

EBSD texture analysis of an AlCuMg alloy for different solidification rates

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ABSTRACT

The 3xx series aluminium alloys are widely used for automotive applications. However, increments in engine power density result in higher alloy mechanical properties requirements for components such as cylinder heads. These alloys should perform better at high temperatures (>200 °C). A good alternative to the traditional Al-Si alloys are the Al-Cu based alloys. However, hot tear tendency is a big obstacle for the widespread use of this family of alloys [1]. The present work focus on determine the relationship between crack occurrence and grain orientation, as a result of the solidification rate. Grain refinement elements such as Ti and Zn are added to the alloy to reduce hot tearing tendency. Two different variants of AlCuMg alloy are evaluated at different solidification rates.

Keywords: hot tearing, texture, aluminium, grain refinement

INTRODUCTION

Environmental regulation as well as fuel economy has driven the automotive industry towards smaller and more efficient engines. The first step towards these goals has been the migration from ferrous alloys to aluminium for the production of cylinder heads and cylinder blocks for internal combustion engines (ICE). More than 95% of the worldwide production of cylinder heads for passenger vehicles is fabricated using aluminium alloys, mostly Al-Si system. Also almost 50% of Cylinder blocks are made out of aluminium. In the past few years hybridization is the preferred alternative to reduce harmful emissions to the atmosphere. A hybrid engine is the combination of an ICE and electric motors [2].

A result of using electric motors is the reduction in size of the ICE. OEMs demand the same power out of the ICE engines, leading to higher power densities. This translates to the cylinder head and cylinder block producer into developing higher resistant alloys. Higher engine output requires alloys

with higher resistance at high temperatures. Currently the best performance (cost vs mechanical properties) for gasoline applications is achieved by the alloy AlSi7Cu3 (319-type): UTS= 195 MPa and YS= 175 MPa. For Diesel engines the preferred alloy is the A356+0.5Cu (developed by Nemak), where the mechanical properties at 200 °C are UTS= 160 MPa; YS= 140 MPa; Elong=9%.

Other main factor to increase power and engine efficiency is thermal conductivity. Higher thermal conductivity allows the engine designer to pursue more power out of the ICE, since the resultant higher temperature can be more efficiently controlled by a material with higher thermal conductivity. Heat extraction is done by the engine coolant systems. In this regard the 356-type alloys are the best alternatives (at 200 °C): 179 W/mK against 147 W/mK.

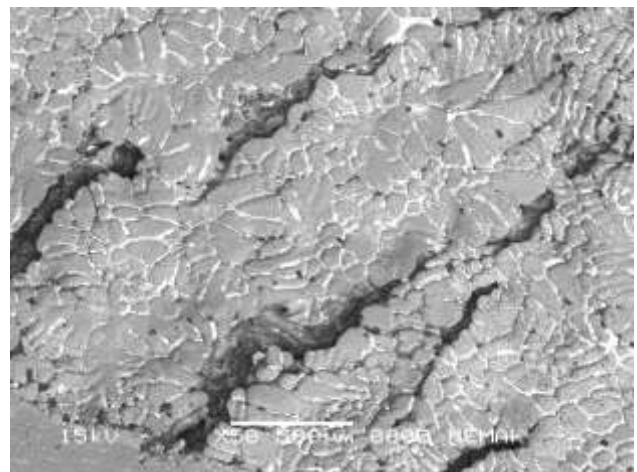


Figure. 1: Hot tear due to contraction in a Al-Cu alloy.

It is clear that the Cu containing alloy (319) has superior mechanical properties at high temperature, however the 356 alloys have better thermal conductivities. Nemak has developed an alloy of the 2xx series (Al-Cu) where both, mechanical properties at high temperatures and high thermal conductivities are achieved [3-5]. The alloy AlCu5Mg achieves mechanical properties at 200 °C in the order of UTS= 260 MPa; YS= 230 MPa and

Elong=11%. Thermal conductivity at 200 °C is 175 W/m²K.

A shortcoming of this type of alloys is hot cracking due to contraction during the solidification process. Although the casting process has been developed for rapid solidification rates by adding grain refiners, like in the Gravity in Semi Permanent Mould process (GSPM), there is still more to be known in order to improve this alloy performance for slower solidification rates [4-6]. Grain size and orientation have a great influence on the hot tearing tendency of this alloy.

Several versions of the Al-Cu system were developed by Nematik pursuing high mechanical properties with low hot crack tendency. The two best alternatives are evaluated in this work.

This paper presents the results of a study conducted at the Universidad Politecnica de Cataluña where solidification rates are correlated to grain orientation for two different alternatives of the Al-Cu alloy.

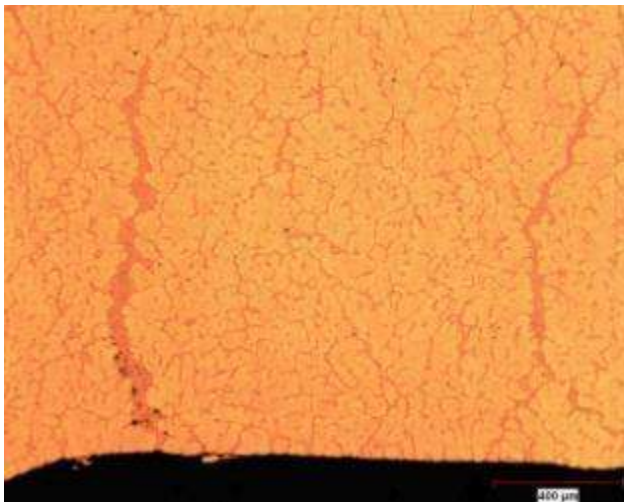


Figure 2: Self-healing effect of prone hot tears areas in a cylinder head.



Figure 3: Hot tear located at a combustion chamber of a cylinder head

TEXTURE

The distribution of crystallographic orientations of a polycrystalline material is called texture. When these

orientations are randomly distributed it is said that no texture is observed. In the case of the Al-Cu alloys studied in this work, which exhibit cellular solidification, their orientation might be an indicator of the properties or the propensity of a defect to take place during the solidification process.

Texture can be determined by Electron Backscattered Diffraction (EBSD) techniques in Scanning Electron Microscopy (SEM). Several textures are commonly found in materials such as Cube (001)[100]; Brass (110)[-112]; Copper (112)[11-1]; Goss (110), [001] and S (123)[63-4].

Pole Figures are used to describe polycrystalline texture components. These indicate the preferential planes and directions of the material. It is necessary to establish the reference plane systems as it is presented in Figure 4.

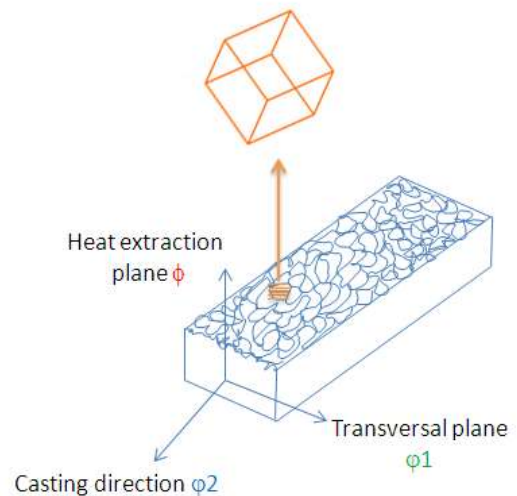


Figure 4: Reference system of sample and grain.

Once the preferential planes and directions are defined, the Euler angles are obtained (Figure 5).

Euler spaces are constructed by rotating the ϕ_1 ϕ_2 angles between 0° and 90°. See Figure 6.

Results are described in the poles figures. These are produced by an analysis of stereographic projection referenced to the higher density planes for a FCC material {111}, <110> as shown in figure 7.

EXPERIMENTAL PROCEDURE

Samples were obtained from actual cylinder heads and blocks produced using the both alloys. These were cut out and polished using standard metallographic techniques. Polishing was performed using sand paper with colloidal silica in several steps

(9, 3 1 and 0.25 μm) silica. Then electrolytic polishing was performed in a Lectroplo-S[®] electro-polisher using 6V for 6 seconds. Chemical composition of the alloys is shown in Table 1. The set of experiments is shown in Table 2.

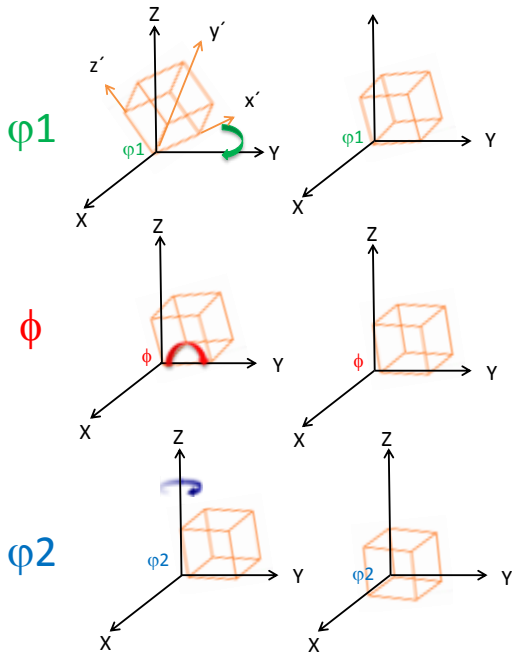
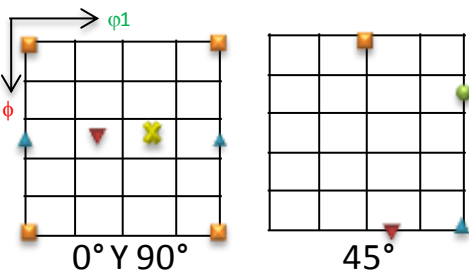


Figure 5 Euler angles definition.



- Cubo {100} <001>
- ▼ Brass {101} <121>
- ▲ Goss {101} <010>
- Copper {112} <111>
- ▲ Goss {101} <101>
- ✕ S {123} <634>

Figure 6 Euler spaces ϕ_1 ϕ_2 for the Orientation Distribution Function (ODF)

Table 1. Alloy 1 chemical composition (wt%).

	Cu	Mg	Mn	Si	Fe	Ti	Zr
Alloy A	4.2-5.0	0.2-0.35	0.2-0.5	0.05 max	0.1 max	0.15-0.30	-
Alloy B	7.0-8.0	0.1 max	0.4-0.6	0.1 max	0.2 max	0.1 max	0.2-0.4

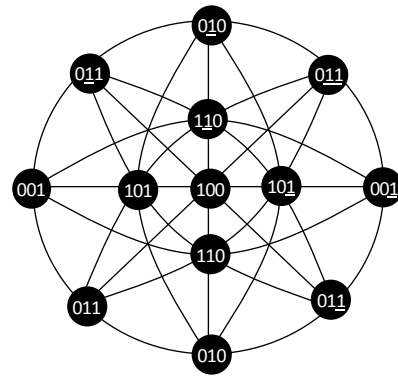


Figure 7 Slip system for the FCC {111} <110>

Texture was measured in a Scanning Electron Microscope (SEM) JEOL JMS-7001F field emission, using Electron Backscattered Detector (EBSD). The software used for texture data analysis is Channel 5 (Oxford Instruments HKL). Acceleration voltage 20 KV and steps of 5-8 μm . Measuring field was 15X15X15 μm^3 [6].

Table 2. Alloy 1 chemical composition (wt%).

Sample ID	Alloy	Grain size (mm)	Hot tear	Grain refiner	Solidification rate ($^{\circ}\text{C}/\text{seg}$)
B1	A	70	Yes	Ti	3
B2	A	150	No	Ti	0.1
B3	A	120	Yes	Ti	0.3
W2+Ti	A	70	No	Ti	0.13
W4+Ti	A	120	No	Ti	1
W5+Ti	A	150	No	Ti	3
W2	A	70	No	--	0.13
W4	A	120	No	--	1
W5	A	150	No	--	3
AA+Ti	A	90	Yes	Ti	3
AB	A	90	Yes	Ti	3
L1	B	301	Yes	Zr	3
L2	B	281	Yes	Zr	1

RESULTS AND DISCUSSION

Grain orientation is shown in figures 8 to 11. For alloy A no preferential grain orientation is observed for any of the solidification rates. For rapid solidification rates (3 $^{\circ}\text{C}/\text{sec}$) where mechanical properties and thermal conductivity are maximum grains are randomly oriented. The same is true for alloy B. However based on previous work performed by A Rodriguez et al alloy B is far more sensitive to hot crack due to contraction [8].

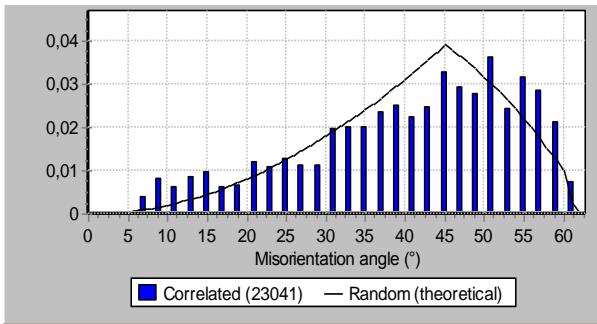
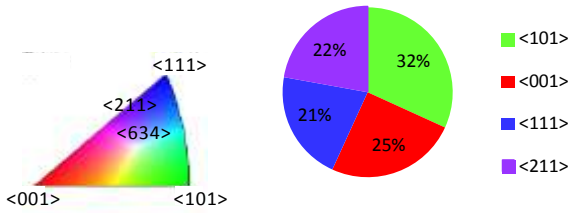
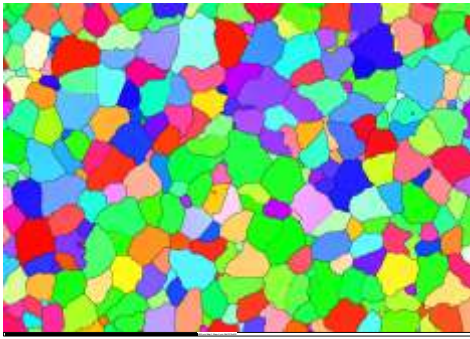


Figure 8: Preferential Orientation of a sample of Alloy A for a solidification rate of 3 °C/sec.

In figure 9 a sample with a crack due to contraction is observed (continuous path highlighted in green). This sample was analyzed to determine if grains surrounding the defect presented some preferential orientation. It is clear that no correlation exists between grain orientation and the fracture.

Also for alloy B no grain orientation is observed. It is evident that grain size is independent of orientation. Since these samples are castings, grain orientation for more traditional alloys such as Al-Si where grains formed by dendrites are heavily influenced by heat extraction. For high solidification rates (above 3 °C/sec) columnar grains are observed. These are “broken” by additions of grain refiners as the ones used in this work (Ti and Zn) [6].

Unlike Al-Cu systems, grain size does not have a significant effect on the mechanical properties of the Al-Si system.

Pole figures (figure 13) are stereographic representations of the preferential slipping planes of

the FCC system. This technique is more efficient for materials that were subject to mechanical deformation. In the case of the castings and for the cellular nature of the alloy it was expected to shed light on the influence or lack of thereof on the behavior of the Al-Cu systems.

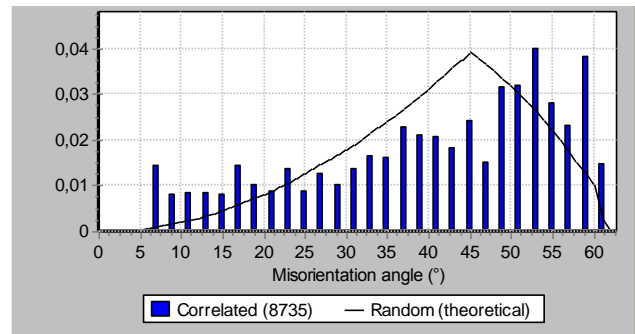
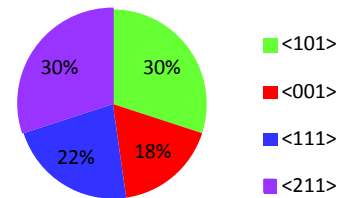
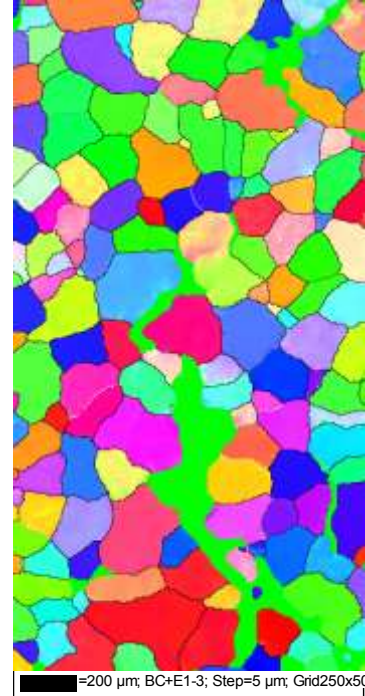


Figure 9: Preferential Orientation of a sample of Alloy A for a solidification rate of 0.3 °C/sec.

Histograms show in figures 8 to 10 confirm the randomness of all analyzed samples. Misorientation angle is the degree of mismatch of the grains in the sample. All samples show a high degree of misorientation [10].

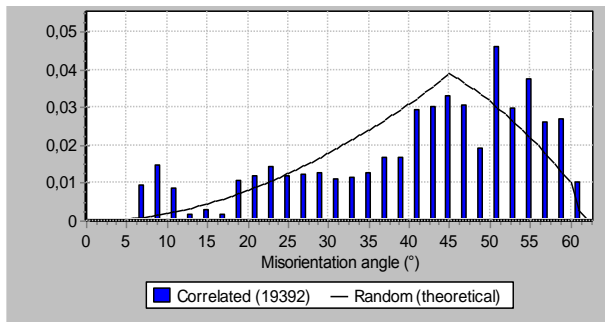
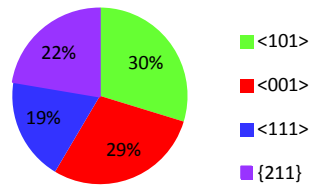
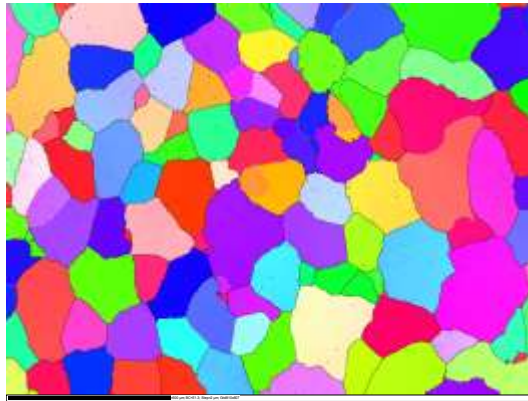


Fig. 10: Preferential Orientation of a sample of Alloy A for a solidification rate of 0.1 °C/sec

The premise that grain orientation existed in a Al-Cu alloy due to cooling rate seems to be unsubstantiated. This finding is very valuable. Grain size which determines physical properties such as thermal conductivity and mechanical properties, must be controlled by chemical means, rather than designing the process looking for specific cooling rates.

Hot tearing is due to the wide freezing range of the Al-Cu alloy and the internal loading arising from the solidification process itself. Grains adjacent to hot tears do not present any orientation, not even in the heat extraction direction.

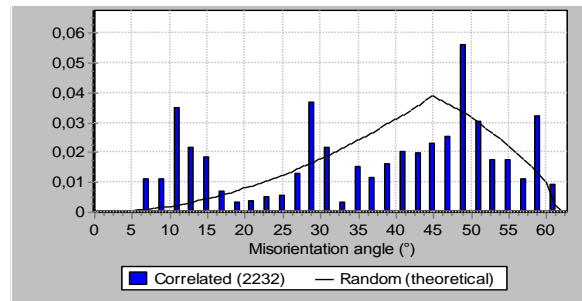
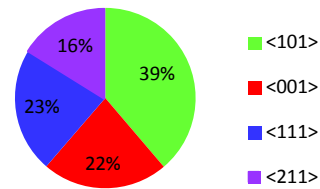
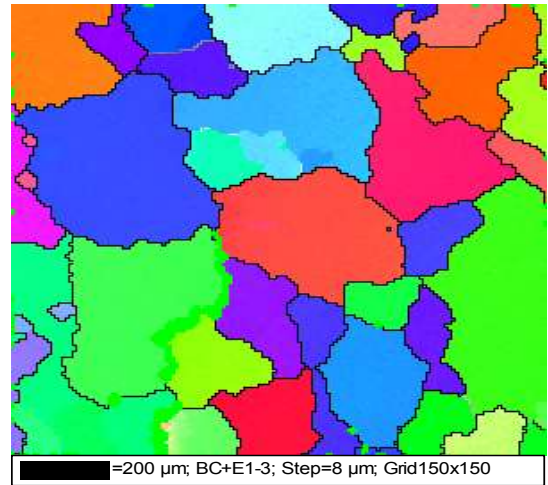


Fig. 11: Preferential Orientation of a sample of Alloy B for a solidification rate of 3.0 °C/sec

In the alloy A the orientation distribution function (ODF) the predominant components are Goss ({110}, <001>) and S ({123}, <634>). This is shown in figures 8 to 11.

CONCLUSIONS

This work shows that there is no correlation between grain orientation and solidification rate for the Al-Cu alloys analyzed in this work. The original hypothesis were additional to grain size, orientation had a major role on hot tear tendency is discarded.

The degree of randomness found in all the samples regardless of the alloy shows that solidification rate does not has an influence on grains or the cracks due to contraction.

Both the inverse pole figures and orientation distribution function (ODF) show a slight incline towards the textures $\langle 101 \rangle$ y $\langle 634 \rangle$. This is evidence of the random nature of the texture of the material.

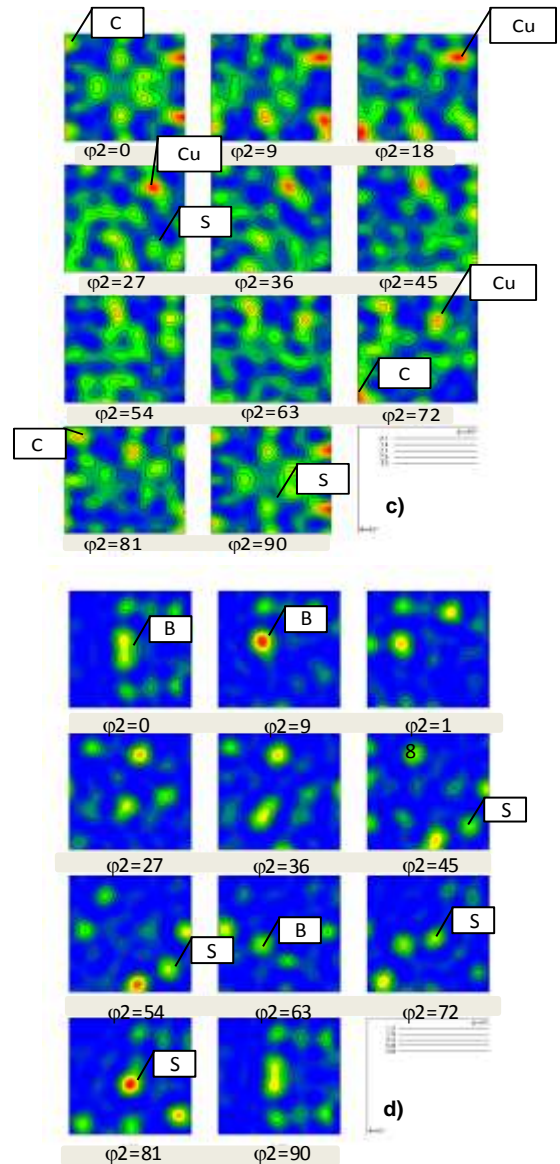
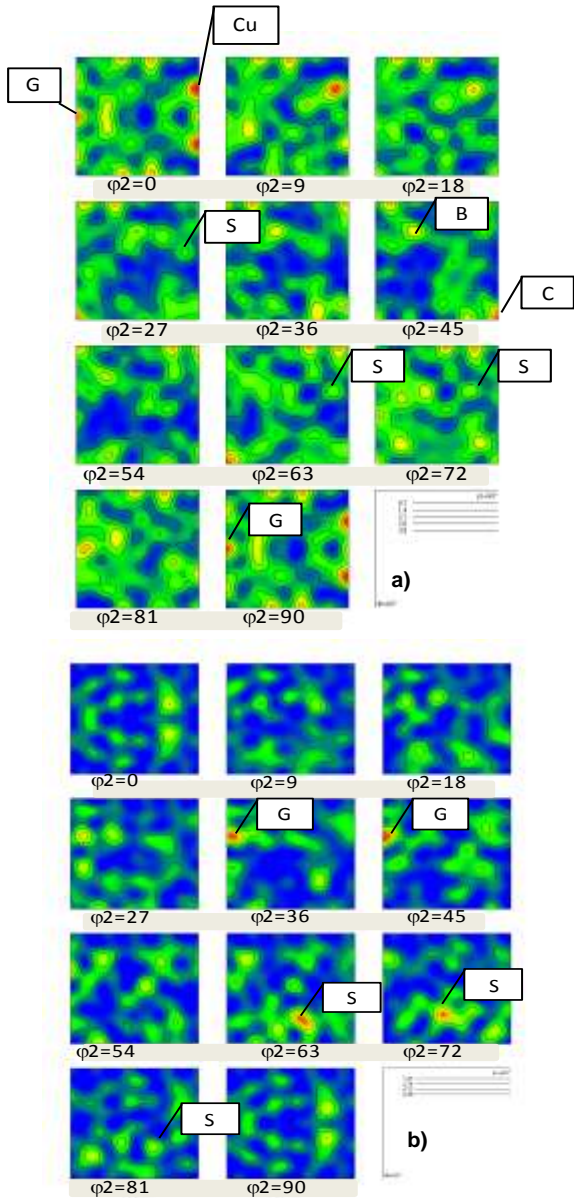


Fig. 12 $\varphi_2 = \text{constant}$ ODF section of experimental textures for a) 3, b) 0.1 and c) 0.3 °C/sec for alloy A, d) 3°C/sec for alloy B

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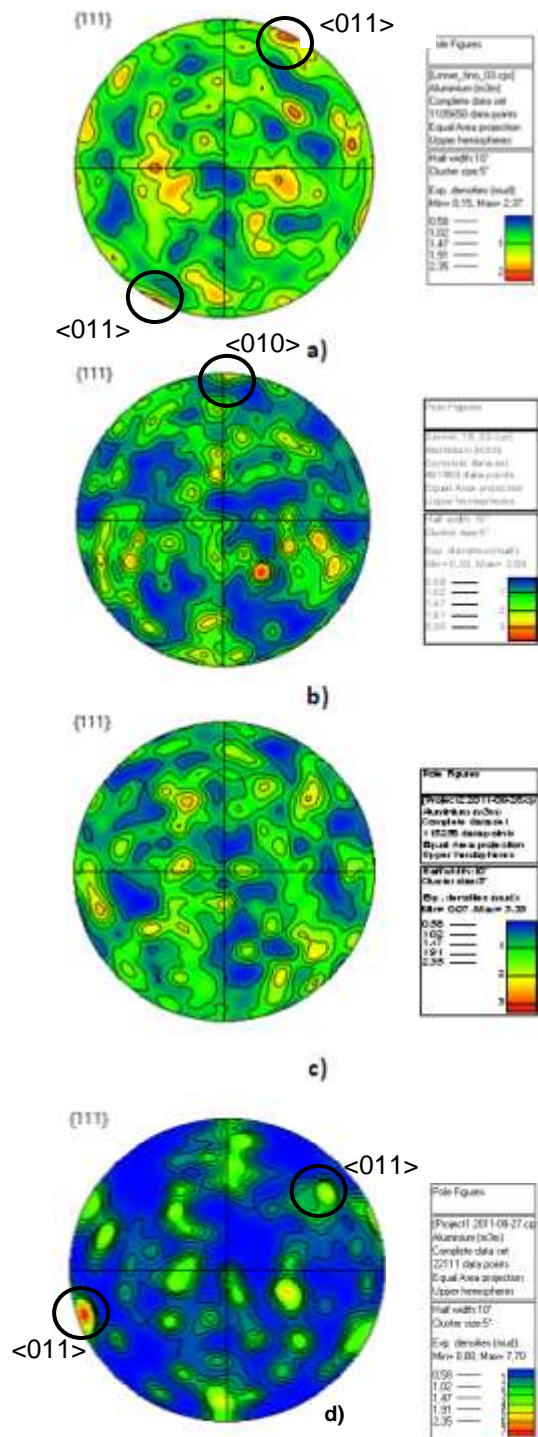


Fig. 13 Pole figures for a) 3, b) 0.1 and c) 0.3 °C/sec for alloy A, d) 3°C/sec for alloy B

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