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Comparison of Properties of Heat Treated Aluminum Alloy 6061 in Magnetic and Non-Magnetic Field Environments

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Abstract
In this work, 13 mm thick AA6061 was solution heat treated at 560^{o}C for 2 hours to homogenize the grains, then quenched in water at room temperature. The quenched alloy was then cold rolled to 85% deformation, which is 2 mm thickness. The rolled specimen was then cut into smaller pieces for heat treatment at 350^{o}C, 400^{o}C and 450^{o}C in a 20 Tesla resistive magnet for 10, 20, 40 and 60 minutes. Similar heat treatments were repeated on another set of samples after the magnet was turned off using the same furnace. Texture measurements and microhardness values in the samples were measured and analyzed. Results of the texture measurements using the volume fractions of the β-fiber show enhancement of recovery when magnetic field was applied as compared to when the magnetic field was turned off. Microhardness data for all the samples show a lot of scatter in their values and no significant changes can be reported on them.

Keywords: aluminum alloy 6061, heat treatment, 20 Tesla, magnetic field

1. Introduction
Aluminum alloy 6061 is widely used for structural applications and it is heat treatable. In this work, we explore effects of magnetic field on a heat treatable aluminum alloy 6061 when heat treated in a high magnetic field of 20 Tesla. Previous work [1] on aluminum alloy was on a nonheat treatable aluminum alloy 3013. A major reason for this work is to look at how much effect would the application of 20 Tesla magnetic field have on an heavily deformed aluminum in the course of its heat treatment for eventual industrial application in an automotive and rolling industry, for example.

High and low magnetic fields have been employed since 1913 to influence the properties of materials during heat treatment operations. The first work on magnetic field heat treatment was in 1913 and was carried out by Pender and Jones [2] where they reported improvement in permeability of a Fe-4%Si alloy as a result of the application of an a.c. magnetic field during cooling from 800^{o}C to room temperature. Since then researchers and scientists have explored changes in the grain microstructure and texture evolution due to magnetic fields application in the course of heat treatment of heavily deformed materials at different temperatures and periods of time. Mostly, focus was on ferromagnetic materials, but recently findings have also been reported on paramagnetic materials such as zinc [3] and aluminum [1, 4] alloys.

2. Experiment
The basic starting raw material used in this work was a 13 mm-thick plate of an heat treatable aluminum alloy 6061 which was solution heat treated at 560^{o}C in a box furnace for 2 hours to homogenize the grains, then quenched in water at room temperature. The quenched alloy was then cold rolled down to approximately 2 mm thickness; that is about 85% deformation.

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The rolled specimen was thereafter cut into smaller pieces of about 10 mm x 10 mm cross sections and heat treated in a 20 Tesla resistive magnet with 50 mm bore. A furnace of 17 mm bore was inserted into the magnet and temperatures used for the heat treatments were 350^{o}C, 400^{o}C and 450^{o}C for 10, 20, 40 and 60 minutes. The same heat treatments with the same parameters were repeated using the same furnace still inserted into the magnet after the magnet has been turned off. Each test specimen was inserted in the furnace keeping its rolling direction parallel to the direction of the magnetic field.

Texture measurements and microhardness values in the samples were measured using an x-ray diffractometer and microhardness tester respectively. *popLA* (preferred orientation package, Los Alamos) software was used to analyze the texture data and a Fortran program to calculate volume fractions from the crystal orientation data (COD) files. The volume fractions of the β–fiber in the aluminum alloy were used to quantify the texture developed in the alloy. In an FCC metal such as aluminum, the beta-fiber runs from the Cu- {112}<111> orientation through the S {123}<634> orientation to the B- {011}<211> orientation. The volume fraction of the beta-fiber for each sample was obtained by summing those of its B, Cu and S components. The load used for the micrhardness test is 200gf. The average of lengths of the two diagonals of the indent (impression) were measured and used to determine the Vicker's microhardness number (VHN). After putting into consideration the type of Wilson-Tukon Series 200 microhardness tester used for this test, the magnification (500X) of the lens used for the readings, the load (200 gf) and the d values measured, the formula used to calculate the VHN is given by:

$$VHN = \frac{552.54}{d^2}$$

where d = average lengths of the two diagonals of indented area in mm. The texture measurements were repeated three times, while microhardness data were obtained at ten different locations on each specimen; this was done to minimize errors. Average values of the volume fractions and microhardness were used for analysis and reported in this write-up.

3. Results and Discussion

Effect of time and temperature on the texture

As shown in Figures 1, 2 and 3, the volume fraction of the beta fiber for the magnetically heat treated samples slightly increased as the time and temperature for heat treatment changed as compared with those heat treated without magnetic field. These slight increases are more feasible at 400^{o}C and 450^{o}C. These results indicate some enhancement of recrystallization with the application of the 20 T magnetic field. In the paper by [5], aluminum alloy 3103 which is a nonheat treatable aluminum alloy, was found to show a similar increase in recrystallization after heat treatment in a 17 T resistive magnet. This work thus confirms and further proves that recrystallization can be slightly enhanced in both nonheat treatable and heat treatable aluminum alloys. It is worth reporting that the errors in the volume fractions data were between ±0.1 and ±0.3; which could not have made any changes in the reported trends in Figures 1, 2 and 3.

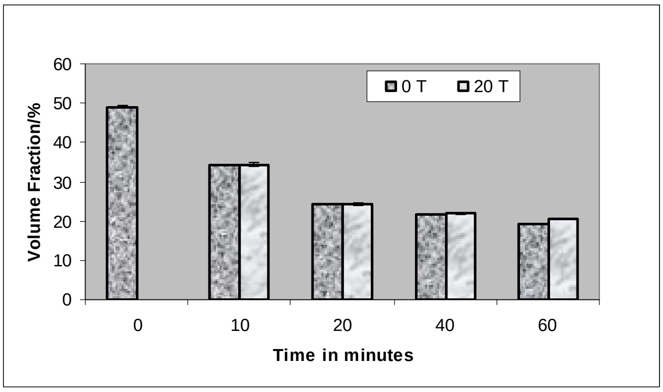

Figure 1: Changes in Beta Fiber Volume Fraction for Samples Heat Treated at 350^{o}C.

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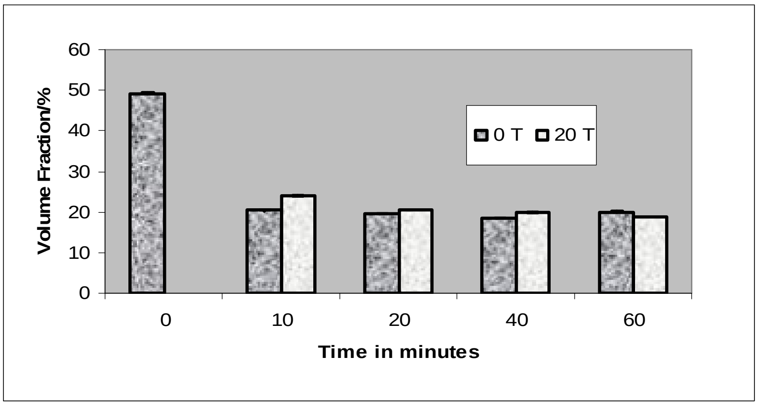

Figure 2: Changes in Beta Fiber Volume Fraction for Samples Heat Treated at 400^{o}C.

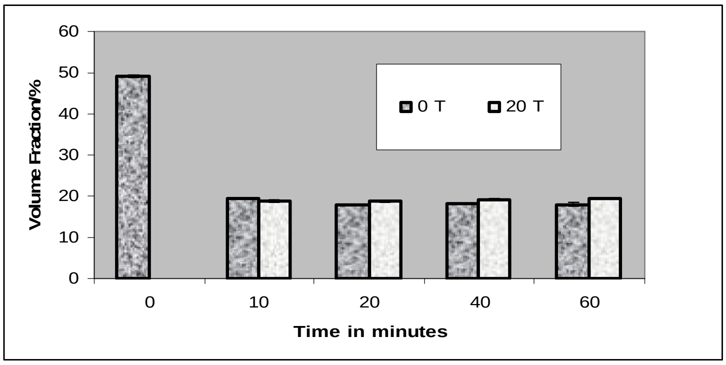

Figure 3: Changes in Beta Fiber Volume Fraction for Samples Heat Treated at 450^{o}C.

Effect of Heat Treatment on Microhardness

Figures 4 and 5 show the variations of the microhardness with respect to changes in time (40 and 60 minutes) and temperature. These figures with the error bars indicated in them show that apart from the initial high value of the microhardness after the rolling deformation, subsequent heat treatment led to reduction in microhardness of the material. Because all the microhardness data obtained for the heat treated samples are within the data range and error bars, it can be concluded that the recrystallization process did not lead to any noticeable changes in microhardness.

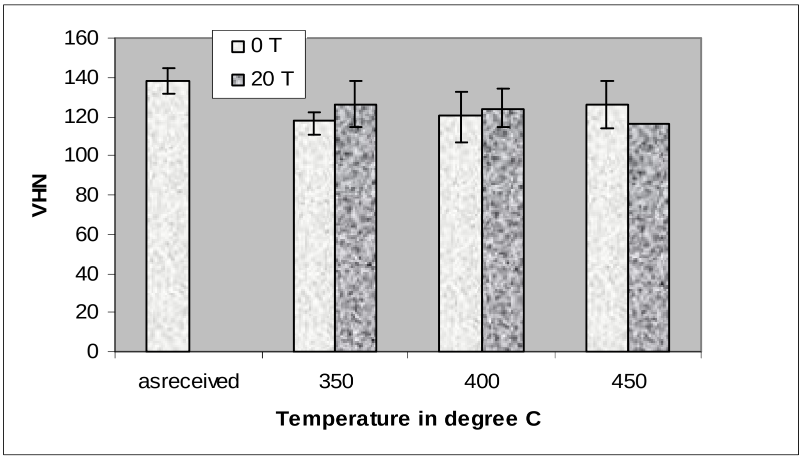

Figure 4: Temperature Effect on Microhardness values for 40 minutes.

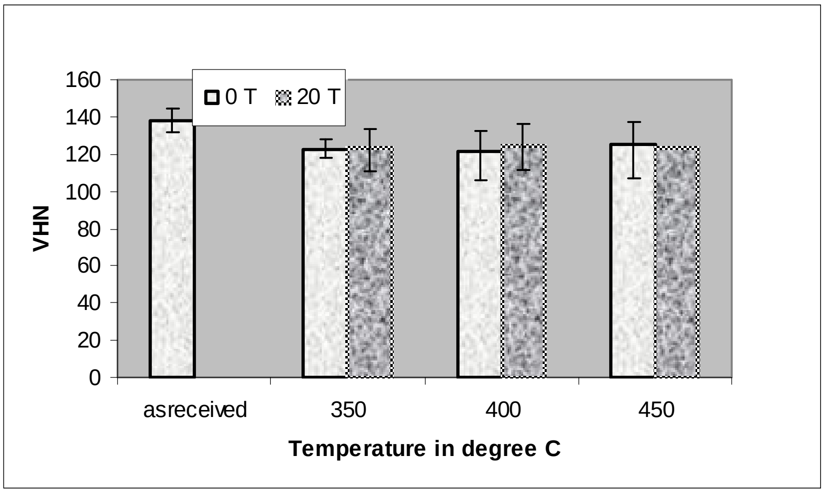

Figure 5: Temperature Effect on Microhardness values for 60 minutes.

4. Conclusion

In summary, it can be concluded that in the process of heat treating aluminum alloy 6061 in a 20 T magnetic field at recrystallization temperatures for periods of time of up to 60 minutes, it has been found that there was a slight enhancement of the recrystallization, when compared to the same heat treated samples in nonmagnetic field (air). No significant changes were found on the microhardness. Also, efforts are being made to look at the effects on the grain boundary misorientation and grain size distribution with the hope of finding a quantitative explanation of the reported changes; this result may be reported elsewhere.

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