TO STUDY THE CORRELATION BETWEEN MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AL-MG-CR ALLOY AFTER WORK HARDENING

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ABSTRACT The effect of cold-work and heat treatment on the microstructure development and changes occurred in the mechanical properties of Al-Mg-Cr alloy has been studied at large. The samples were homogenized at 573 K for one hour and allowed to cool at room temperature. X-ray fluorescence spectroscopy (XRF) was employed to ensure the exact elemental composition of the alloy. The samples were cold worked under normal static load of 30 KN with time variation to get 1% to 7% reduction in thickness. After work hardening the samples were aged for four hours at 373K. Optical microscopy was used to study the microstructure. Vickers hardness test was carried out to study hardness, which was improved as a result of work hardening. The steady state creep rate was found to be decreased as a result of above-mentioned treatment.

1. INTRODUCTION

Aluminum- Magnesium- Chromium is a non-heat treatable alloy [1-2] that is generally known for its excellent corrosion resistance. The Al-Mg-Cr alloys have a wide range of strength, good forming and welding characteristics, and high resistance to corrosion as has been shown by Haszler et. al. [3]. The work of Gholinia, et. al. [4] showed the conditions under which micron-scale structure can be developed in Al-Mg-Cr alloy. The Niikura, et. al. [5] related with the refinements of recrystallized grain and its effects on mechanical properties in Al-Mg alloys. For the purpose of obtaining aluminum P/M materials strengthened by solid solution of Mg and dispersion of transition metal compounds, Fujii, et. al. [6] worked on rapidly solidified Al- Transition metals with addition of Mg Rapid solidification (RS). Jian et. al. [7] Investigated the influence of chemical composition on the microstructure and mechanical properties of Al Mg alloys. The work of Taleff, et. al. [8] showed that the solute-drag creep was observed in many aluminum alloy containing magnesium concentration from as little as 2 wt%, to the limit of solubility. Kaigorodeva [9] worked on microstructure and mechanical properties evolution during long term aging of Al-Mg alloy by optical and transmission electron microscopy as well as tensile test and corrosion resistance decreased during aging which result from film like grain boundary B' and β phase precipitation. The work reported by Savas et. al. [10] covered a comparative investigation of the Aluminum-Magnesium cast alloys containing up to 10% Mg.
To our knowledge, not a lot of work has been done to find the correlation between microstructure development and the changes occurred in mechanical properties of Al-Mg-Cr alloy after cold work. To find the correlation, pre-prepared Al-Mg-Cr alloy was subjected to study with reference to the mechanical properties and microstructure development as a result of cold work followed by aging.

The paper has been divided into four major sections followed by many subsections. Section 1 introduces the field and what major work has been done until now in this field. Section 2 describes the sample preparation steps. While the section 3 provides the results of research completed here followed by the comprehensive discussion including elemental analysis, optical microscopy, creep studies, effect of work hardening on steady state creep rate, and the hardness studies. The fourth section concludes the work.

2. EXPERIMENTAL SET-UP

As stated above, to find the correlation between microstructure and mechanical properties of Al-Mg-Cr alloy, the pre-prepared Al-Mg-Cr alloy was subjected to cold work followed by aging. For this purpose seven samples were prepared. The elemental composition was determined using x-ray fluorescence spectrometer (XRF). The samples were homogenized at 573 K in an electric furnace for an hour and allowed to cool at room temperature. These samples were cold worked from 1% to 7% reduction in thickness under normal static force of 30 kN in isothermal condition. After cold working, the samples were aged for 4 hours at 373 K. Optical microscopy was used to study the microstructure of properly etched samples. Vickers hardness test and creep test were carried out to investigate the mechanical properties of the samples.

3. RESULTS AND DISCUSSION

3.1. ELEMENTAL ANALYSIS
The material under study was an Al-Mg-Cr alloy system. After having x-ray fluorescence spectrometry for the elemental analysis the principal composition of the alloy comes out to be as shown in Table.1

<table>
<thead>
<tr>
<th>Element</th>
<th>Al</th>
<th>Mg</th>
<th>Cr</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt. %</td>
<td>94.65</td>
<td>4.8</td>
<td>0.1</td>
<td>0.2</td>
</tr>
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</table>

Table 1: Elemental analysis of the principal composition of the Al-Mg-Cr Alloy based upon XRF.
3.2. OPTICAL MICROSCOPY
The microstructure of the Al-Mg-Cr alloy has been examined by optical microscope. The optical micrograph of the samples of alloy is shown in Fig.1 - Fig. 7.

Fig.1 & Fig 2 are the micrographs of Al-Mg-Cr alloy samples subjected to work hardening form 1% & 2% under normal static force of 30 kN and heat treated at 373 K, respectively. Two types of species can obviously be seen. Firstly the lighter gray equiaxed precipitates with coarse grain boundaries constituting the host matrix. Their average grain size lies in the range 30 μm ~ 170 μm. Secondly black precipitates of smaller size are observed. These precipitates are irregular in shape and size and are randomly distributed over the matrix at grain boundaries and within a grain. Almost no significant change of microstructure is observed in sample with 2% work hardening.

Fig.3 & fig 4 are the micrographs of Al-Mg-Cr alloy samples subjected to work hardening from 3% & 4% under normal static force of 30 kN and heat treated at 373 K. Equiaxed grains with average grain size in...
the range 22 µm ~ 145 µm are observed indicating slight grain refinement as a result of cold work. Black precipitates are seen to be segregated at grain boundaries resulting in decrease in population of these precipitates within the grains. Furthermore, minor refinement of the grain boundaries is also observed in sample with 3% & 4% work hardening.

Fig.5 & fig.6 are the micrographs of Al-Mg-Cr alloy samples subjected to work hardening form 5% & 6% under normal static force of 30 kN and heat treated at 373 k, respectively. Equiaxed grains with average grain size in the range 20 µm ~ 140 µm are observed. Significant grain refinement as a result of cold work is observed in these samples. Black precipitates segregation and growth at grain boundaries resulting in decrease in population of these precipitates within the grains is observed in these micrographs. It is also observed that the black precipitates have attained small circular palette shapes and have become significant within the grains. It is obviously observed that the microstructure of the Al-Mg-Cr alloy has been refined and there is significant grain boundaries refinement in sample with 5% & 6% work hardening.

Fig.7 is the micrograph of Al-Mg-Cr alloy sample subjected to work hardening form 7% under normal static force of 30 kN and heat treated at 373 k, respectively. Equiaxed grains with average grain size in the range 20 µm ~ 135 µm are observed. No significant microstructural changes are observed in this sample. It indicates that the grain size has attained a saturation state i.e. grain size has turned almost insensitive to work hardening. Negligible refinement in the grain boundaries is observed in this sample.
3.3. CREEP STUDIES

The creep test on the Al-Mg-Cr alloy has been performed at constant stress of 100 MPa and temperature of 493 K for 12 hours. The Fig. 8, shows the combined plot of creep curves of all the seven Al-Mg-Cr alloy subjected to work hardening from 1% to 7% under normal static force of 30 kN and heat treated at 373 K.

All the samples have similar creep behavior except the sample with 4% work hardening. The only and the most important difference in the creep behavior of all Al-Mg-Cr alloys is that of creep deformation rate. The creep studies, carried out for 12 hours at 493 K ± 1% and 100 MPa revealed that the steady state creep rate (SSCR) of all the samples lie in the range $0.0080 \mu m / sec. \sim 0.0155 \mu m / sec$. 
Fig. 8: Combined Creep Plots of Al-Mg-Cr alloy at 493 K, 100 Mpa, Cold Worked 1 – 7%.

Table 2: Effect of % Cold Work on Steady State Creep Rate

<table>
<thead>
<tr>
<th>S. NO.</th>
<th>COLD WORK (%)</th>
<th>SSCR (µm / Sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0.0155</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>0.0146</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
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<td>0.0093</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>0.0083</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>0.0080</td>
</tr>
</tbody>
</table>

3.4. EFFECT OF WORK HARDENING ON STEADY STATE CREEP RATE
The steady state creep rates (SSCR) of all the samples were worked out. The plot of steady state creep rate versus the aging time is shown in Fig. 9. The SSCR decreases, in general with increasing work hardening, shows a little increase for sample with 4% work hardening, and then decreases at a very small rate. The steady state creep rate lies in the range 0.0080 µm/sec ~ 0.0155 µm/sec. It is observed that minimum steady state creep rate comes out for samples with 6% & 7% work hardening and afterward it
seems to be less sensitive to work hardening. However the overall creep deformation of the sample with 7% cold work comes out to be minimum.

![Plot of SSCR VS % Cold Work](image)

**Fig. 9. SSCR Vs. % Cold work.**

![HARDNESS PLOT OF Al-Mg-Cr ALLOY Vs %COLD WORK](image)

**Fig. 10. Vickers Hardness Vs. % Cold work.**

### 3.5 HARDNESS STUDIES

The Vickers hardness plot is shown in Fig. 10. (the effect of work hardening of Al-Mg-Cr alloy subjected to work hardening form 1% ~ 7% under normal static force of 30 kN and heat treated at 373 K, lying in the range 70 ~ 84 VHN.

The Vickers hardness in the initial part of hardness plot rises with work hardening with a higher rate and achieves steady state after 4% work hardening of the samples. The maximum Vickers hardness comes out for samples with 6% & 7% cold work.
4. CONCLUSION

It is concluded that the work hardening carried out on Al-Mg-Cr alloy affect the microstructure and mechanical properties. It is observed that the microstructure and mechanical properties are more sensitive towards work hardening for initial stages of cold work. Afterwards these effects become less sensitive towards work hardening.

REFERENCES