Evolution of texture and its influence on the failure of components in some aluminium alloys

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Abstract. This paper describes the evolution of crystallographic texture in three of the most important high strength aluminium alloys, viz., AA2219, AA7075 and AFNOR7020 in the cold rolled and artificially aged condition. Bulk texture results were obtained by plotting pole figures from X-ray diffraction results followed by Orientation Distribution Function (ODF) analysis and micro-textures were measured using EBSD. The results indicate that the deformation texture components Cu, Bs and S, which were also present in the starting materials, strengthen with increase in amount of deformation. On the other hand, recrystallization texture components Goss and Cube weaken. The Bs component is stronger in the deformation texture. This is attributed to the shear banding. In-service applications indicate that the as-processed AFNOR7020 alloy fails more frequently compared to the other high strength Al alloys used in the aerospace industry. Detailed study of deformation texture revealed that strong Brass (Bs) component could be associated to shear banding, which in turn could explain the frequent failures in AFNOR7020 alloy. The alloying elements in this alloy that could possibly influence the stacking fault energy of the material could be accounted for the strong Bs component in the texture.

1. Introduction
The aerospace industry uses a variety of aluminium alloys in different forms like sheets, forgings, extruded rods, welded components and machined components for launch vehicle and satellite applications. The aluminium alloys used in the aerospace industry are subjected to a variety of processing operations to realize the final product. These processes invariably introduce crystallographic texture in the material which in turn influences the mechanical properties. In this context, it is important to characterize the texture formed, both at macro and micro level.

This paper deals with the evolution of crystallographic texture three most important aerospace aluminium alloys AA2219, AA7075 and AFNOR7020 in a cold rolled and artificially aged condition. In-service applications indicate that the as-processed AFNOR7020 alloy fails more frequently compared to the other high strength Al alloys used in the aerospace industry [9-12]. An attempt has been made to correlate the texture to the failure pattern in the three aluminium alloys used in the aerospace industry.

Texture was determined by pole figure measurement and by calculating the Orientation Distribution Function (ODF). The ODFs were further analyzed for the estimation of the texture fibres and the volume fraction of the texture components. Micro-texture measurements were performed using Electron Back-Scatter Diffraction (EBSD).

2. Experimental

2.1 Starting materials
AA2219 alloy was received in the form of sheets and plates. These alloys are used in the T87 temper, wherein a small amount of cold working (7\%) is given to the material after solution treatment before artificially aging it. The alloy AA7075 was received in the form of a thick plate in the T7351 condition (solution treatment + stabilized), while the alloy AFNOR 7020 was received in the form of sheets in
T651 condition (solution treatment plus artificial aging). The chemical composition and temper designations of the Al alloys used for the study are given in Table 1.

| Alloy Designation | Initial condition | Alloy forms | Zn | Mg | Cu | Cr | Mn | Zr | Fe | Si | Al |
|-------------------|-------------------|-------------|----|----|----|----|----|----|----|----|----|
| AA2219            | T87 (ST*+CW**+AA*** | Plates (7.2 mm) | 0.1 max | 0.02 max | 5.8-6.8 | 0.18 | 0.2-0.4 | 0.1-0.25 | 0.3 max | 0.2 Max | Bal |
| AA7075            | T7351 (ST+SB#) | Plates (15 mm) | 5.1-6.1 | 2.1-2.9 | 1.2-2.0 | 0.2-0.3 | 0.3 max | 0.05 max | 0.5 max | 0.40 Bal |
| AFNOR 7020        | T651 (ST+AA) | Sheets (1.8mm) | 4.0-5.0 | 1.0-1.4 | 0.20 | 0.1-0.15 | 0.05-0.35 | 0.08-0.2 | 0.4 max | 0.35 Bal |

*ST = Solution treated
**CW = Cold worked
***AA = Artificially aged
#SB = Stabilized

2.2 Cold Rolling and Aging
The as-received AA2219 sheets and plates were solutionized at 535±5 °C followed by water quenching and then subjected to multi-pass rolling at room temperature without any intermediate annealing. After the final pass, the samples were artificially aged at 163 °C for 24 hours and air cooled. The as-received AA7075 and AFNOR7020 alloy sheets and plates were solutionized at the respective solutionizing temperatures (465±5 °C) followed by water quenching and then subjected to rolling at room temperature in multiple passes. The alloy AA7075, after cold rolling, was artificially aged at 163 °C for 24 hours and then air cooled. For the AFNOR 7020 alloys, a two step aging cycle was followed. In the first cycle, samples were subjected to 100 °C for 6-8 h followed by air cooling. This was immediately followed by the second step aging at 163 °C for 24 h and air cooling.

2.3 Bulk texture measurements
Bulk texture measurements were carried out using a PANanalytical MRD X-ray texture goniometer with Cu Kα radiation. Four incomplete pole figures, namely, {111}, {200}, {220} and {311} were measured at the mid-thickness sections of the specimens. The measured incomplete pole figure data was used to calculate the orientation distribution function (ODF). The complete pole figures were recalculated from the ODFs. The volume fraction of the individual texture components was determined from the ODFs considering a Gaussian spread of ±10°.

2.4 Electron back-scatter diffraction (EBSD) analysis
EBSD measurements were carried out on the FEI QUANTA FEG-SEM, with TSL data acquisition software. An area 100 µm X 200 µm was scanned with a step size of 0.2 µm. The criterion for identification of low and high angle grain boundaries was set as misorientation angle range 2-15° and 15-180° respectively.

3. Results and discussion

3.1 Bulk texture
The (111) pole figures for the material AA2219 in the starting condition as well as the cold rolled and aged materials is given in Figs. 1(a) and (b). The (111) pole figure of the starting material shows some near cube orientations. The overall texture, however, appears weak. As the material is cold rolled up to 95% thickness reduction, the deformation texture components appear and the overall texture becomes stronger. The (111) pole figures for the starting material AA7075 along with the cold rolled samples are presented in Figs. 1(c) and (d) and that for the AFNOR7020 alloy are given in Figs. 1(e) and (f). It is clear that the texture of both these starting materials has strong Cu and weak Bs and S components.
With increase in rolling deformation up to 70%, the Cu component gradually weakens and the Bs and S texture components become stronger.

The constant $\phi_2 = 0^\circ$, $45^\circ$ and $65^\circ$ sections of the ODFs for the starting material in the solution treated condition and after 70% rolling deformation are shown in Fig.2. The major texture components are observed to be Cu, Bs and S. In the solution treated and naturally aged condition, weak cube component is also observed. On increasing the amount of cold deformation, the cube component disappears. As the amount of cold rolling is increased to 70%, the Cu component gradually weakens from the 50% cold rolled to the 70% cold rolled condition.

Fig. 1: (111) pole figures for (a,b) AA229, (c,d) AFNOR7020, and (e,f) AA7075 alloy samples.

Fig 2. $\phi_2 = 0^\circ$, $45^\circ$ and $65^\circ$ sections of the ODFs for 95% cold rolled (a) AA2219 and for 70% cold rolled (b) AA7075 and (b) AFNOR7020 alloy samples obtained from the mid thickness.
The ODFs also reveal that Bs and S components of texture become stronger, as the amount of cold rolling is increased from 50% to 70%. The texture of the starting material is characterized by discrete [001]∥ND fibre with the intensity maxima at rotated cube position, more precisely at (001)[1\(\overline{3}0\)] location. A sharp increase in the Bs component with increase in rolling deformation is clearly discernable in the ODF sections. The strengths of Cu and S components, however, do not change with cold rolling.

3.2 Microstructural analyses

Image Quality (IQ) maps for cold rolled AA2219 alloy samples are shown in Fig. 3 and that for the AA7075 and AFNOR7020 alloy samples are shown in Fig. 4. It is clear that the materials are highly cold worked. The IQ map also becomes more diffuse and darker, as the amount of cold work in the materials increase. Black spots in the IQ maps are due to cavities where the second phase precipitates were present and have come out during electro-polishing. The microstructure of the AFNOR7020 alloy consists of extensive shear bands predominantly aligned at angles from the rolling direction. The shear banding could be either due to the higher volume fraction of the precipitates and the associated strain fields around them or it could be attributed to reduced stacking fault energy of aluminium due to the alloying elements.

In order to understand the texture development in the three types of alloys, \(\phi_2\) sections of the ODFs for similar cold reduction (70%) were compared. It is clear that AFNOR7020 alloy develops a stronger texture compared to the AA2219 and AA7075 alloys. A comparison of the texture development for the three alloys as a function of cold rolling deformation indicates that all the three deformation texture components, viz., Cu, Bs and S become stronger with increase in cold rolling. Amongst the deformation texture components, the Bs and S components emerge stronger in comparison with the Cu component as the amount of the cold rolling increases [1-6]. Cu component is observed to be weak in AA7075 alloy and relatively stronger in AFNOR7020 alloy samples.

The strongest Bs component is observed in the AFNOR7020 alloy. This is attributed to the shear banding. Shear bands are clearly observed in the cold rolled samples of AFNOR7020 alloy. This is in agreement with Engler [16], who suggested that such a texture transition in aluminium alloys could be due to shear banding. Humphreys and Hatherly [14] have observed shear bands in Al-Zn-Mg alloy cold rolled to 90% similar to the one observed in the AFNOR7020 alloy cold rolled to 70% used in this study. Previous studies on Al-Zn-Mg alloy [15, 16] have indicated that colonies of shear bands are usually several grains thick and the bands in alternate colonies are in opposite senses so that a herringbone pattern develops. This is exactly similar to the shear bands observed in the AFNOR7020 alloy cold rolled to 70% used in this study as given by the IQ maps in Fig. 4. The shear bands marked
adjacent to the thick black line have an orientation of 40˚ to the rolling plane whereas those marked parallel to the dotted black lines have an orientation of 35˚ to the rolling plane. The former is known as ‘Brass type’ shear band while the latter is known as ‘Copper type’ shear band. Any grain boundaries in the colony are crossed without deviation. The above mentioned “copper type” shear bands occur in a variety of materials and their occurrence depends on a number of factors like grain size and the addition of magnesium to aluminium which promotes shear banding.

Usually, Brass type texture is favored in low stacking fault energy (SFE) materials. The presence of Mg and Zn in the Al-Zn-Mg alloy lowers the SFE, hence favoring Bs type of texture [8]. Amongst the alloys studied, AFNOR7020 shows pronounced shear bands compared to AA7075 probably due to the higher Zn: Mg ratio in this alloy. This could explain the more frequent failures in AFNOR7020 alloy as shear bands are known to cut across the thickness of the material and cause catastrophic failures.

4. Conclusions

1. The already present deformation texture components in the starting material, Cu, Bs and S strengthen with increase in rolling deformation, while the recrystallization texture components, Goss and Cube, weaken.
2. The examination of the ODFs reveals that the alloy AFNOR 7020 developed a stronger texture compared to the other two alloys.
3. In AA7075 alloy, the S component is stronger than the other two deformation texture components. No shear bands are observed even at high percentages of rolling in the AA2219 and AA7075 alloy samples.
4. The Bs component is stronger in AFNOR 7020 alloy, which is attributed to shear banding. Cu and Bs type shear bands are observed in the cold rolled samples. This is probably due to the higher Zn: Mg ratio in this alloy.
5. The presence of shear bands could account for the frequent failures in AFNOR7020 alloy as shear bands are known to cut across the thickness of the material and cause catastrophic failures.

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References

[1] Dillamore, I.L. and Roberts, W.T., 1964, *Acta Metall.*, 12, 281
[2] Pospiech, J. and Lücke, K., 1978, *Acta Metall.*, 26, 1709
[3] Suwas, S., Singh, A.K., Rao, K.N. and Singh, T., 2002, *Z. Metallkd.*, 93, 918.
[4] Suwas, S., Singh, A.K., Rao, K.N. and Singh, T., 2002, *Z. Metallkd.*, 93, 928.
[5] Suwas, S., Singh, A.K., Rao, K.N. and Singh, T., 2003, *Z. Metallkd.*, 94, 1313.
[6] Suwas, S., and Singh, A.K., 2003, *Mater. Sci. Engg.*, **356A**, 368
[7] Leffers, T. and Ray, R.K., 2009, *Prog. Mater. Sci.*, **54**, 351
[8] Smallman, R.E. and Green, D., 1964, *Acta Metall.*, **12**, 145
[9] Jha, A.K., Ramesh Narayanan P., Sreekumar. K. and Sinha, P.P., 2010, *Engg. Failure Anlys.*, **17**, 562
[10] Jha, A.K., Murty, S.V.S.N and Jacob E., 2002, *Engg. Failure Anlys.*, **9**, 709
[11] Jha, A.K., Naga Sirisha G., Ramesh Narayanan P. and Sreekumar. K., 2009, *J. Failure Anlys. Prevn.*, **9**, 414
[12] Jha, A.K., Ramesh Narayanan, P., Diwakar, V., Sree Kumar, K., and Mittal, M.C., 2004, *Engg. Failure Anlys.* **11**, 463
[13] Ramesh Narayanan, P., Suwas, S., Sree Kumar, K., Sinha, P.P., and Ranganathan, S., 2012, *Mater. Sci. Forum* **702-703**, 315
[14] Humpherys, F.J., and Hatherly, M., 2004, *Recrystallization and Related Annealing Phenomena*, Second Edition, (Elsevier, U.K.)
[15] Duckham, A., Knutsen, R.D., and Engler, O., 2001, *Acta Mater.*, **49**, 2739
[16] Engler, O., 2000, *Acta Mater.*, **48**, 4827