Optimization of the heat and mechanical treatment of the Al-Zn-Mg-Li alloy

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Abstract

In terms of high strength in relation to mass the alloys of aluminium – lithium find more and more use mainly in aircraft industry like in spacecraft. At present intensive investigations are carried out in aim of use of Al – Li in automotive industry in particular to components subject to fatigue wear. It could contribute to replace transmission’s elements made from traditional materials by aluminium - lithium alloys. However low resistance to wear due to forming of thin Al2O3 layer which is reproducing in friction contact disqualifies using aluminium alloys in friction contact. From this point of view first stage of investigation was to enhance hardness properties of the substrate by applying thermo-mechanical treatment.

In this article the results of heat treatment of Al-Zn-Mg-Li alloy were presented. During investigations optimum parameters (time-temperature) of the solution heat treatment were elaborated. Micro hardness on the cross-section were investigated. Phase, chemical composition and morphology were determined. It was found that hardness after thermo-mechanical treatment of Al-Zn-Mg-Li is about 20% higher than for AlCu4Mg1 (7075 –T6) alloy.

1. Introduction

As the density is low and the modulus is increased, alloys with the addition of lithium have been applied mainly in the aircraft industry, and increasingly in the automotive industry [3]. The application of Al-Li alloys in the automotive industry has been motivated by reduced CO2 emissions to the atmosphere and decreased fuel consumption. The decrease in fuel consumption is proportionate to the decrease in the total mass of a given vehicle. Additionally, a drop in harmful emissions to the atmosphere is observed.

As the strength and tribological properties of Al-Li alloys are low if compared to other materials applied in the automotive industry, they can only be used for the structural elements of vehicles and their particular subsets [4].
The introduction of alloy additives such as Zn, Cu and Mg and thermal processing in combination with surface processing brought about increased strength and tribological properties of Al-Zn-Li alloys [5-6]. However, as lithium occurs in alloys and its relative affinity to atmospheric oxygen is high, alloy thermal processing requires the application of a protective atmosphere in which oxygen content should not reach more than 1ppm.

The optimization of such parameters as the time and temperature of Al-Li alloy processing based on heating and supersaturation leads to maximum dissolution of components of α(Al) alloy dissolved in a solid solution [7]. As a metastable supersaturated solution is generated, the free energy of the system increases [8]. Mechanical processing leads to the introduction of maximum strain through dislocation and defects in the crystalline lattice. The introduction of maximum strain leads to storage of nucleation energy for new phases [9].

Areas of higher energy in combination with thermal energy supplied in the course of aging lead to the creation of a metastable phase δ". The phase δ" is replaced by the generation of homogeneous phases δ' Al₃Li which are coherent with the matrix [10]. The separated phases enhance strength properties of the alloy with a simultaneous preservation of its elasticity [11].

2. Experimental

The experiment was based on thermal and mechanical processing on alloys specified in Table 1.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Li wg.%</th>
<th>Zn wg.%</th>
<th>Mg wg.%</th>
<th>Cu wg.%</th>
<th>Al wg.%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Zn-Mg</td>
<td></td>
<td>4.14</td>
<td>1.41</td>
<td>1.56</td>
<td>93.89</td>
</tr>
<tr>
<td>(7075)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al-Zn-Mg-Li</td>
<td>2</td>
<td>5.6</td>
<td>0.6</td>
<td>1.93</td>
<td>92.18</td>
</tr>
</tbody>
</table>

Subsequently, the specimens were subjected to compression from 0 to 60%. Mechanical processing took place using a standard materials testing machine of a compressive force of 200 kN. To obtain a given plastic deformation, the specimens were subjected to compressive force. After obtaining a given deformation, the specimens remained under a constant force for 15 s to eliminate elastic deformation.

The final investigations were based on increasing alloy strength properties through aging. The process was carried out in the range of 70 - 160°C, which made it possible to examine the influence of time on material strengthening. The degree of material strengthening was defined by HV0.1 hardness testing using a Zwick hardness tester. The measurement was performed for the following process durations: 0.5h, 1h, 2h, 3h, 6h, and 12h. Specimen aging took place in motor oil for protection against surface oxidation.

3. Experimental results

3.1. Processes of specimen supersaturation

Figure 1 shows a sample change of hardness degree in the course of supersaturation of investigated alloys: Al-Zn-Mg and Al-Zn-Mg-Li, respectively, at a temperature of 540°C and 550°C. The decrease of HV0.1 hardness reflected the degree of component dissolution in solid solution α(Al). The examination of microstructure makes it possible to reveal the non-homogenous distribution of phase δ in the alloy structure. Figure 2a. shows a sample microstructure of alloy Al-Zn-Mg-Li and Al-Zn-Mg (Fig. 3a) prior to saturation. On the other hand, morphological analysis of Al-Zn-Mg-Li and Al-Zn-Mg (7075) alloy proves that after supersaturation at 540°C for 3h only trace quantities of undissolved phase δ Al₃Cu remain in the alloy structure (Fig. 2b, 3b). The greatest changes of specimen hardness (from 175 to 100 HV0.1) are observed.
The analysis of phase composition (Fig. 4) of the Al-Zn-Mg-Li specimen before and after supersaturation at 540°C for 3h confirmed that the Al$_2$Cu phase was dissolved in the solid solution $\alpha$(Al).

### 3.2. Mechanical processes

The next stage of the study was to conduct plastic processing of the alloys based on compressing within the range of deformation from 0% to 60%.

The analysis of hardness profiles proves that the greatest increase of hardness is attained for plastic deformation in the range of 35÷45% (Figure 4). After exceeding this value, no further increase in the hardness of the investigated specimens is observed. On the other hand, deformation over 60% leads to cracking of the specimen surface as a result of exceeding the maximum compressive strength of the investigated materials and, consequently, their decohesion.
3.3. Specimen aging.

Investigations of aging at 160°C were based on the generation of a finely dispersive phase δ′ Al₃Li in the continuous medium of the investigated materials.

Figure 5a,b,c,d shows the results of hardness increase for the specimens with different strain values applied in the function of time exposed to the process of aging at 80°C and 160°C.

Analysis of temperature influence in the process of specimen aging consisted of the comparison of hardness increase. The hardness obtained at 80°C (Figure 5a,b) was by about 30% greater than that obtained at 160°C. The application of a greater strain to increase hardness after aging at 160°C did not bring about the expected changes. Comparing the Al-Zn-Mg and Al-Zn-Mg-Li
alloys, a hardness greater by 10% is observed in the lithium alloy, at 230 HV₀.₁. Analysis of the phase composition (Fig. 6) of the Al-Zn-Mg-Li specimen after the process of aging at 80°C for 12h confirmed that the Al₃Li phase was generated in the solid solution α(Al). From the analysis of metallographic pictures (Fig.6a, 6b) it follows that the mean size of the generated phases remains in the range from 1.6 to 2.1µm for Al-Zn-Mg-Li and from 2.0 to 4.0µm for Al-Zn-Mg (7075).

![Fig. 6. Sample phase composition K₀Co of AL-Zn-Mg-Li alloy after aging at 80°C](image)

![Fig. 6a. Sample structure of Al-Zn-Mg (7075) alloy after aging at 80°C for 12h](image)

![Fig. 6b. Sample structure of Al-Zn-Mg-Li alloy after aging at 80°C for 12h](image)

4. Observations and conclusions

The present study leads to the conclusions that optimization of thermal and mechanical parameters makes it possible to increase the hardness of modern Al-Zn-Mg-Li alloys by about 20% as compared to the high-strength 7075 alloys in T6 condition, applied mainly in the aviation industry. This results from the fact that finely dispersive coherent phases Al₃Li and Al₂Cu are generated in the course of aging in the continuous medium of the investigated alloy.

The next stage of study will be the optimization of thermal processing in the Al-Li system and the subsequent process of aging to obtain a matrix with a grain size of under 500nm with disperged manometric phases.

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References


