Residual stress state in titanium alloy remelted using GTAW method

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Abstract
Test materials comprised two-phase titanium alloy Ti6Al4V (Grade5). The surface of the tested alloy was remelted by means of TIG welding method using variable current-voltage parameters. The investigations aimed to determine surface geometry and residual stresses in the remelted surface layer in the investigated alloy.

Keywords: heat treatment, mechanical properties, titanium

1. Introduction

Advances in investigations and development of materials with improved functional properties is mainly stimulated by its future application [1-5].

The most efficient methods of modification of structure and properties of materials are obtained, among other things, through use of concentrated heat sources. The benefits of the performed surface treatment processes (hardening, alloying) include: opportunities of local treatment, formation of layer structure, higher rate of the process, wide opportunities of selection of chemical composition and functional properties. Application of concentrated heat sources for surface treatment leads, as proved by various research groups, to structural and phase changes and, in consequence, to constitution of surface layer with entirely new properties [6-13].

An essence of application of laser beam, plasma or welding arc is focusing of energy on very small area of material. The constituted surface layer is characterized by improved functional properties with higher hardness and friction resistance while the demanded core properties remain unchanged.

Surface treatment of materials allows for creation of surface layer with thickness that ranges from decimals of millimetre to several millimetres.

Proper selection of parameters for the performed surface treatment leads to obtaining of the surface which does not require further finishing and thus it is characterized by the expected surface geometry.

Ti-6Al-4V (Grade 5) is the most frequently used alloy and accounts for 60% of total titanium production. It is used in the cases where combination of increased strength, lower density, good formability and corrosion resistance (aviation, space, automotive, marine industry, sports equipment, medicine) is required. One of the drawbacks of titanium alloys is, among other things, their small resistance to tribological wear and oxidation.

Wide application of titanium alloys for technology and medicine creates opportunities of searching for new methods of modification of currently used titanium alloys with tendency to improvement in their properties.

In consideration of the fact that residual stresses in material has great impact on durability and properties of the modified component, the investigations aimed to determine these parameters in the remelted surface layer.
2. Materials and Methodology

Materials for investigations was Ti6Al4V titanium alloy with chemical constitution presented in Tab. 1.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>C</th>
<th>Fe</th>
<th>O</th>
<th>N</th>
<th>Al</th>
<th>V</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 5</td>
<td>0.024</td>
<td>0.20</td>
<td>0.10</td>
<td>0.002</td>
<td>6.30</td>
<td>4.12</td>
<td>reminder</td>
</tr>
</tbody>
</table>

Surface treatment was carried out by means of GTAW (Gas Tungsten Arc Welding) - TIG welding method using variable current/voltage parameters: I=10-40A, V=12-15V and the rate of source of 330 mm/s.

Sample surface, after remelting, was then subjected to further tests. Structural tests were carried out in Joel 5400 scanning microscope. Surface microhardness tests in remelted titanium alloy were carried out using Vickers method with Future Tech. Corporation FM7 hardness tester. Surface geometry tests were carried out using Hommelwerke profilometer at the measured distance of 5 mm. Residual stresses tests were carried out using \(\sin^2\psi\) X-ray method, which is a non-destructive method that allows for precise localization of measurement points. X-ray tests involved using Seifert XRD-3003 diffractometer, equipped in goniometer which allows for sample rotation.

The following conditions of measurement of residual stresses were used: Co lamp radiation - \(K_{\alpha}\), diffraction plane - (102), diffraction angle: \(2\Theta=58-64^\circ\), sample inclination angle \(\psi\): 0 - 45° every 5°.

Existence of residual stresses in the material is accompanied with certain changes in crystal lattice that lead to angular shift of reflexes on diffractogram. This shift is mainly a result of elastic deformation of crystal lattice which corresponds with macroscopic deformation of the sample. Analysis of reflexes from planes family allows for determination of the extent and directions of deformations, which is then reconverted into stresses using X-ray elastic constants. \(\sin^2\psi\) method is based on Hook’s equation for plane stress with components of deformation ellipsoid. Practical measurement consists in determination of \(\varepsilon_{\psi}\) deformation of crystal lattice for several \(\psi\) angles. Spatial arrangement of deformations with plane stress on the surface of an element is presented in Fig. 1.

A series of tests for variable \(\psi\) angles allowed for decomposition into principal components according to the following procedure:
- determination of \(\varepsilon_{\psi}\);
- taking several measurements of variable \(\psi\) angle (necessary for determination of principal stresses direction),
- plotting of the obtained deformation values onto \(\varepsilon_{\psi}\) - \(\sin^2\psi\) diagram,
- drawing a straight line connecting measurement points and determination of its \(\sigma\) inclination angle.

3. Test Results

Remelting of titanium alloy surface, as proved by microstructural tests, caused appearance of cellular and dendrite structures in remelting path as a result of rapid crystallization that accompanies the applied treatment (Fig. 2).
The results of microhardness tests are presented in Fig. 3. Remelting hardening of the surface of two-phase titanium alloy caused rise in microhardness in the case of all applied current/voltage variants.

![Graph showing microhardness distribution](image)

**Fig. 3.** Distribution of microhardness in samples before and after remelting hardening.

Results of surface geometry tests are presented in Tab. 2.

**Table 2. Roughness parameters of the remelted samples**

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Remelting Parameters</td>
<td>10A</td>
<td>20A</td>
<td>30A</td>
<td>40A</td>
</tr>
<tr>
<td>Ra</td>
<td>0.53</td>
<td>0.56</td>
<td>0.73</td>
<td>1.97</td>
</tr>
<tr>
<td>Rmax</td>
<td>3.54</td>
<td>5.63</td>
<td>9.93</td>
<td>18.24</td>
</tr>
<tr>
<td>Rt</td>
<td>3.86</td>
<td>6.62</td>
<td>9.93</td>
<td>18.24</td>
</tr>
<tr>
<td>Rp</td>
<td>2.40</td>
<td>4.72</td>
<td>5.19</td>
<td>8.51</td>
</tr>
</tbody>
</table>

Ra – arithmetic average deviation of the roughness profile from the mean line
Rmax – maximal distance of the highest peak of the profile from the lowest valley
Rt – vertical distance between the highest peak and lowest valley
Rp – highest profile peak height

The profiles recorded for the investigated samples are presented in Fig. 4-7

![Profiles of surface geometry](image)

**Fig. 4.** Profiles of surface geometry for samples remelted with 10A

Rise in applied current parameters results in linear increase in roughness parameters in remelted surface.

Results for residual stress state for all the samples are compared in Table 3.

**Example of diffraction peak for the samples remelted with I=10A and I=40A are presented in Fig. 8 and 9.**

**Table 3. Residual stress state in surface layer of the titanium alloy**

<table>
<thead>
<tr>
<th>Samples</th>
<th>Stress MPa</th>
<th>Adjustment factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial sample</td>
<td>350</td>
<td>0.962</td>
</tr>
<tr>
<td>Remelted sample I=10A</td>
<td>360</td>
<td>0.973</td>
</tr>
<tr>
<td>Remelted sample I=20A</td>
<td>480</td>
<td>0.984</td>
</tr>
<tr>
<td>Remelted sample I=30A</td>
<td>520</td>
<td>0.965</td>
</tr>
<tr>
<td>Remelted sample I=40A</td>
<td>560</td>
<td>0.978</td>
</tr>
</tbody>
</table>
4. Conclusions

- According to the investigations, particular residual stresses condition, which impacts on strength properties in the processed elements is a very important effect of the performed surface treatment.
- The assessed residual stress state on the surface of the remelted alloy indicates that remelting and thus process of rapid crystallization with phase transitions that accompany surface treatment lead to appearance of tensile stresses which increase as welding arc intensity rises.
- Remelting hardening on the surface of Ti-6Al-4V alloy led to improvement of microhardness for all the applied current and voltage parameters.
- The resulting surface roughness resulted directly from the applied variants of the treatment and was correlated with them in a linear way.

Acknowledgements

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5. References