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Infrared thermography investigation of the mechanical and thermal properties of laser-shocked Ti64

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Abstract

Laser shock peening (LSP) is widely used for improving mechanical and fatigue properties of metals. It uses high power laser radiation to create shock waves. The resulting plastic deformation and microstructural changes create a complex combination of tensile and compressive residual stress fields. This affects the mechanical and thermal behaviour of the laser-shocked material. Infrared thermography (IRT) could be used to define the thermodynamic state of the laser-shocked material under load and to optimize the LSP mode for different geometries and loading conditions. This work investigates the thermal properties and thermomechanical behaviour of laser-shocked Ti64 under quasistatic tensile using IRT.

1. Introduction

Laser shock peening (LSP) is technique of surface straitening of metal materials. The ability of a high energy laser pulse to generate shock waves and plastic deformation in metallic materials was recognised and investigated in the 1960s [1, 2]. Plastic deformation in the surface layer of a metallic material after LSP generates fields of tensile and compressive residual stresses. The optimum LSP mode (i.e. the optimum combination of tensile and compressive residual stresses) allows the material strength and fatigue properties to be improved. Laser impact treatment produces a layer with a modified microstructure [3], which is reflected in the material's ability to release heat during elastic and plastic deformation under loading conditions. Infrared thermography (IRT) could be used to define the thermodynamic characteristics of the loaded material after LSP and to optimise the LSP mode for a given part geometry and loading conditions. The aim of this work is to determine the influence of laser-shock treatment on thermal properties and heat release of titanium alloy Ti64 during quasistatic tension of flat specimens using IRT.

2. LSP conditions

For LSP, we used an original laser setup assembled at the Institute of Continuous Media Mechanics of the Ural Branch of the Russian Academy of Sciences. The setup includes Nd:YAG high energy laser Beamtech SGR-Extra-10 and industrial robotic manipulator STEP SR50. Additional optic system produces the laser beam with a square-form profile of 1 mm side. The pulse duration and energy of laser impact were 10 ns and 1 J, respectively. The aluminium foil of 80µm was used as an ablative layer. The treatment area was on the surface of the front and back side of specimen and includes all working part of specimen without butt. Specimen geometry and treatment zone are shown in Figure 1. The laser beam was directed along the normal to the surface. The measurement of obtained residual stresses versus the depth of the treated layer (figure 2) was carried out by the hole drilling method using an automatic system MTS3000-Restan (according to ASTM E837-13a).

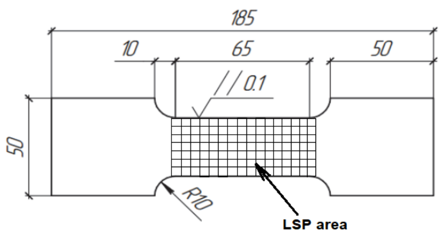

Fig. 1. Flat specimen geometry of laser-shocked titanium alloy Ti64

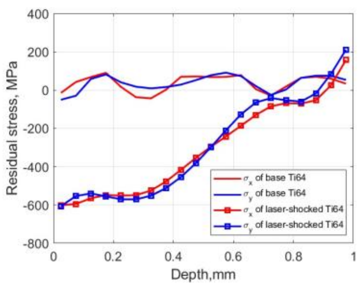

Fig. 2. The dependence of residual stress components (σ_x, σ_y) on the subsurface layer depth

The maximum value of both compressive residual stress components of laser-shocked material is on the specimen surface and equal to 600 MPa approximately. The depth of the compressive residual stress field is about 900 µm. The residual stress in the material without LSP is constant on average. It is 25 MPa within the margin of error.

3. Determination of thermal constants and thermomechanical behaviour of laser-shocked Ti64 under quasi-static tensile loading by IRT

Infrared measurements have been used to investigate thermal constants of laser-shocked specimen and untreated specimens on the basis of developed flash method [4]. An optical heat source with high power was used for heating the rear surface of sample and an infrared camera FLIR SC5000 detected the temperature field evolution on the its front surface. To define thermal diffusivity *α* and thermal conductivity *λ*, we solve the optimization problem (related to *α* and *λ*) and find the best correspondence between the experimentally obtained temperature evolution of the heated point and theoretical solution (1) described in [4]. Results are presented in table 1.

$$T(t)=\frac{q}{4\lambda l}\left[\ln\left(\frac{4\alpha}{\omega^2}t+1\right)+2\sum_{n=1}^{\infty}(-1)^n\exp\left(\frac{\pi^2n^2\omega^2}{4l^2}\right)\cdot\left(\Gamma\left[0,\frac{\pi^2n^2\omega^2}{4l^2}\right]-\Gamma\left[0,\frac{\pi^2n^2\left(4\alpha t+\omega^2\right)}{4l^2}\right]\right)\right] \quad (1)$$

Table 1. *Thermal constants of laser-shocked Ti64 and Ti64 untreated specimens obtained by IRT*

Material	Thermal diffusivity $\alpha \cdot 10^6 (m^2 s^{-1})$	Thermal conductivity λ $(Wm^{-1}K^{-1})$
Untreated Ti64	7.41	7.83
Laser-shocked Ti64	8.06	6.76

Quasistatic tensile of flat Ti64 specimens after LSP and without treatment was carried out with a simultaneous registration of temperature field of the specimen surface by IRT and movement of the specimen working area by video extensometer. The speed of grip movements was 2.5 mm/min. Figure 3 shows a typical specimen deformation diagram and temperature evolution of treated and untreated specimens of titanium alloy Ti64.

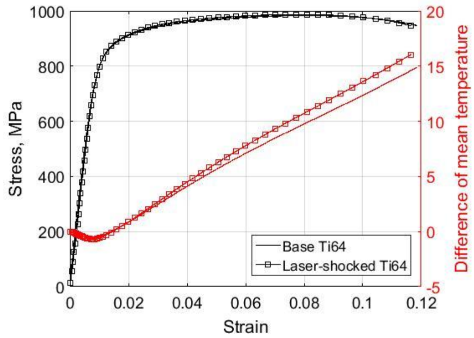

Fig. 3. Typical deformation diagram of Ti64 and mean temperature changes evolution during quasistatic tensile of Ti64 specimens after LSP and without LSP

4. Conclusion

Comparative analysis of the typical deformation diagram and time dependence of mean temperature changes showed that LSP did not alter the mechanical properties of treated Ti64, but LSP specimens dissipated slightly more energy during plastic deformation. This could be explained by differences in the thermal constants of laser-shocked and untreated Ti64 specimens caused by plastic deformation and microstructural changes in the subsurface layer of the treated specimens.

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