THE TEXTURE BEHAVIOR OF Al-Mg-Sc ALLOYS

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Abstract: *Three alloys of Al-Mg with and without scandium are cold worked at different percentage and then annealed. The texture behavior of the alloys is studied by X-ray diffraction technique. The X-ray diffraction analysis is done using a PHILIPS PW1830 diffractometer with Cu-K_α radiation. It is found that the addition of scandium in Al-6Mg alloy influences the development of texture. The cube texture (100)[001] is preferred in the alloy in the initial stages of deformation, whereas beyond 50% deformation, the maximization of (220) intensity indicates that a mixed texture is developed on increasing the percent reduction.*

Keywords: *Al-Mg alloys, Cold working, Annealing, Texture, X-ray diffraction.*

INTRODUCTION

Grains in polycrystalline materials are known to undergo rotation during plastic deformation. As a result, preferred orientation of a group of grains is often exhibited in the deformed material[1]. The deformed material with such a texture can also yield preferred orientation upon annealing. The annealing texture so obtained may or may not be different from the prior deformation texture. The macroscopic properties of materials are significantly influenced by the presence of such textures[2, 3]. The experimental alloys are required to be subjected to complex forming processes in order to render them useable in target applications.

It is, therefore, important to gain some insight into the probable texture formation in the experimental alloys. It has been observed by previous researchers that differently oriented deformed grains, if present, incorporate different amount of strain energy. If there is dispersion of second phase particles in fine forms, the growth of the components with smaller strain energy may be inhibited, thereby allowing the other technologically desirable grain orientations to dominate the microstructure in the annealed samples[4].

Various techniques are available to determine textures in materials[5]. However, limited conclusions regarding the nature of preferred orientation may be drawn from the comparison of calculated line intensities with those obtained from a diffractometer scan. It is obvious that anisotropy in mechanical properties arisen out of annealing texture existing within the material is a decisive factor for deep drawing. The experimental alloy is meant for manufacture of such items, which require quite often a complicated forming process.

In the present work, the experimental Al-Mg-Sc alloys are cold worked and annealed. It appears of worth to understand the preferred orientation generated in the deformed alloys. Also it is interesting to investigate if there is any change in deformation texture upon annealing the alloys as it leads to the formation of fine precipitates of Al_3Sc. This paper describes the analysis of the results of X-ray diffraction with a view to identify the role of scandium in the development of texture in Al-6Mg alloys.

EXPERIMENTAL

Melting was carried out in a resistance heating pot furnace under a suitable flux cover (degasser, borax etc.). Heat input was varied for developing base Aluminum-Magnesium alloys and Aluminum-Magnesium alloys containing scandium at various levels. In the process of preparation of the alloys, the commercially pure aluminum (99.5% purity) was taken as the starting material. Firstly, the aluminum and aluminum-scandium master alloy were melted in a clay-graphite crucible; then magnesium ribbon (99.7% purity) was added by dipping into the molten metal. The final temperature of the melt was always maintained at 780 ± 15^{o}C with the help of an electronic controller. Variation of the scandium percentage was accomplished by its respective additions of master alloy. Casting was done in preheated cast iron metal moulds of 12.5 x 51.0 x 200.0 mm. At different reduction percentages, cold rolling of the alloys in as cast alloys were carried out with a rolling mill. The sample sizes were 9 x 12 x 50 mm and the deformation given was about 1.25 mm per pass. The samples in as cast and cold rolled states were isothermally aged at 300^{o}C for different ageing times ranging from 30 to 240 minutes.

All of the alloys were analyzed by wet chemical and spectrochemical methods simultaneously. The chemical compositions of the alloys are given in Table 1. The X-ray diffraction analyses of the cast, cold rolled and heat treated samples of the alloys were carried out using a PHILIPS PW1830 diffractometer with Cu-K_α radiation. Peak intensity (heights of the peaks in the pattern) for different planes were collected from the individual X-ray diffraction (XRD) pattern and the ratio of the planes was calculated from those data.

Table. 1: Chemical Composition of the Experimental Alloys (wt%)

Alloy	Mg	Sc	Zr	Ti	Cu	Fe	Mn	Si	Al
1	6.10	0.000	0.000	0.001	0.081	0.382	0.155	0.380	Bal
2	5.90	0.200	0.001	0.002	0.081	0.345	0.132	0.360	Bal
3	6.02	0.600	0.001	0.003	0.061	0.293	0.086	0.320	Bal

Remarks: Alloy 1 Al-6 wt% Mg, Alloy 2 Al-6 wt% Mg-0.2 wt% Sc and Alloy 3 Al-6 wt% Mg-0.6 wt% Sc

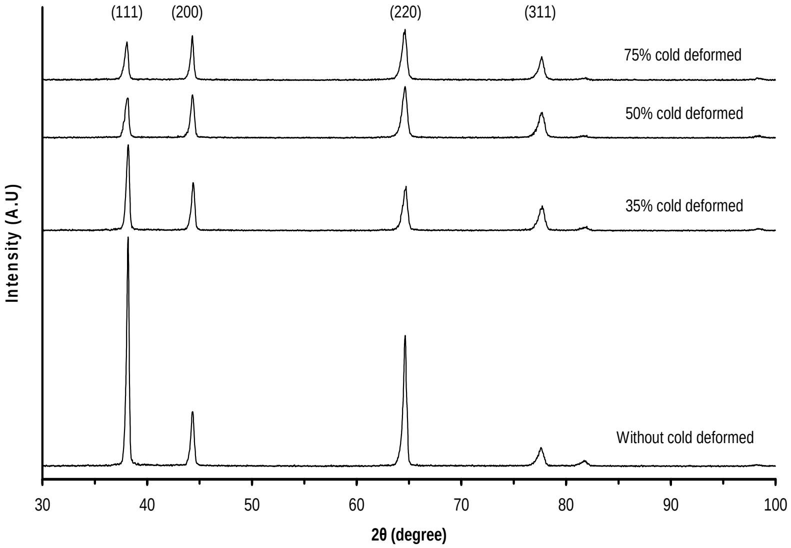

Figure 1: X-ray diffraction (XRD) pattern for different cold deformed alloy 1.

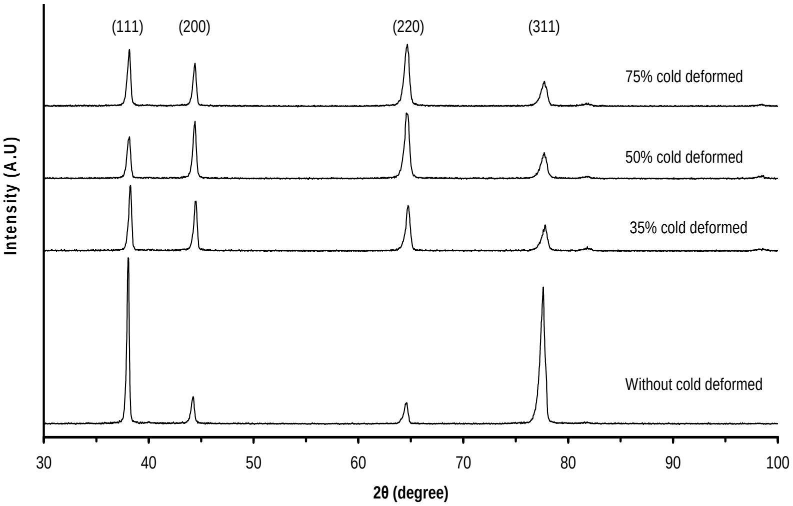

Figure 2: X-ray diffraction (XRD) pattern for different cold deformed alloy 2.

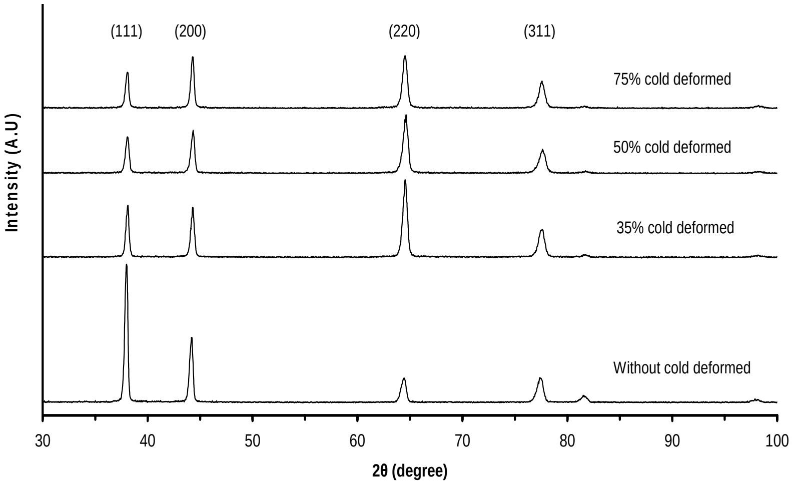

Figure 3: X-ray diffraction (XRD) pattern for different cold deformed alloy 3.

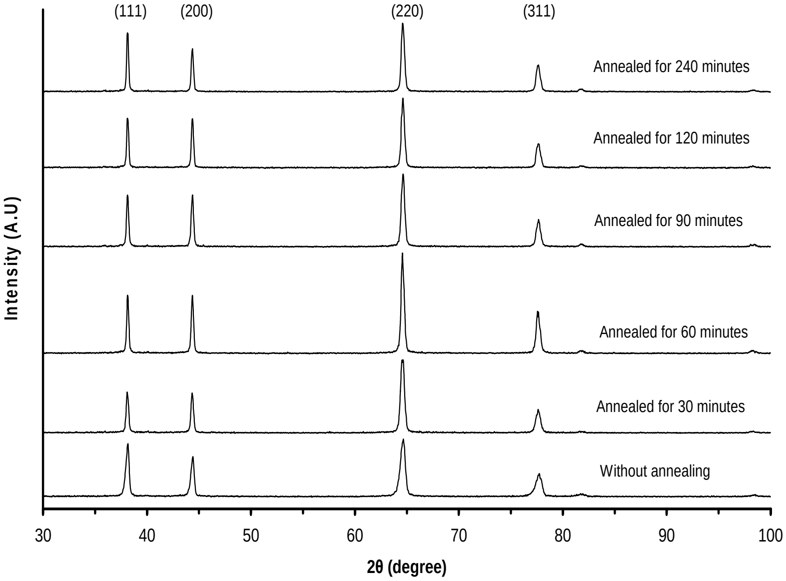

Figure 4: X-ray diffraction (XRD) pattern for 75% cold deformed alloy 2, annealed at 300^{o}C for different time durations.

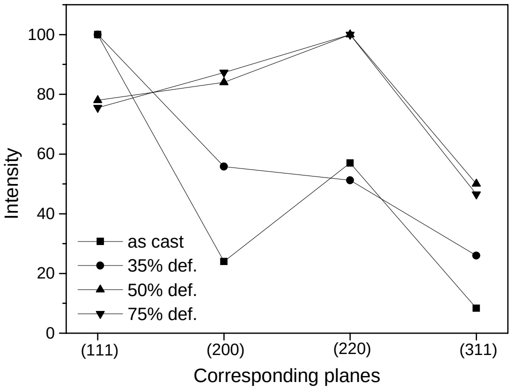

Figure 5: Relative intensity of reflecting planes of alloy 1

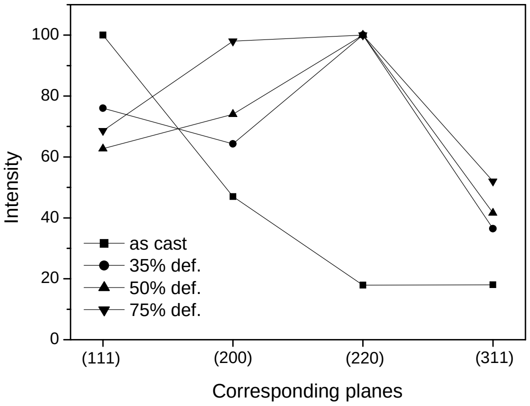

Figure 7: Relative intensity of reflecting planes of alloy 3

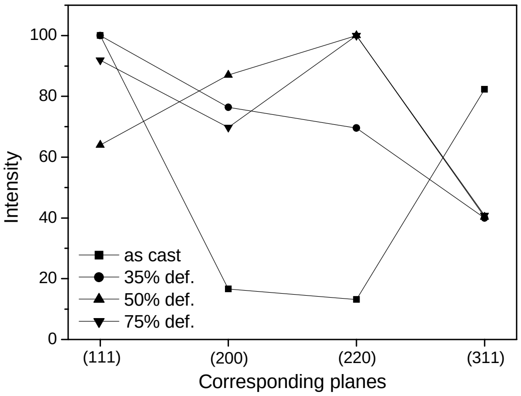

Figure 6: Relative intensity ratio of reflecting planes of alloy 2

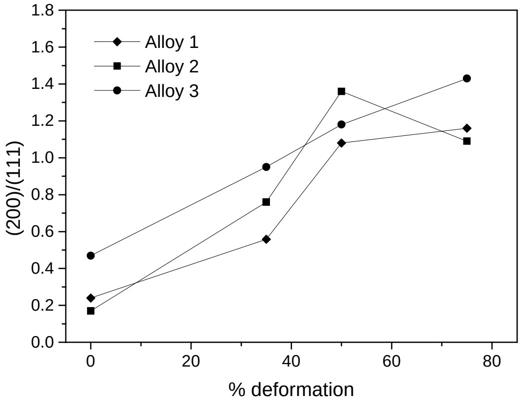

Figure 8: Intensity ratio (200/111) as a function of degree of deformation (%).

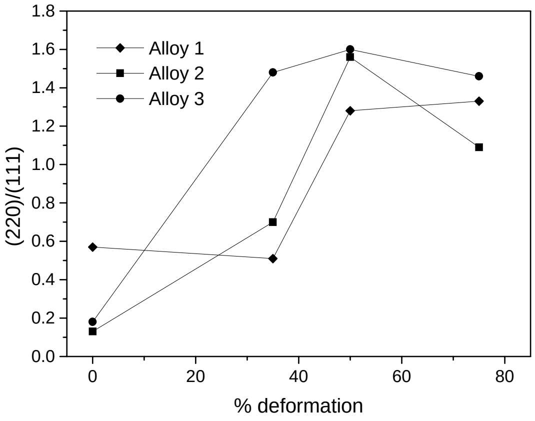

Figure 9: Intensity ratio (220/111) as a function of degree of deformation (%)

RESULTS

The effects of cold deformation of the three alloys on the intensities of the X-ray peaks are shown in Figs. 1-3. Figure 4 shows the effect of annealing time at 300°C on the intensities of X-ray peaks of alloy 2 deformed at 75%. Distribution of relative intensities of major reflecting planes viz. (111), (200), (220) and (311) of the experimental alloys at different deformations is shown in Figs. 5-7. Figure 5 demonstrates that there is definite change in the intensity distribution profile in base alloy at different percentage of deformation. In general, it is observed that the intensities of (200) and (220) reflections are considerably increased with increasing deformation. Intensity of (311) reflection is also increased with increasing deformation. The plane of highest relative intensity, that is (111), records lower values in the deformed samples. It therefore appears that a preferred orientation tends to develop in the deformed alloy 1.

When scandium is added to the base alloy (alloy 2) the intensity distribution profiles in respect of the same four reflecting planes change with different trend (Fig. 6). The plane of maximum intensity (111) records a fall in relative intensity at 50% deformation. However there is some increase at 75% deformation. On the contrary (200) reflection shows increasing intensities up to 50% deformation and then it falls. The intensity of (220) reflection shows a consistent increase with increasing deformation percent and becomes maximized at 50% reduction and onwards. However, the relative intensity of (311) reflection decreases with increasing deformation. In case of alloy 3, it is found from Fig. 7 that (111) reflection is of reduced intensity in the deformed samples. The intensity of (200) reflection increases significantly with deformation of 50% and above. In the deformed samples of alloy 3 the relative intensity of (220) reflection is found maximum at all deformation levels. (311) reflections depict increase in intensity with deformation.

From such results it becomes apparent that, in scandium added alloys there is a greater tendency of increasing values of relative intensities of (220) and (200) reflections in the deformed samples.

It follows from intensity calculation data that in aluminum based alloys the (111) is the plane of maximum relative intensity followed by (200) and then (220) and (311) being quite close. Since a change in the normally expected intensity distribution profile is noted in deformed samples, the intensity ratios of 200/111 and 220/111 are plotted in Fig. 8 and Fig. 9 from the results of diffractograms shown in Figs. 1-4. Figure 8 indicates that deforming the experimental alloys leads to proportional increase in the intensity of (200) planes as compared to (111) planes. This would imply that more number of (200) planes have become parallel to the rolling surface. Thus a preferred orientation of (200) planes is inherent in deformed Al-Mg alloy, though the effect is marginally lessened at a high deformation percent. In 0.2 wt% Sc alloy, the trend of variation in 200/111 intensity ratio is same; but its values are not only increased but also the maximum appears as a lower deformation percent. Thus scandium is found to have aided preferred orientation during deformation. On increasing the percentage of scandium, the intensity ratio continuously increases within the range of deformation percent applied to the samples.

Figure 9 exhibits the change in intensity ratios of reflecting planes 220/111. From the figure, a trend of preferred orientation similar to that of (200) is noted. However scandium has again aided the attainment of higher values of intensity ratio than the base alloy. Also the position of maximum intensity ratio is shifted towards lower deformation percent. Thus both deformation and scandium addition are favorable in securing a (220) preferred orientation in Al-Mg alloy. On comparison with ratio values of corresponding alloys in Fig. 8, it would appear that 220/111 ratios are of higher magnitude than those of 200/111 ratios. Thus rotation of grains in favour of (220) being parallel to the rolling surface is more preferred than (200) planes.

The variations of relative intensities of different reflecting planes with scandium content of alloy are shown in Figs. 10-13. Figure 10 of as cast alloy shows that (111) planes give rise to highest intensity at all scandium levels. In case of (200) reflection, the increase in scandium content beyond 0.2 wt% has led to appreciable increase intensity. (220) plane records a small increase in intensity on increasing the scandium beyond 0.2 wt%. While both (220) and (200) exhibits lowered intensities upon addition of scandium up to 0.2 wt%, the (311) reflecting planes show a significant rise in its intensity during the same composition region.

However, prominent change is noted after the deformation of the alloy. The intensity of (220) planes rises to maximum at 0.6 wt% Sc at the level of 35% deformation. The intensity of (200) and (311) increases up

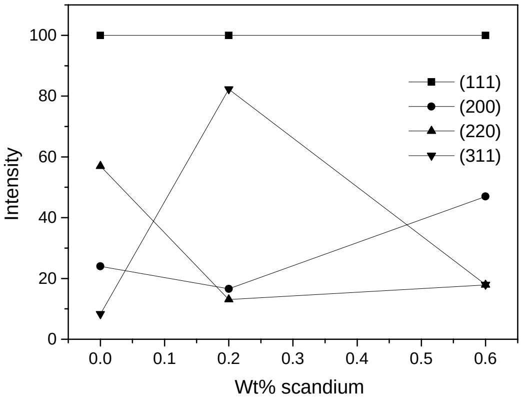

Figure 10: Relative intensity as a function of scandium concentration in cast alloys.

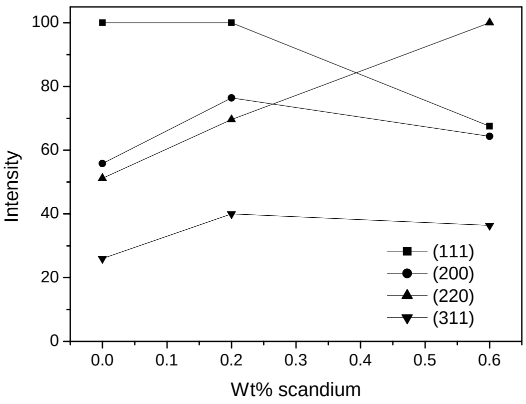

Figure 11: Relative intensity as a function of scandium concentration at 35% deformation.

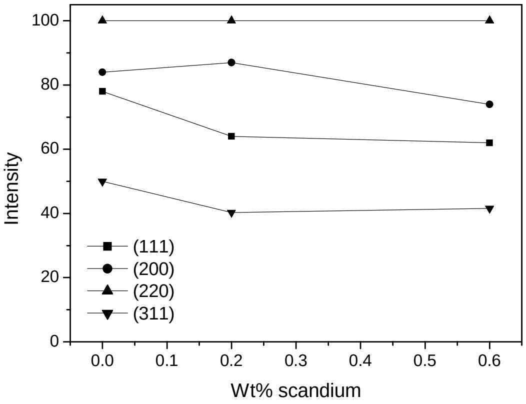

Figure 12: Relative intensity as a function of scandium concentration at 50% deformation.

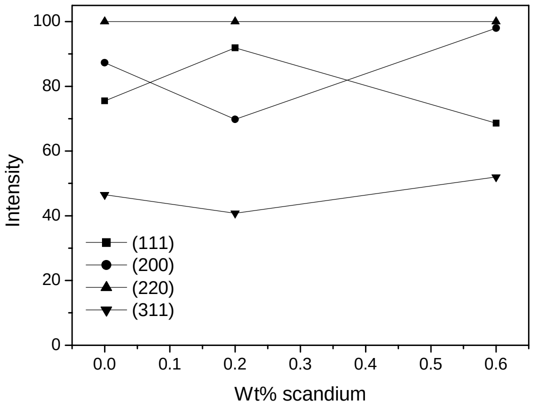

Figure 13: Relative intensity as a function of scandium concentration at 75% deformation.

to 0.2 wt% Sc and then they decrease. A drastic fall in intensity of (111) reflection is also noticed beyond 0.2 wt% Sc. It may be noted that the intensity values of (311) always lie well below the values of (200) and (220).

At 50% deformation level, the (220) reflection remains the maximum for all scandium levels to signify the sufficiency of deformation of this amount in maximizing the (220) reflection. The (200) intensity changes by small amount initially increasing up to 0.2 wt% and then decreasing slightly at 0.6wt% Sc level. Both (111) and (311) records an initial fall in intensities with scandium content and then remains more or less constant. Comparison of intensity values at different scandium contents hints upon the fact that scandium is more sensitive to increasing (220) reflection.

At the level of 75% deformation the (220) reflection remains at maximum intensity at all Sc levels. In this respect its behavior is similar to that of 50% deformation. (200) reflection however shows a different trend. Following a small decrease up to 0.2 wt% Sc it is increased significantly at higher concentration. In contrast there is a good reduction in (111) reflected intensity on increasing scandium from 0.2 to 0.6wt%. (311) reflection behaves similar to (200) with lower intensity values at all compositions. Thus in the case of 75% reduction, the dominating reflecting planes are (220) and (200). The reduction in intensity of (111) reflection is supplemented by the concurrent increase in the intensities of (311) and (200). It follows from these results that in the deformed sample, increasing amount of scandium prefers the attainment (220) orientation, which is untrue for alloys without deformation. With high deformation percent the fraction of (200) planes oriented favorably is also seen to increase.

The variation of reflective intensities for each reflecting planes with percentage of deformation are shown in Figs. 14-16. In the base alloy the (111) reflection maintains its maximum intensity only up to 35% deformation beyond which it falls to a constant value. The (220) planes exhibit an increase in intensity concurrent with the fall on intensity of (111) reflection. At 50% and above it attains maximum intensity. Both (200) and (311) reflection record increasing intensities with increasing deformation percent up to 50% and beyond this, they remain constant (Fig. 14). In case of alloy with 0.2 wt% Sc the maximum intensity of (111) reflection decreases on increasing deformation percent up to 50% and then it increases. The (200) reflection increases with increasing deformation, reaches its maximum at 50% and then reduces to some extent. (220) reflection intensity starts increasing with the onset of deformation and reaches a maximum at 50% deformation. The intensity of (311) reflection decreases with deformation up to 35% and beyond this it remains more or less constant (Fig. 15).

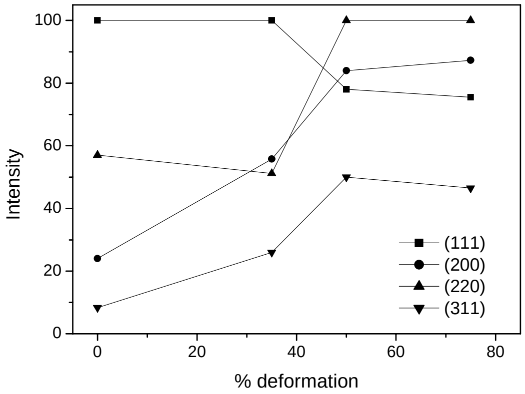

Figure 14: Relative intensity of alloy 1 at various degrees of deformation.

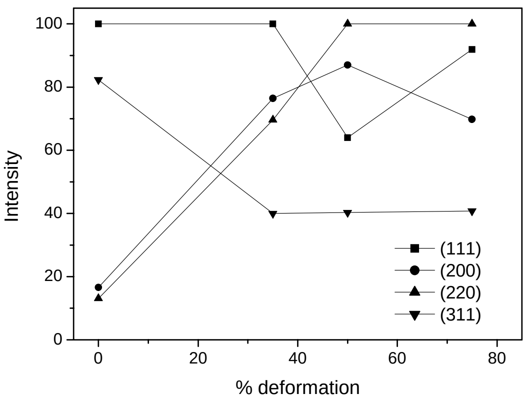

Figure 15: Relative intensity of alloy 2 at various degrees of deformation.

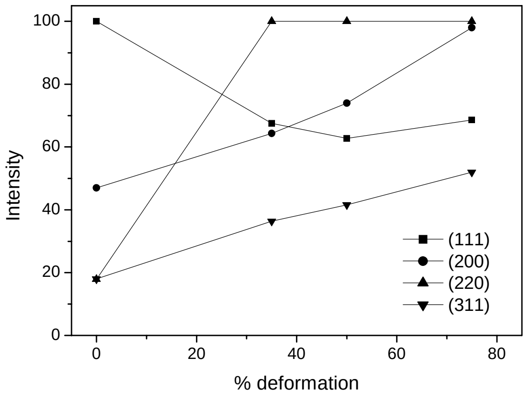

Figure 16: Relative intensity of alloy 3 at various degrees of deformation.

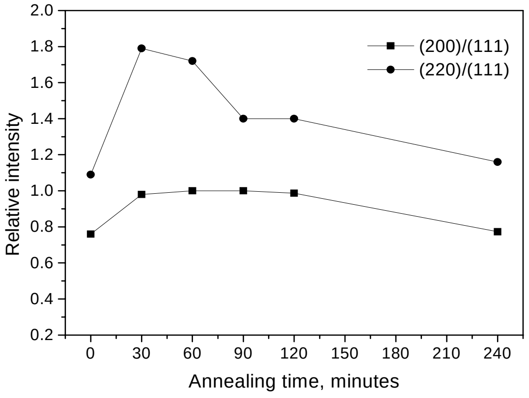

Fig. 17: Relative intensity ratios of 75% cold deformed alloy 2 as function of annealing time (min) at 300^{o}C.

For 0.6 wt% Sc alloy the situation is different. Right from the onset of deformation (220) reflection increases in intensity, reaches its maximum at only 35% deformation and maintains constancy at higher deformation percent. However the intensity of (111) reflection gets reduced immediately after deformation and reaches its minimum at 35%. Beyond 35% it records a marginal rise. Following an initial near constancy value, the intensity of (200) reflection increases significantly beyond 35% and reaches a value almost equal to (220) reflection at 75% deformation. A similar trend with lower intensity value is noted in case of (311) reflection (Fig. 16).

The development of annealing texture is described in Fig. 17. Which shows the variation of 200/111 intensity ratio with annealing time at 300^{o}C. It is found that 200/111 intensity ratio increases at the onset of annealing and after some annealing time (30min) it remains fairly constant. This means that like deformation texture, the annealing of the Al-Mg-Sc alloy also prefers to develop the similar cube texture. The 220/111 intensity ratio increases very steeply just at the onset of annealing. It however decreases quite significantly up to annealing time of 90 min. beyond which it remains more or less constant. But the magnitude of 220/111 remains considerably higher than 200/111 at all annealing times.

DISCUSSION

It is known that the forming process like rolling may lead to preferred orientation of grains. During deformation, the grains in the polycrystalline alloys undergo rotation in a complex way determined by the imposed forces, slip and rotation of the adjoining grains. These often result in a non-random orientation.

From the results of diffractogram it is possible to derive limited conclusion concerning the nature of texture developed during deformation and annealing of specimens. The line intensities of the diffractograms can be obtained accurately in accordance with the calculation of intensity of the diffracted beams from a specimen when the crystals therein are oriented randomly. Radical disagreement between the observed and calculated intensities is an immediate indication of occurrence of texture in the experimental sample. Thus, if in a diffractogram a given reflection is of abnormally high intensity, this would mean that the corresponding planes are preferentially oriented parallel to the sheet surface. Such orientation distributions of grains are termed as deformation texture. Generally rolling of aluminum sheets results in a mixed texture of (100)[001] and (110)[011].

The increment of intensities of (200) and (220) reflection with increasing deformation percent is evidence that the base alloy is amenable to produce a mixed deformation texture. The addition of scandium in Al-6Mg alloy influences development of texture as substantiated by the observed changes in the distribution profile of intensities of particular reflections in the diffractograms. The decrement of intensity of (111) reflection at the expense of increment in intensities of (200) and (220) is a certain indication of development of preferred orientation of the corresponding planes parallel to sheet surface. Increase in (200) reflection up to 50% deformation implies that the cube texture (100)[001] is preferred in the alloy in the initial stages of deformation. Beyond 50% deformation, the maximization of (220) with the associated fall in (200) intensities indicates that a mixed texture (110)[011] and (100)[001] is developed on increasing the percent reduction. Such type of mixed texture is known to be common in a deformed aluminum and its alloys. It is to be pointed out that in an ideal situation of random grain orientation, the relative intensity of (220) in FCC aluminum is about half of (200) and one fourth of (111). Therefore maximization of (220) over (200) and (111) is indicative of the fact that scandium effects the rotation of

(110) type planes in Al-Mg alloys to a much greater extent than (100) set of planes. This would be true even if we understand that addition of Magnesium changes to some extent the relative intensities of the concerned planes due to structure factor effects.

Further, the increase in scandium content enhances the development of preferred orientation with dominance of (220) planes becoming parallel to sheet surface. It is not out of place to mention that development of deformation texture in a grain is influenced by slip and rotation of the adjoining grains. The angles between (100) and (110) planes with the slip plane (111) in FCC crystals are 54^o and 35^o respectively. Therefore for any particular loading situation the rotation of (110) planes towards the slip planes is better envisaged. This may be a reason why the tendency of dominance of (110)[011] in the mixed deformation texture is noted.

Following Fig. 8 one would observe that preferred orientation of (200) is continuously facilitated up to a certain deformation percent. The critical deformation percent at which preferred orientation of (100) planes maximizes is seen to decrease with scandium addition. There is an earlier report where the degree of preferred orientation of (200) planes was found to decrease with deformation percent up to a certain critical value (~ 32%) beyond which it was seen to increase[6]. However in the present case the observation is different in the sense that it is increased up to a certain critical deformation percent (~50%) and then it decreases. The maximum occurs at a lower percent deformation with scandium addition. It appears plausible that with increase in imposed forces (i.e. high deformation percent) the rotation of preferred plane takes place to a greater extent. At high deformation percent restraint from adjoining regions in respect of slip and rotation becomes importantly resistive and hence there is a fall in preferred orientation of (200) planes. But a still higher scandium does not show such maximum within the region of percent deformation.

In case of (220) planes it is found from Fig. 9 that preferred orientation is favoured by increasing deformation percent up to 50% in the base as well as 0.2 wt% Sc alloy. However 0.2 wt% Sc addition has increased the fraction of preferred orientation of (220) planes, as deformation percent increases. Further addition of scandium has not only reduced the critical deformation percent for maximum preferred orientation but also has greatly improved the fraction of planes oriented parallel to sheet surface. On comparison of ratios 220/111 and 200/111 for all deformation percents (Figs. 8 and 9) it is clear that in the experimental alloy system the (110)[011] texture dominates over the cube texture (100)[001] at all deformation percent and this tendency is enhanced by scandium addition.

The observation that scandium up to 0.2 wt% in undeformed state does not influence the intensities of (200) or (220) planes to any appreciable extent is suggestive of the fact that at this level scandium is not able to influence the oriented nucleation to any great extent. Since in an undeformed alloy the question of rotation of grains to develop deformation texture does not arise, any significant deviation from the ideal intensity distribution profile is to be accounted for by the influence of scandium on structure factor. The atomic scattering factor of scandium is higher than aluminum and magnesium and hence on the assumption that scandium atoms are randomly distributed in the alloy matrix there has to be a positive change in structure factor due to the reason that the average atomic scattering factor shall have to be computed for statistically averaged atoms (on the basis of atom fraction of elements). The multiplicity factor of (220) is higher than (200) and (111) set of planes (twelve, six and eight respectively), whereas it is least in (200). Hence the relative enhancement of integrated intensity due to structure factor effect will be greatest in (220) planes. The relatively high magnitude of increase in the intensity of (311) reflection is ascribed to its high multiplicity factor (24) thereby making it more responsive to the increase in structure factor in scandium treated alloy.

However, the contribution of scandium in the enhancement of intensity is relatively small in undeformed alloy. While considering the results of Figs. 11-13 it is found that influence of scandium on intensities of (200) and (220) is significantly high. Such high degree of improvement in deformed alloys cannot be explained simply on the basis of the effect of scandium on the enhancement of structure factor. It is interesting to note that so long as scandium content is less than 0.2 wt% the rise in intensity of (200) reflection is not so significant. This is true for most of the deformation percentages. This means that it is only the imposed forces, which lead to the development of cube texture without any significant contribution from the addition of scandium. At higher percent deformation the maximization of (220) intensity at all scandium level is due to the fact that this particular set of planes is more amenable to preferred orientation by the imposed forces presumably because it makes a lower angle with the slip plane (111) thereby needing less amount of rotation to get themselves aligned preferentially. But at a lower percent deformation increasing scandium content is seen to have preferred (220) plane to become parallel with the sheet surface. This clearly indicates that scandium addition is quite responsive to the development of the dominating (110)[011] texture in the alloy system. This effect of scandium may be attributed to the favorably oriented nucleation of crystals. This is so possible because the precipitates of Al_3Sc normally present in cast Al-6Mg alloy lead the nucleation of grains with non-random orientations that is preferred orientation of particular grains in relation to the probable deformation texture. Because of the close similarity of the crystal structures of Al_3Sc and pure aluminum it may be surmised that the precipitates of Al_3Sc induces the nucleation of primary crystallites onto a particular crystallographic plane and that is how a non-random orientation appears.

Deformation texture with dominating (110)[011] component is inducible in Al-Mg alloy without any scandium addition (Figs. 12-13). This means that the experimental base alloy possesses the inherent tendency of developing a mixed texture of (110)[011] and (100)[001] cube. However due to reasons already stated a higher deformation percent favors the preferred orientation of (110) type planes parallel to the sheet surface[3].

As explained earlier the 0.2 wt% Sc alloy increases the intensity of (200) and (311) reflections due to structure factor effect at low deformation. The small amount of material with constituent cube texture is already present in the material. Upon deformation a prominent cube component is revealed. However with increasing imposed forces the rotation of (220) planes ultimately inhibits the furtherance of the increase in cube component. Thus deformation alone favors the preferred alignment of (220) planes more than any other planes presumably due to the stored elastic energy effect. (110)[011] texture is known to be associated with higher stored elastic energy[6]. It is, therefore, more probable that they remain parallel to rolling surface to take up higher stress. Hence this component supersedes the cube component at high deformation percent without any regard to the presence of scandium. If scandium is present in higher amount, the achievement of higher proportion of (110)[011] constituent texture ought be realized due to nucleation of preferred orientation and hence a maximization of this component is realized only at 35% deformation in 0.6 wt% Sc alloy[7].

The development of cube component as a constituent annealing texture is explainable on the basis of orientated nucleation hypothesis. It is obvious that in a material with aforesaid deformation texture, suitable orientations of nuclei are always present. These nuclei have grown to give rise to the cube components. This is similar to previous observation with aluminum where cold rolled and annealed material developed a mixed texture of constituent components (100)[001] (cubic texture) and (110)[011]. The behavior of the variation of 220/111 intensity ratio is indicative of reorientation of (111) planes with progress in annealing. There is a very steep rise in the intensity ratio just at the onset of the annealing. This signifies that due to high stored strain energy in the deformation texture constituent, there remains huge number of nuclei of preferred orientation for recrystallisation. Owing to high amount of deformation, driving force for recrystallisation is also very high. Therefore a fast recrystallisation takes place with the favorable nuclei producing (110)[011] texture. Thus the growth (110)[011] texture component is more pronounced during annealing the 0.2 wt% Sc bearing alloy. It may be noted the stored energy of this component is larger than the cube component. There is no dispersion of precipitates at lower annealing time. Hence reorientation is possible due to relaxation. At higher annealing time precipitates of Al_3Sc appears and these help to suppress the growth of cube component and also prevent reorientation by resisting movement of grain boundary and sub-boundaries. This is why decrease of 220/111 intensity ratio becomes smaller.

CONCLUSION

The addition of scandium in Al-6Mg alloy influences development of texture. The development of (110)[011] texture is more prevalent in the deformed alloys containing scandium.

The cube texture (100)[001] is preferred in the alloy in the initial stages of deformation, whereas beyond 50% deformation, the maximization of (220) intensity takes place.

The imposed forces lead to the development of cube texture without any significant contribution from the addition of scandium.

A mixed texture of (110)[011] and (100)[001] is developed in the experimental alloy. However scandium and imposed deformation leads to the dominance of (110)[011] in the mixed texture.

Growth of (110)[011] texture is favored during annealing of scandium added alloy.

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