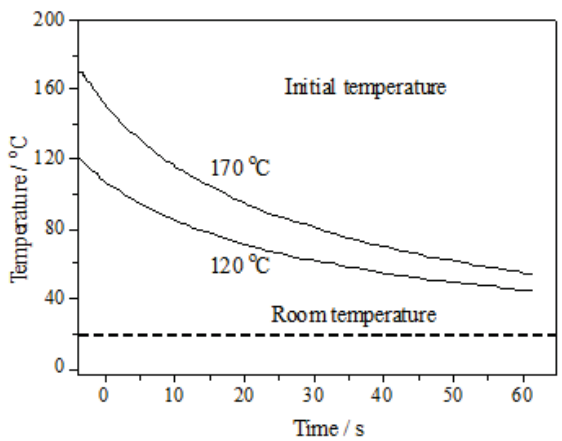

Fig. 1. Temperature decrease during warm shot peening.

3. Results and analysis

3.1. Conventional shot peening residual stress field

The depth distributions of the residual stress in different intensities of SP specimens are presented in Fig. 2. It can be seen that with increasing of peening intensity, the depth of compressive residual stress zone (δ_c) increases but the value of surface residual stress (σ_s) is nearly unchanged with the constant value of about -50 MPa. In 0.5 mmA peening intensity, the depth of compressive residual stress zone (δ_c) is about 820 μm. Comparing depth profiles of 0.3 mmA and 0.5 mmA peening intensities, it can be seen that the value of maximum residual stress (σ_m) and the depth of maximum compressive residual stress (δ_0) do not increase significantly and values of the maximum residual stress (σ_m) in this two cases are about -290 MPa, which is approaching the tensile strength of matrix 6061Al. This phenomenon represents the value of maximum residual stress (σ_m) which reaches its limit after 0.3 mmA peening intensity condition. The residual stress field is related to plastic deformation. When peening intensity increases, the shots' kinetic energy increases and induces a larger plastic deformation in near surface region. Furthermore, the residual stress field is also related to material own mechanical property.

Therefore, the value of maximum residual compressive stress keeps nearly constant when peening intensity reaches certain value. Compared to 0.3 mmA peening intensity, 0.5 mmA peening intensity only increases peening time (coverage) and induced a deeper compressive residual stress region. As the maximum compressive residual stress of shot peened specimen is nearly approaching matrix material tensile strength (about 300 MPa) in the condition of 0.3 mmA peening intensity, increasing peening intensity can only increase depth of compressive residual stress field but can not increase the value of maximum compressive residual stress.

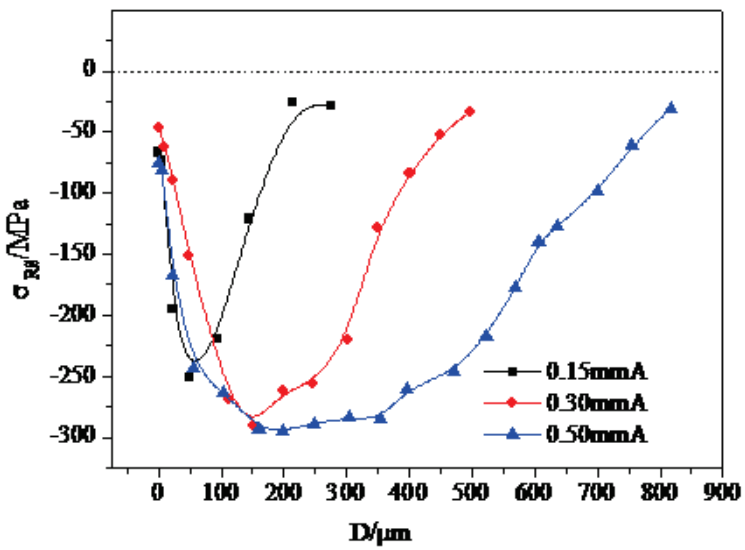

Fig. 2. Influence of shot peening intensity on residual stress field of SiC_w/Al composite.

3.2. Modified warm shot peening residual stress field

The depth distributions of the residual stress of specimens after SP at different initial temperatures (T_{ini}) are presented in Fig. 3. It can be seen that the value of compressive residual stress increases with the depth to the peak value and then decreases in all different peening conditions. Comparing with conventional shot peening treatment, modified warm shot peening can greatly increase maximum compressive residual stress (σ_m), the depth of maximum compressive residual stress (δ_0) and the depth of compressive residual stress zone (δ_c) but can not influence the value of surface residual stress (σ_s). Increasing the preheat temperature from 120°C to 170°C, the characteristic parameters of peened specimen δ_0 increase but σ_m, σ_s and δ_c remain almost unchanged. To be specific, after 170°C preheat + 0.15 mmA peening intensity treatment, the maximum compressive residual stress (σ_m) is about -278 MPa, the depth of maximum compressive residual stress (δ_0) is about 120 μm and the depth of compressive residual stress zone (δ_c) is about 295 μm.

In modified warm shot peening process, repeated plastic deformation takes place in surface layer of peened specimen with continuous impacts of shots. As the temperature is high in the beginning of modified warm shot peening process, the recovery, the recrystallization and the dislocation's generation/recombination take place more easily in deformation layer under the combination influence of shots impact and high temperature. Meanwhile, the dislocations pile up around the reinforcement particles because of the pin effect of the reinforcement particles on dislocation in metal matrix composites. With shot peening treatment processing, the specimen temperature becomes lower and the movement of dislocation become difficult, which can stabilize the dislocation structure and therefore contribute to a higher stability of the induced residual stresses.

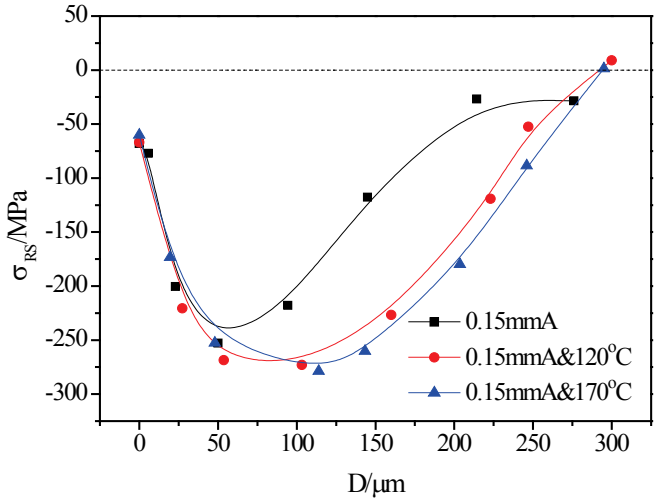

Fig. 3. Influence of warm peening intensity on residual stress field of SiC_w/Al composite

3.3. Stress peening residual stress field

During stress peening process, certain stress loading is carried out on peened specimen with the aim of producing tensile stress inside of that specimen and this loading is removed after shot peening. This kind of shot peening can increase the residual stress values of peened specimen because of elastic recovery. Some research shows the pre-loading should not be too high otherwise the superposition of external stresses and inherent residual stresses results in residual stress relaxation. Therefore, 100 MPa and 150 MPa were chosen as pre-load stress in 0.15 mmA peening intensity. The residual stress depth profiles of specimens after SP with different stress loadings are presented in Fig. 4. It can be seen that comparing with conventional shot peening treatment, all the characteristic parameters of residual stress field increase dramatically after stress peening. In the condition of 100 MPa and 150 MPa stress peening, the values of surface residual stress (σ_s) and the maximum residual stress (σ_m) increase about 100 MPa respectively meanwhile the depth of compressive residual stress zone (δ_c) and the depth maximum compressive residual stress (δ_0) in these two cases also increase. After 0.15 mmA peening intensity with 150 MPa stress loading, the depth of compressive residual stress zone (δ_c) is about 450 μm, which is nearly 2 times the depth of compressive residual stress zone (δ_c) with conventional peening treatment

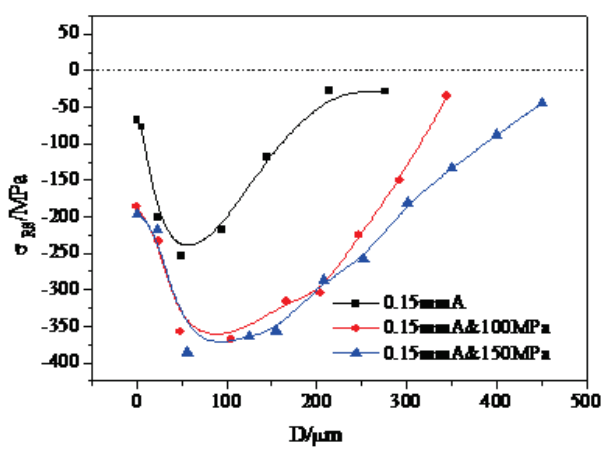

Fig. 4. Influence of stress peening on residual stress field of SiC_w/Al composite.

3.4. Compound peening residual stress field

According to modified warm peening and stress peening residual stress depth profiles, it can be seen that both of these two methods can improve residual stress field but each of them has some shortcomings. Specifically, warm peening can increase the depth of compressive residual stress zone (δ_c) and thermal stability of peened specimen but can not efficiently increase the values of surface residual stress (σ_s) and maximum compressive residual stress (σ_m). Moreover, in order to avoid the recovery and stress relaxation behaviors of peened specimen in heating status, the temperature must stay below the recrystallization temperature. In terms of stress peening, this kind of peening process can increase all values of characteristic parameters of residual stress field. However, the pre-stress loading has a limit which is 0.5 times the specimens yield strength. Furthermore, the pre-loading should be small in order to avoid plastic deformation of peened specimen in practice. Therefore, in order to obtain a better strengthening effect while reducing the pre-treatment influence on material own property, compound peening treatment was carried out on SiCw/Al composite specimen.

Fig. 5 shows the residual stress depth profiles of specimens after different SP treatments (with 120°C for warming peening, 100MPa for stress peening and 120°C +100 MPa for compound peening). It can be seen that with the same peening intensity, the maximum compressive residual stress of compound peening specimen is about -400MPa and the depth of compressive residual stress field of compound peening specimen is largest with a value of 450 μm. Comparing compound peening and stress peening stress distribution profiles, it can be seen that surface residual stresses of this two cases are nearly identical, which means that preheating can not increase the value of surface residual stress. This conclusion of warm peening is the same to previous conclusion shown in Chapter 3.1. Under the influence of stress loading during shot peening and preheat before shot peening, the maximum residual stress and the depth of compressive residual stress field of peened specimen increase dramatically via compound peening. To sum up, compound peening can combine the advantages of warm peening and stress peening and optimize the residual stress field of peened specimen.

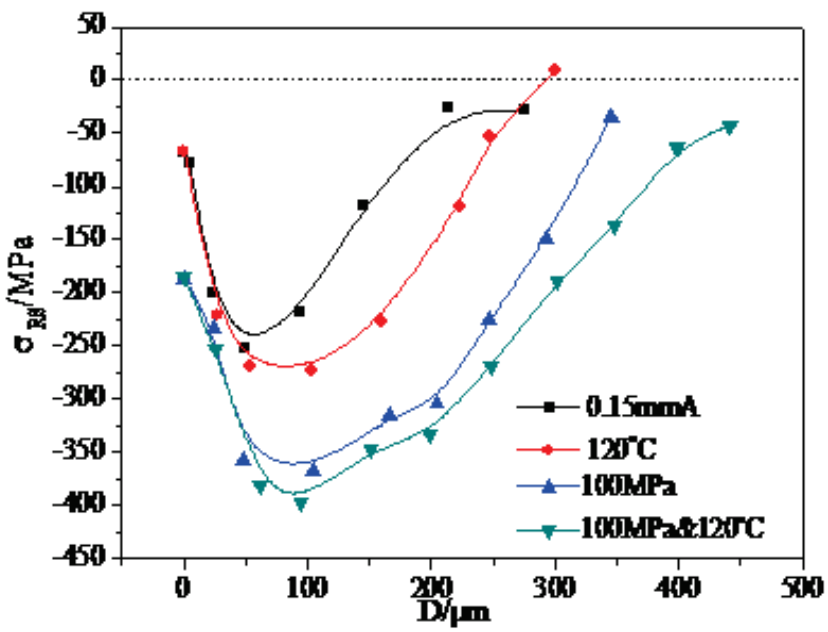

Fig. 5. Influence of compound peening on residual stress field of SiC_w/Al MMC.

4. Conclusion

The residual stress depth profiles with different kinds of shot peening treatment were investigated via X-ray measurements. Results showed that conventional shot peening could improve residual stress field of SiC_w/Al composite but the improvement had a limit. Therefore, warm shot peening , stress shot peening and compound shot peening treatment were carried out on SiC_w/Al composite specimens respectively in order to obtain a optimal residual stress field. With the same peening intensity, modified warm shot peening could increase the maximum residual stress and the depth of compressive residual stress layer as well as improve stability of residual stress field. With the same peening intensity, stress peening could increase all characteristic parameters of residual stress field efficiently. Compound shot peening combined the advantages of modified warm shot peening and stress shot peening and further improved every characteristic parameter of residual stress field in relative low heating temperature and low loading stress. Compound shot peening seemed to be the most appropriate treatment to optimize residual stress field and then increase the fatigue strength of SiC_w/Al composite.

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