Surface remelting treatment of 7075 aluminum alloy—microstructural and technological aspects

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Abstract

7075 aluminum alloy in the T6 state was subjected to surface remelting treatment using Gas Tungsten Arc Welding (GTAW). The changes in the material microstructure were examined by means of light microscopy, scanning electron microscopy and EDS. Moreover, profilometric tests and comparative measurements of material hardness in the state before and after the treatment were conducted. In the remelted layer strong microstructure refinement and the disappearance of microstructure banding were found. A fine dendritic microstructure was dominant in the remelted zone. Use of the GTAW method reduced the number of intermetallic precipitates in the surface layer. A consequence of dissolving the precipitates was a decrease in the hardness of the material in relation to the hardness before the modification. All the samples were characterized by the presence of a remelted zone, a narrow partially remelted zone and a wide heat affected zone. With an increase in the heat source travel speed, and consequently less heat entering the remelted material, the dimensions of the individual zones decreased. The conducted research showed that GTAW technology can be used in the surface remelting treatment of aluminum alloys and can be a competitive solution in comparison to other technologies.

1. Introduction

In the age of continuous improvement of fabrication technologies, the attention of researchers is more frequently focused on shaping the microstructure and properties of the product surface layer [1–6]. One of the modern methods of modifying the surface layers of engineering materials is surface heat treatment carried out using concentrated heat sources such as a laser beam or plasma jet. For instance magnesium alloys [7, 8], plasma sprayed coatings [9, 10], aluminum alloys [11–13] and other engineering materials are subjected to treatment by means of concentrated heat sources. Aluminum alloys are materials with a very wide application resulting from their low density and good strength properties. One of the aluminum alloys having a high application importance is the 7075 alloy. Owing to the good strength properties of the 7075 alloy in the T6 state (supersaturated and artificially aged alloy), very good thermal and electrical conductivity, easy machinability and low density, this material is used in many branches of industry, among others in the automotive, aerospace, machine or shipbuilding industries. Surface remelting treatment is carried out in order to fragment the microstructure, homogenize the material and eliminate or reduce the sizes of large secondary phases on the surface of the alloy and is usually performed by means of laser technology. CO₂ lasers [14], excimer [13] and diode lasers [11] are usually used for this purpose. For example Chan et al [13] investigated the corrosion resistance of a 7075-T651 alloy subjected to surface remelting conducted with an excimer laser and found that the treatment significantly improved the corrosion resistance of the alloy when subjected to an immersion test in a NaCl solution. They also discovered that improvement in the corrosion pitting resistance is probably due to reduction of the constituent particles in the modified layer as well as chemical homogenization of the matrix material. In turn, in [11] a high power diode laser was employed for surface remelting of a 7075-T6 alloy. The
The authors revealed that the treatment produces a fine dendritic microstructure region at the surface, whose depth depends mostly on the temperature at the surface of the material, and only marginally on the scanning speed of the laser beam. A high power diode laser was also applied to remelt a 7075-T651 alloy in work [12]. The authors stated that the re-solidified laser-melted layer was refined by eliminating the detrimental constituent particles and grain boundary network present in the wrought structure. A comparative corrosion study determined by potentiodynamic polarization measurements in a 3.5% NaCl solution showed that the corrosion current was reduced five-fold in the melted surface compared to the untreated substrate. Although the issue of laser processing of various aluminum alloys has been the subject of many research works and is richly documented in world literature, there are relatively few reports on the use of welding technologies in the remelting treatment of these alloys. This is partly due to the fact that welding technologies are mainly associated with the process of joining materials, and to a small extent with technology that can be used in surface engineering. This is an inappropriate approach as electric arc treatment can lead to similar effects as those of a laser beam or plasma jet. As shown by the results of works [15–19], GTAW surface remelting treatment allows one to bring about favorable changes in the surface layer of the modified material. The advantages of welding technologies lie primarily in the availability of welding equipment, ease of implementation, low equipment cost and low cost of machining.

In this study, the technological and microstructural aspects of the GTAW surface remelting treatment of 7075 aluminum alloy were analyzed and discussed.

2. Material and experimental procedure

The material for the study was 7075 aluminum alloy samples cut from rolled metal sheets with the thickness of 15 mm. The chemical composition of the aluminum alloy is presented in table 1. Before the treatment, the surface of the samples was chemically cleaned to eliminate contaminants.

Surface treatment was carried out using a FALTIG-315AC/DC inverter power source, and a tungsten electrode with the addition of 2% ThO₂. The addition of ThO₂ favorably affects the stability of the arc, and thus facilitates reproducibility of the remelting effects at given parameters. The treatment was performed using a direct current with positive polarity, which forced the application of an electrode with a large diameter due to the much higher thermal load of the electrode during machining than using negative polarity. An electrode with a diameter of 4 mm was employed in the experiment. In order to prevent melting of the electrode and the passage of tungsten to the weld pool during the DCEP remelting tests, the pre-process current shaping of the electrode tip was used. A current pulse with a specific amplitude and duration of action causes the electrode tip to round off, so that it is able to absorb the heat generated by the arc without melting it during the remelting process. Rounding the electrode tip is associated with greater arc dispersion than when welding with DCEN negative polarity, which is characterized by a more focused arc compared to DCEP. The purpose of using DCEP positive polarity was also to achieve a wider and shallower remelting zone for surface layers compared to DCEN. The shielding gas flow was 15 l min⁻¹, and the distance of the electrode tip from the sample surface was 2 mm. The shielding gas was argon (Ar4.5). The treatment was carried out using a welding current I = 150 A and arc voltage U = 11.4 V and varying value of heat source velocity V of 20 to 60 cm min⁻¹. The treatment parameters are summarized in table 2. Microscopic examinations were performed by means of an Olympus GX41 light microscope and a JEOL JSM-6610LV scanning microscope. EDS examinations were carried out using an x-ray microanalyzer by Oxford Instruments. The hardness measurement was performed by means of a Shimadzu HMV-G20 microhardness tester equipped with a Vickers indenter. The applied load was 980.7 mN and the load time amounted to 10 s. Hardness tests were conducted on all the samples on the middle part of the transverse cross-section. Profilometric tests were carried out on a 10 mm section using a Taylor Hobson TALYSURF 120 profilometer.

| Table 1. Chemical composition of 7075 aluminum alloy. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Alloy           | Zn   | Fe   | Cu   | Mn   | Mg   | Cr   | Si   | Ti   | Al   |
| 7075            | 5.5  | 0.3  | 1.6  | 0.15 | 2.4  | 0.2  | 0.2  | 0.1  | rest |

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3. Results

3.1. Microstructure of starting material

The 7075 aluminum alloy in its initial state had a heterogeneous microstructure, consisting of an Al matrix and numerous intermetallic phase precipitates located along the rolling direction. An example of the alloy microstructure in the T6 temper condition is shown in figures 1(a) and (b). The elongated shape of the grains and the location of the precipitates gave the material its banding characteristics. The dimensions of the precipitates were varied and ranged from 0.5 to 10 \( \mu \)m (figure 1(b)). The presence of large intermetallic phases in the microstructure of the material is one of the main reasons for the low corrosion resistance of the 7075 alloy since these precipitates have high cathodic activity compared with the alloy matrix. On the other hand, these phases reinforce the material and improve its mechanical properties. As can be seen, the location of the intermetallic phases did not result from the location of the grain boundaries. The phases were present both at the grain boundaries and inside the grains. The EDS analysis of the precipitates revealed the presence of several types of intermetallic phases, i.e. irregular shaped bright precipitates rich in aluminum, iron and copper, and darker precipitates of a more regular shape, rich in aluminum, silicon and oxygen.

| Band no. | Heat source travel speed [cm min \(^{-1}\)] | Welding current [A] | Arc voltage [V] | Arc power [W] | Linear energy [J mm \(^{-1}\)] |
|----------|------------------------------------------|---------------------|----------------|--------------|-------------------------------|
| 1.       | 20                                       | 150                 | 11.4           | 1710         | 513                           |
| 2.       | 40                                       | 150                 | 11.4           | 1710         | 256.5                         |
| 3.       | 50                                       | 150                 | 11.4           | 1710         | 205.2                         |
| 4.       | 60                                       | 150                 | 11.4           | 1710         | 171                           |

Table 2. Treatment parameters.

![Figure 1. Microstructure of 7075 alloy in initial state, banding and rolling structure (a), intermetallic phases (b).](image-url)
3.2. GTAW remelting treatment

Remelting treatment of the 7075 aluminum alloy was performed by GTAW. In this method, an electric arc glows between an infusible tungsten electrode and the material to be welded. Depending on the remelted material, GTAW can be performed with a direct current of positive or negative polarity or alternating current. When welding unalloyed and high-alloy steels, the tungsten electrode is usually connected to the negative pole and the ground terminal to the positive pole of the welding machine, however, when welding aluminum and aluminum alloys, a one-way current with positive polarity or alternating current is used. During remelting using positive polarity (DCEP-Direct Current Electrode Positive), the electrons flowing from the material to the electrode cause about 70% of the heat to concentrate in the arc zone of the electrode. Thus, an electrode that accumulates a significant amount of heat must have a higher thermal capacity to prevent it from overheating and, as a result, melting. During experimental tests, no significantly higher electrode wear was observed compared to the use of DCEN negative polarity. The electrode wear was mainly due to the need to properly prepare the electrode tip before the remelting process. The need to use electrodes with larger diameters results in a broader remelted zone, which is deliberate and advisable in the case of surface remelting treatment. On the other hand, positive ions of high energy flowing from the electrode towards the material colliding with its surface cause the oxide layer to break. This process is referred to as cathodic cleaning. The specificity of the phenomena during remelting with positive polarity causes the metal surface to be cleaned of oxides, while the remelting is wider and shallower than remelting with a negative polarity (DCEN- Direct Current Electrode Negative). Nonetheless, the lack of cathodic cleaning in the case of using negative polarity excludes this way of generating the arc for the remelting treatment of non-ferrous metals, including aluminum, magnesium and their alloys because their surface is covered with non-flammable oxides. The most frequently used type of current during the welding of non-ferrous alloys using the GTAW method is alternating current, the application of which results in equal heat distribution between the electrode and the base material. However, in the case of remelting treatment, continuous polarity changes and the necessity for arc re-ignitions with a frequency equal to that of the current, lead to disturbances in the stability of the arc. On the other hand, the greater amount of heat generated in the material (in relation to DCEP) causes considerable waviness in the surface of the molten and then solidified metal. The mentioned factors indicate that the most effective method of remelting light metal alloys is GTAW using positive polarity. This variant was used in this work. The influence of the current type on the remelted zone size is shown in figure 2. The surface treatment scheme of the 7075 aluminum alloy by means of the GTAW method is shown in figure 3.

During the surface treatment, despite the presence of a thin oxide layer on the aluminum surface, the stability of the electric arc was not disturbed. The presence of an oxide layer on the surface of aluminum and aluminum alloys is a natural consequence of the high affinity of aluminum for oxygen. Practice shows that the using a protective gas shield during GTAW treatment limits, but does not completely prevent the formation of an oxide layer on the material surface.

Evaluation of the size of the area of microstructural changes induced by the processing performed as a function of the remelting parameters showed that with a decrease in the heat source travel speed, and with a constant value of welding current and arc voltage, a reduction in the dimensions of the remelted zone (RZ) was recorded, both the depth of remelting and the width of the remelted band. In the case of the analyzed samples, the depth of the remelted zone was 478 μm, 518 μm, 619 μm and 693 μm and the width of the remelted zone was about 4 mm, 4.5 mm, 4.8 mm and 5.1 mm, respectively for $V = 60$ cm min$^{-1}$, 50 cm min$^{-1}$, 40 cm min$^{-1}$, 20 cm min$^{-1}$. Measurement of the remelting depth was conducted in the central part of the band. A similar pattern was observed in the intermediate zone characterized by partial remelting (PRZ). The thickness of the partially remelted zone was about 183 μm, 203 μm, 228 μm and 274 μm, respectively for $V = 60$ cm min$^{-1}$,
50 cm min$^{-1}$, 40 cm min$^{-1}$ and 20 cm min$^{-1}$. The largest zone was the heat affected zone (HAZ), adjacent to the base material (BM) because its thickness was approximately twice the thickness of the RZ. The effect of surface remelting of the 7075 alloy using GTAW is presented in figures 4 and 5, while in figure 5 the measurement results of the depth of the remelted zone and the thickness of the partially remelted zone are additionally shown.

Examples of the macroscopic effects of the treatment showing the nature of changes in the geometric structure of the alloy surface caused by remelting are shown in figure 6.

No microcracks or other discontinuities within the bands were found. The bands were continuous and homogeneous along the entire length, and their edges were parallel to each other. To illustrate the surface roughness and the variability of the surface geometric structure as a function of the heat source travel speed, profilometric studies were performed. The measurements of the main roughness parameters, i.e. $R_a$ and $R_z$, showed that the values of these parameters decreased with an increase in the heat source velocity, although at the highest velocities, i.e. 50 and 60 cm min$^{-1}$, this regularity was not detected. All the analyzed samples were also characterized by a lower roughness than the material in the initial state.
3.3. Microstructure of remelted layer

Investigations by means of light microscopy revealed significant changes in the microstructure of the remelted layer in relation to the state before the treatment.

All the samples showed the presence of a remelted zone (RZ), a narrow partially remelted zone (PRZ) and a wide heat affected zone (HAZ) adjacent to the base material (BM). The dimensions of the RZ, PRZ and HAZ increased with decreasing the heat source travel speed. The banding effect of the location of the precipitates and the rolling structure of the alloy were completely eliminated by surface treatment. A characteristic feature was the presence of a fine dendritic microstructure, while the size of the dendrites greatly increased further from the modified surface and their morphology changed from cellular dendrites near the top of the surface to columnar dendrites near the PRZ. The variability of the microstructure as a function of distance from the surface is shown in figure 7. It was also found that the intermetallic phase precipitates present in the microstructure of the starting material were completely dissolved in the aluminum matrix during the GTAW treatment. This effect was noted to a lesser extent in the case of the partially remelted zone, where precipitates were still present, although their distribution was more even and did not show any banding characteristics. The fact of dissolving the precipitates is important in the context of assessing the corrosion resistance of the 7075 alloy. It should be assumed that dissolving the precipitates and redistributing the elements within the solidification layer will lead to improvement in the resistance of the aluminum alloy to pitting corrosion. Intermetallic phase precipitates are not only sensitive to thermal influences [20], but are also primary sources for the nucleation of corrosion pits. In the remelted zone, the presence of small secondary precipitates rich in aluminum, zinc, magnesium and copper,
located in interdendritic spaces (figure 8) was also found. The results of EDS analyses of these precipitates are presented in table 3.

3.4. Hardness
Hardness measurement is one of the basic research methods enabling very fast practical verification of the correctness of the made assumptions and the applied processing parameters, and tell a great deal about the nature of microstructural changes taking place in the material. Despite the strong refinement of the
microstructure of the 7075 alloy and its homogenization, a hardness lower by about 20% compared to the hardness of the starting material was recorded after treatment.

The average hardness of the starting material was 135 HV0.1, while the average hardness of the modified material measured in the central part of the remelted zone was 110 HV0.1, and in the partially remelted zone it was 118 HV0.1.

The reduction in hardness is primarily a consequence of dissolving the intermetallic precipitates in a solid aluminum solution, and the absence of these precipitates was not able to compensate for the microstructure refinement after GTAW treatment, homogenization of the material, or the presence of small secondary precipitates at the dendrite boundaries. The mechanical properties of the alloy are affected not only by the type and number of precipitates, but also by their shape and size. An example of the course of material hardness as a function of distance from the surface is shown in figure 9. There were no significant differences or regularities between the hardness of the material and the heat source travel speed, the average hardness measured in the remelted zone was similar for all the samples and was respectively: for sample No. 1 about 108 HV0.1, for sample No. 2 about 109 HV0.1, for sample No. 3 about 116 HV0.1, and for sample No. 4 about 106 HV0.1.

**Table 3.** Results of EDS analysis of precipitates.

| Element | Weight % | Atomic % |
|---------|----------|----------|
| Al      | 90.79    | 94.56    |
| Zn      | 5.57     | 2.40     |
| Mg      | 2.01     | 2.32     |
| Cu      | 1.63     | 0.72     |

**Figure 8.** Results of EDS analysis of precipitates.

**Figure 9.** Change in hardness as function of distance from the surface.
4. Conclusions

The following conclusions can be drawn from this study:

1. GTAW treatment leads to complete elimination of the banding and rolling structure characteristics of the starting material.

2. GTAW surface treatment leads to the production of characteristic zones in the surface layer, i.e. the remelted zone, partially remelted zone and the heat affected zone adjacent to the base material.

3. Changing the heat source travel speed, with a constant current and arc voltage, determines the amount of heat entering the remelted material, and consequently the dimensions of the individual zones. The dimensions of the RZ, PRZ and HAZ decrease with increasing the speed of the heat source.

4. GTAW surface treatment allows one to reduce and/or to completely eliminate intermetallic phase precipitates from the surface of the alloy.

5. The consequence of dissolving the precipitates during the remelting treatment is a reduction in the material hardness.

6. GTAW is a technology that is fully usable in performing surface remelting treatment of aluminum alloys, which can be an alternative solution to other surface remelting techniques.

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