PTC 2003 TC

Separata

SPRAY FORMED HYPEREUTECTIC ALUMINIUM ALLOYS - CRYSTALLOGRAPHIC ORIENTATION

H. de O. Santos, M. M. Serna, N. B. de Lima, I. Costa, J. L. Rossi
Av. Lineu Prestes, 2242, Cidade Universitária, CEP 05508-000
Instituto de Pesquisas Energéticas e Nucleares, IPEN/CNEN-SP
hamilta@ipen.br

Abstract

Hypereutectic aluminium-silicon alloys have been wide accepted in the automotive, electric and aerospace industries. This is due to the high strength-weight ratio, to the low coefficient of thermal expansion and the good resistance to the wear and tear. The use of conventional metallurgy for production of these alloys is limited by a narrow range of possible compositions. This can be attributed to the formation and presence of coarse primary silicon particles, because of the slow cooling rate associated to conventional metallurgy. The use of spray forming can overcome this obstacle. The present work was undertaken to analyse the texture by X-ray diffraction techniques of three spray formed aluminium-silicon alloys. One experimental alloy (alloy 1) was hot-rolled and cold-rolled. The other two alloys are in commercial use, alloys 2 and 3. The results from the Laue camera showed texture just in the axial direction of alloy 3. The pole figures also indicated the presence of deformation texture just for alloy 3.

Keywords: spray forming, cylinder liners, Al-Si hypereutectic alloys.

Introduction

Some Al-Si alloys have characteristics such as good wear resistance, low coefficient of thermal expansion combined with a high strength to weight ratio. Due to such properties, these alloys have been used in several applications from the automotive to aerospace and power industries [1-4]. The outstanding wear resistance is due to the high volumetric fraction of the silicon phase and intermetallics. Applications of the Al-Si alloys in the automotive industry, include engine blocks and parts of engines, particularly, cylinder liners. The main

9474

advantages of the use of these alloys are weight reduction, low fuel consumption and less emission of pollutants [1,2].

The use of engine blocks made of hypereutectic aluminium alloys has been considered by many world manufacturers. Blocks of the Al17Si4CuMg alloy are very difficult to cast. They have been produced by expensive processes, such as chill mould casting at low pressure. This process was necessary to obtain refined silicon particles used in the contact area between the cylinder and the piston rings. The conventional die cast Al9Si3Cu alloy has been preferred due to economic reasons. However, the tribological properties of the late alloy do not favour its use in the combustion chamber area. The accepted solution is to use cylinder liners made of cast irons; cast or spray formed high silicon aluminium alloys, composites or coatings in this area [2].

Hypereutectic alloys can be produced by ingot metallurgy [1,2] or by rapid solidification processes, such as melt spinning [4], atomisation [4,5] and spray forming [4-9]. The use of ingot metallurgy for the production of these alloys is limited by the range of possible chemical compositions. That can be attributed to the formation of eutectic phases and coarse primary silicon phase, due to the low cooling rates associated to the ingot metallurgy. The distribution of coarse silicon particles in the alloy leads to low ductility and limited workability of the hypereutectic Al-Si alloys. Many of the problems associated with ingot metallurgy can be overcome by spray forming techniques. The main advantage of the use of the spray forming process is the significant modification of size, morphology and distribution of the primary silicon phase in the matrix, comparatively to the conventional process. The refinement of the primary silicon particles can be achieved by spray forming hypereutectic Al-Si alloys or co-depositing fine Si particles.

The technology for producing cylinder liners by casting iron and spray forming aluminium alloys is well established. The use of aluminium alloys for such application was made possible by the admixture of large amounts of alloying elements that precipitate as hard second phase particles. The use of such alloys with hard particles is viable if these particles are finely dispersed, allowing further mechanical working.

Any aggregate characterised by a condition in which the distribution of crystal orientations is non-random is said to have a preferred orientation, or texture. Preferred orientation is a very common condition. Among metals and alloys, it is most evident in mechanical worked products. It is due to the tendency of the grains in a polycrystalline aggregate to rotate during plastic deformation; each grain undergoes slip and rotation in a complex way that is determined by the imposed forces and by the slip and rotation of adjoining grains. In fact, preferred orientation is generally the rule, not the exception, and the preparation of an aggregate with completely random crystal orientation is a difficult task [10].

The pure aluminium is highly strainable and it induces a particularised texture, common to the material and to the used forming process. However, it was noticed in previous work that larger amounts of silicon added to the aluminium produce a natural barrier that it prevents the texture formation [11]. In order to know the maximum limit of silicon addition that impedes the texture formation in the aluminium matrix is necessary to optimise materials, decreasing or intensifying a certain property already existent. In this work is undertaken a crystallographic orientation study, texture evaluated by x-ray diffraction, of two spray formed hypereutectic aluminium-silicon alloys taken from commercial cylinder liners and an experimental alloy.

Experimental

The materials used in this work were produced by spray forming, an experimental alloy and alloys already in commercial use as cylinder liners. These materials are here denominated as alloy 1 (experimental alloy) and alloys 2 and 3 (which were removed from cylinder liners supplied by two different manufacturers). The alloy 1 was hot and cold rolled to simulate mechanical work in order to allow the analysis of its behaviour regarding texture formation. The hot rolling was performed at 450 °C in 3 % reduction step until to 72 % total reduction in thickness. The cold rolling was accomplished in 5 % reductions step until a total reduction in thickness of 70 % was attained.

The alloys 2 and 3 probably undergone mechanical working such as hot extrusion followed by swaging, typically used during the forming of billets into tubes used as cylinder liners. However, there is no information available of how and under which conditions these mechanical works were performed.

Table 1 displays the chemical composition of the three spray formed hypereutectic aluminium-silicon alloys. The chemical compositions were obtained by atomic absorption spectrophotometry and Si gravimetry.

After a suitable metalographic polishing, the specimens taken from the three materials were etched in a solution of 60 mL of deionised water, 10 g of NaOH and 5g of $K_3Fe(CN)_6$. The specimens were analysed by optical microscopy (MO) and scanning electron microscopy (SEM).

Insert table 1

The x-ray diffraction analyses were accomplished in two diffractometers; one fitted with a back-reflection Laue camera. It was used a Cu tube and Kα radiation. The exposure time in the Laue camera was 3 h, 7 h and 5 h, for alloy 1, 2 and 3, respectively. The working distance between the film and the specimen was of 50 mm, for a power of 40 kW / 30 mA. The other used diffractometer was fitted with a scintillation detector, molybdenum radiation was used at a power of 40 kW / 20 mA. The pole figures were accomplished by the Schulz reflection method and step scanning of 5° for α and ß angles. The specimens taken from the cylinder liners were analysed in the radial direction, tangential and axial as shown in figure 1. This figure presents a schematic drawing of a cylinder liner and the directions parallel to the incident x-ray beam irradiated into the Laue camera.

Insert fig. 1

Results and discussion

It is observed from the chemical composition of the three spray formed aluminium-silicon alloys, that a variation in quantity of Si, Ni and Cu is present, see table 1. Alloy 1 has very little Mg content in relation to the other ones and further, it has the highest amount of Si and Cu which accounts most for the formation of very fine primary silicon particles and intermetallics.

The optical micrographs of the three analysed aluminium-silicon alloys, show a homogeneous distribution of the primary silicon particles (figure 2). These alloys present a silicon concentration high above the eutectic composition, which is roughly 12.5 % in weight, however, with a microstructure evenly distributed and macrosegregation free.

Figure 2 show SEM secondary electron micrographs of the alloys 1, 2 and 3. It is observed three different phases: dark grey phase, corresponding to the continuous aluminium matrix. The medium grey phase corresponds to the primary silicon particles (discontinuous phase). The light grey phase is composed by intermetallics, mainly copper rich. These phases were identified by energy dispersive spectroscopy - EDS. Figure 2 clearly show that the size of the primary silicon particles of alloy 1, are much finer than the other alloys.

Insert fig. 2

It is known that both the aluminium and metallic silicon have CFC structures, and that in the spray forming process, the silicon is not dissolved in the aluminium matrix due to the high cooling rate inherent of the process. The silicon is homogeneously distributed in the matrix, with particles size much smaller than the obtained by conventional processes. In these conditions, the material acts as if it was a heterogeneous mixture, where two CFC structures coexist, not having loss of the characteristics of the aluminium or of the silicon.

Figure 4 presents X- ray diffraction patterns, obtained in a Laue camera for alloy 1, hot rolled (72 % of reduction) and cold rolled (70% of reduction). Figure 7 presents the pole figures for alloy 1 hot rolled (a) and cold rolled (b), where the contour lines appear concentric and the largest intensity in "times random" units is 1.57. This alloy under the rolling conditions did not show any preferential direction orientation, which is not common in aluminium alloys. This can be justified by the presence of great amount of very fine silicon particles (approximately 26 % in weight) and intermetallics that does not undergo plastic deformation. These phases would prevent the texture formation in alloy 1. A literature [12] on texture of aluminium tubes hot extruded and cold swaged, discussed the texture recrystallization under precipitation influence. As mentioned the presence of precipitates may hinder and even block grain boundary movement [12]. Similarly, the presence of very fine silicon and intermetallics particles would prevent crystalline lattices rotation during mechanical work such as rolling, and consequently the texture development.

Insert fig. 3

Figure 5 presents X-ray diffraction pattern, obtained in a Laue camera for alloy 2, where the texture is also not observed. Figure 6a shows the Laue photograph for alloy 3 regarding the radial direction of the cylinder liner. This Laue photograph is similar to the ones obtained for alloys 1 and 2, where texture is not observed. However, figure 6b shows a Laue photograph taken from the axial direction of the cylinder liner, alloy 3, where it can be observed variations in the intensity of the Debye rings, which is characteristic of texture. It should be mentioned that the Laue photograph of figure 6b is not complete, see bottom left corner. This was due to the used specimen that was too small for the available X-ray collimator. The result extracted from the pole figure (figure 9) confirm the presence of a low intensity texture, typical of deformation of aluminium (times random of 2.13).

The texture observation just in a direction is explained by Cullity, B. D. [12] that analyses the fibre texture in an material formed by forces that have rotational symmetry about an axis, for example in wire and rod formed by drawing, swaging, or extrusion. If the incident X-ray beam is normal to the sheet specimen and therefore parallel to the fibre axis, a Debye ring of uniform intensity can be formed. Therefore, a uniform Debye ring is not always evidence of randomly oriented grains. BUNGE, H. J. [13] reported studied textures of swaged aluminium tubes, making a wall cut in the axial direction, opening it and treating it as a sheet shaped sample, but with the aligned fibres texture parallel to the axis of the cylinder.

Insert fig. 4

Insert fig. 5

Insert fig. 6

In a previous work, presented in SDMA 2003 [11] it was just analysed the radial directions of the cylinders liners, alloys 2 and 3, when then the texture absence was verified. The present work comes to complement the previous discussion, besides comparing the existent market alloys with an experimental alloy.

Figure 7 presents the pole figures of alloy 1, hot rolled (a) and cold rolled (b), where the contour lines are concentric, also showing the lack of texture. The pole figures of the alloys 2 and 3 are shown in the figures 8 and 9, respectively. The alloy 2 does not present texture as well as the alloy 1. The alloy 3 presents a deformation texture.

Insert fig. 7

Insert fig. 8

Insert fig. 9

Figure 10 present the X-ray diffraction patterns obtained for the three alloys. The analysis of the spectra shows that both phases (Al and Si) are present, and there are no intermediate AlSi phases.

Insert fig. 10

Conclusions

Regarding alloy 1, which is an experimental aluminium-silicon spray formed alloy, under the used conditions for plastic forming, the hot rolling and cold rolling processes have not induced a deformation texture in the alloy.

The specimens taken from a cylinder liner alloy 2, under the unknown used condition to shape a spray formed aluminium-silicon billet into a tube, have not induced texture.

It is noticed that alloy 3 and respective mechanical work has induced a deformation texture. The amount of silicon and other intermetallics forming elements in the alloy 3, is the smallest in relation to the other two alloys. This may be a circumstantial evidence that there is an upper limit for addition of silicon and other alloying elements into an aluminium, which below it, there is no induced deformation texture.

Acknowledgements. The authors thank the Institute of Physics of University of São Paulo and IPEN for the use of X-rays diffractometers and to the Brazilian Government for awarding a scholarship to H. de O. Santos and FAPESP grant n. 98/07529-5.

References

[1] G. Crivellone, A. Fuganti, C. Mus, D. Salinas, *SAE Special Publication SP-1610* (2001), p. 77-83.

[2] P. Stocker, F. Rückert, K. Hummert, MTZ Motortechnische Zeitschrift vol. 58 no. 9 (1997), p. 16-9.

[3] S. Ozbek, A. R. E Singer, Abstr. Conf. ... London 23-24 November, The Inst. of Metals (1987), p. 9/1-9/3.

[4] E. J. Lavernia, N. J. Grant, Materials Science Engineering no. 98 (1988), p. 381-94.

[5] D. M. Jacobson, Advanced Materials & Process, vol. 157 no. 3 March (2000), p. 36-9.

[6] A. G. Leatham, A. Ogilvy, P. Chesney, J. V. Wood, Metals and Materials, March (1989), p. 140-3.

[7] A. G. Leatham; L. Elias, M. Yaman, T. Itami, Y. Kawashima, P. J. S. Brooks, K. Hummert, D. E. Tyler, P. Cheskis, R. P. Dalal, P. D. Prichard, Proc. of P/M World Congress San Francisco USA, June 23-24 (1992), p. 66-76.

[8] A. G. Leatham, A. Ogilvy, L. Elias, P/M in Aerospace, Defense and Demanding Applications Conf. San Diego 7-10 February (1993), p. 165-75.

[9] J. L. Rossi, F. Ambrozio Filho, J. Vatavuk, D. B. Falleiros, IPEN/CPP Report December

(1997), p. 1-15. (In Portuguese).

[10] B. D. Cullity, Elements of x-ray diffraction, 2nd edition, 296-297, 1978. p. 295-322.

[11] H. de O. Santos, N. B. de Lima, I. Costa, J. L. Rossi, J.C. Santos, M. A. Colosio, SDMA 2003 and ICSF V, v. 1, Bremen, Germany, June 22-25, 2003, 97-101.

[12] N. B. de Lima, K. Imakuma, A. F. Padilha, 41° Congress ABM (1986), v. II, 283-291. (In Portuguese)

[13] H. J. Bunge, Texture Analysis in Materials Science – Mathematical Methods, 1st edition (1969), 245-247.

Tables

Table 1. Chemical composition of spray formed hypereutectic aluminium-silicon alloys (weight %). The techniques used were atomic absorption spectrophotometry and Si gravimetry.

Material	Al	Si	Mg	Ni	Cu	Fe
Alloy 1	balance	26.64	0.02	0.006	5.20	0.19
Alloy 2	balance	23.19	1.00	0.96	2.70	0.19
Alloy 3	balance	20.76	1.10	0.01	4.00	0.21

Figures captions

Figure 1. Schematic drawing of a cylinder liner a section, where the used directions for the Laue photograph are shown.

Figure 2. Optical micrographs of the spray formed alloys 1, 2 and 3, showing the homogeneity of the silicon particles distribution (light grey phase) in the aluminium matrix (white phase).

Figure 3. SEM secondary electrons micrographs, presenting three different areas: aluminium matrix (continuous dark grey phase), silicon (medium grey phase) and intermetallics rich in copper (light grey phase).

Figure 4. Laue photographs of specimens taken from alloy 1, perpendicular to the rolling direction. a) Hot rolled at 450 °C 72 %. b) Cold rolled 70 %. The diffraction lines have a continuous and uniform intensity appearance, which indicate a random crystal orientation.

Figure 5. Laue photograph of the specimen taken from alloy 2, radial direction. The diffraction lines have a continuous and uniform intensity appearance, which indicate a random crystal orientation.

Figure 6. Laue photographs of the specimens taken from alloy 3. a) Radial direction. b) Axial direction. In the radial direction, the Debye rings are continuous and of uniform intensity and these are due to the incident X-ray beam to be parallel to the fibre axis. In the axial direction, the non-uniform blackening of the Debye rings is due to preferred orientation in the specimen.

Figure 7. Pole figures obtained from alloy 1. a) After hot rolling up to 72 % total reduction in thickness. b) After cold rolling up to 70 % total reduction in thickness. These pole figures indicate that under the present mechanical working no texture is observed.

Figure 8. Pole figure obtained from the alloy 2, whose specimen was taken from a cylinder liner. This pole figure shows that the specimen has no texture.

Figure 9. Pole figure obtained from the alloy 3, whose specimen was taken from a cylinder

liner. This pole figure shows that the specimen has a typical aluminium deformation texture.

Figure 10. Diffractometer traces of the spray formed hypereutectic aluminium silicon alloys.

Figure 1

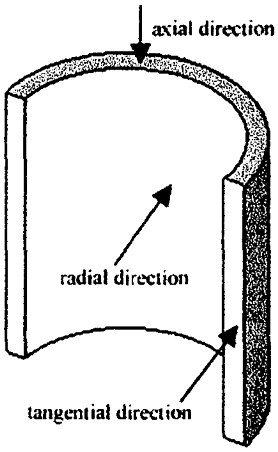
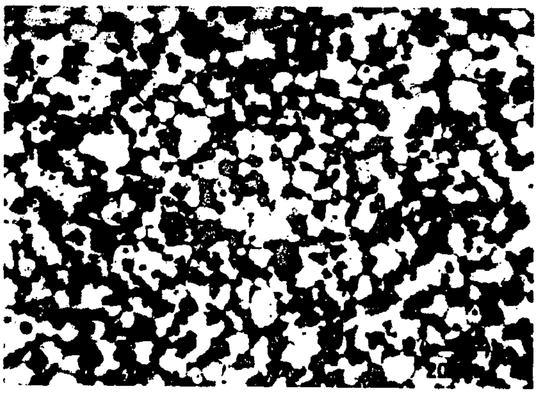
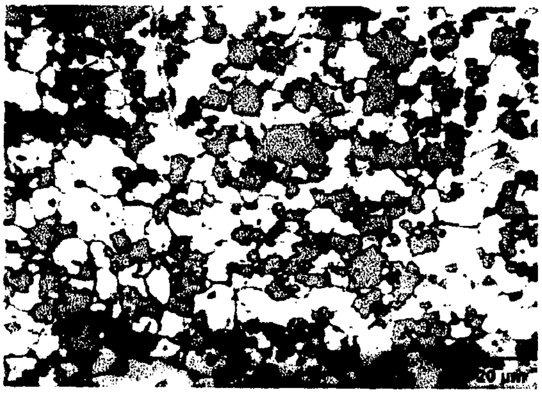


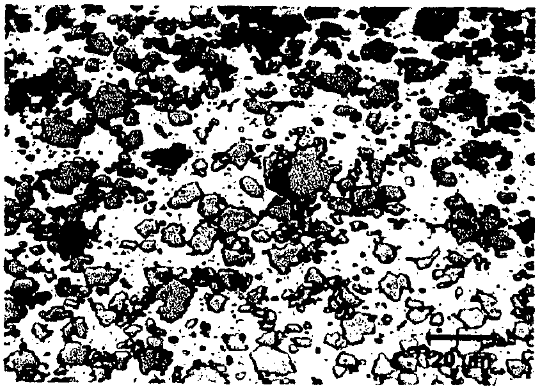
Figure 2



Alloy 1

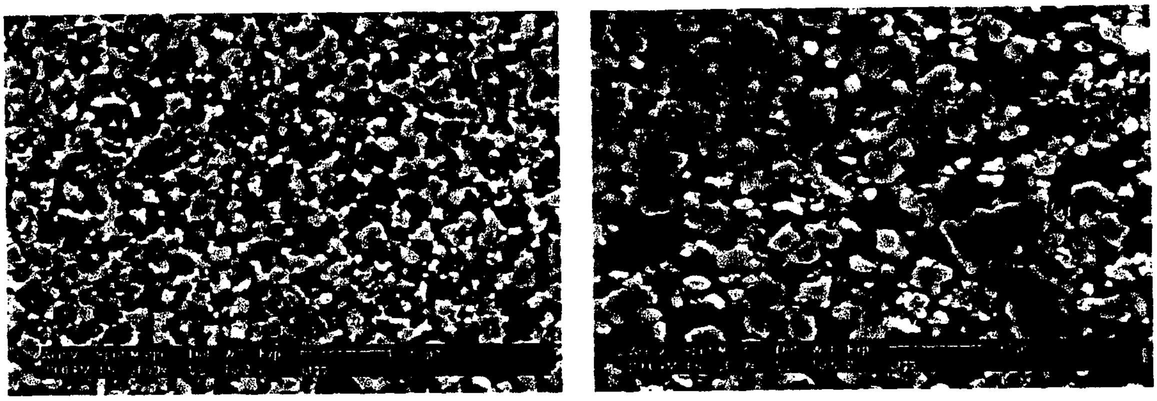


Alloy 2



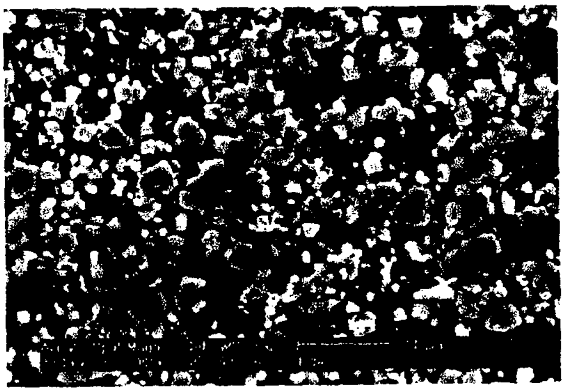
Alloy 3

Figure 3



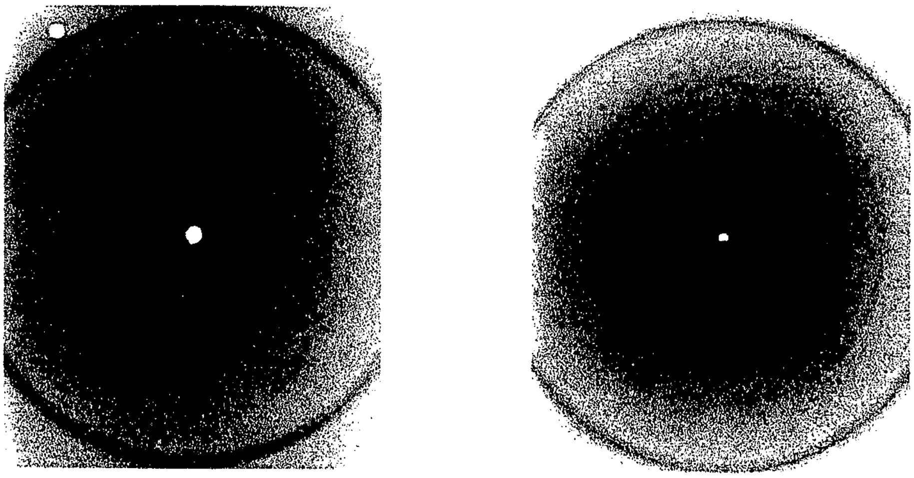
Alloy 1

Alloy 2



Alloy 3

Figure 4



a)

b)

Figure 5

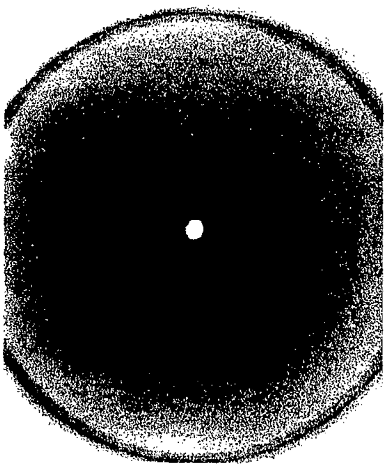
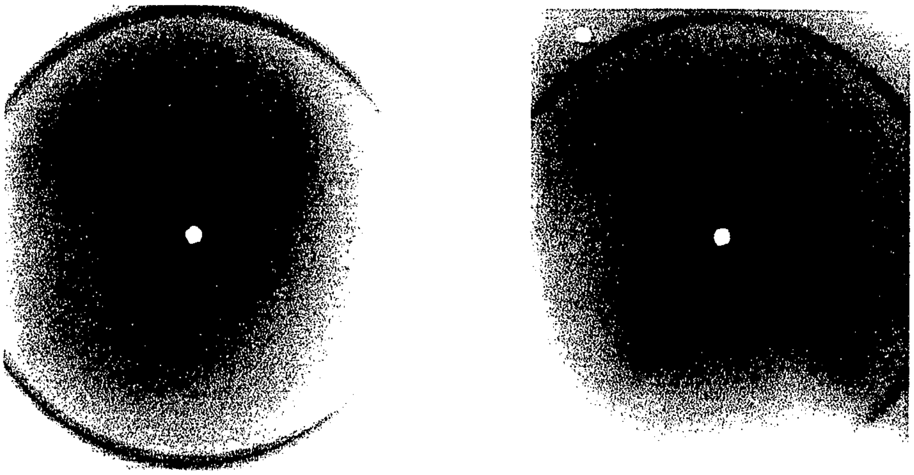
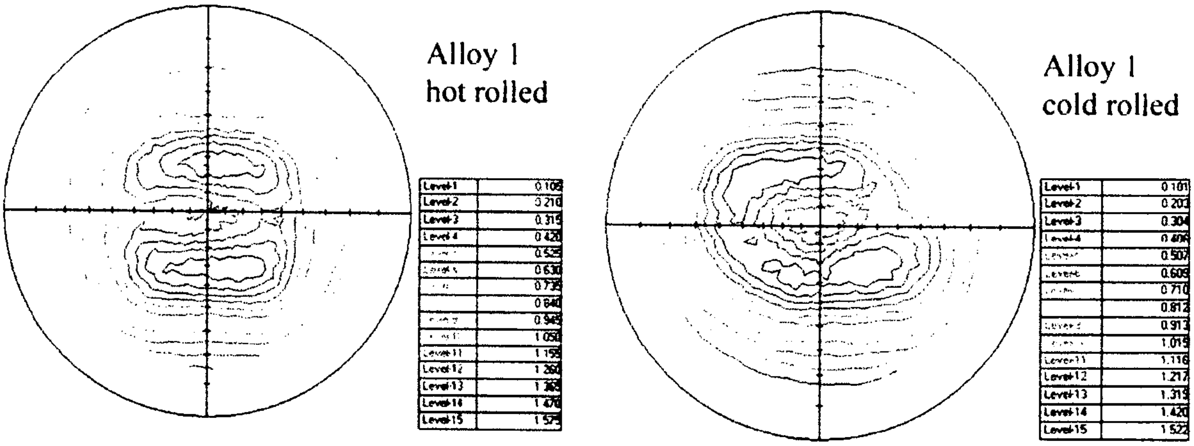


Figure 6



a) b)

Figure 7



a) b)

Figure 8

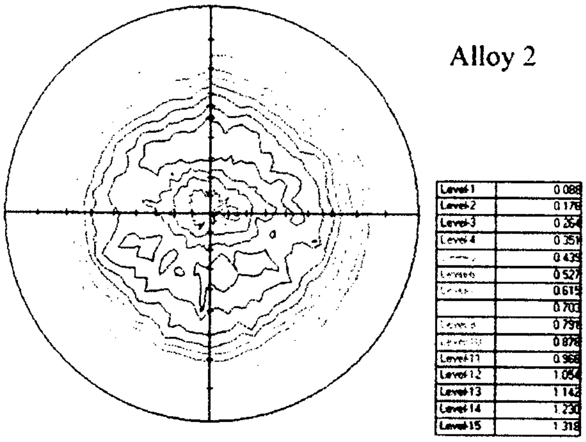


Figure 9

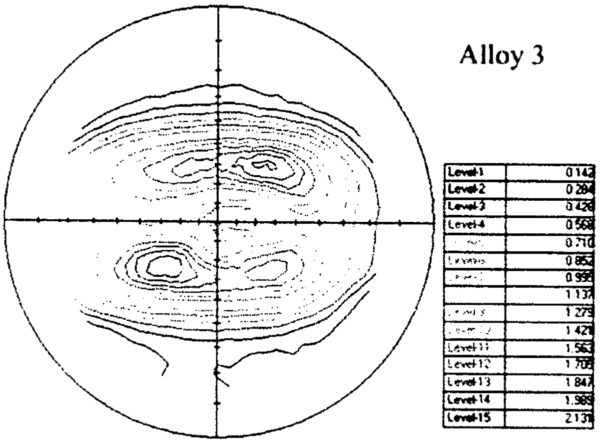
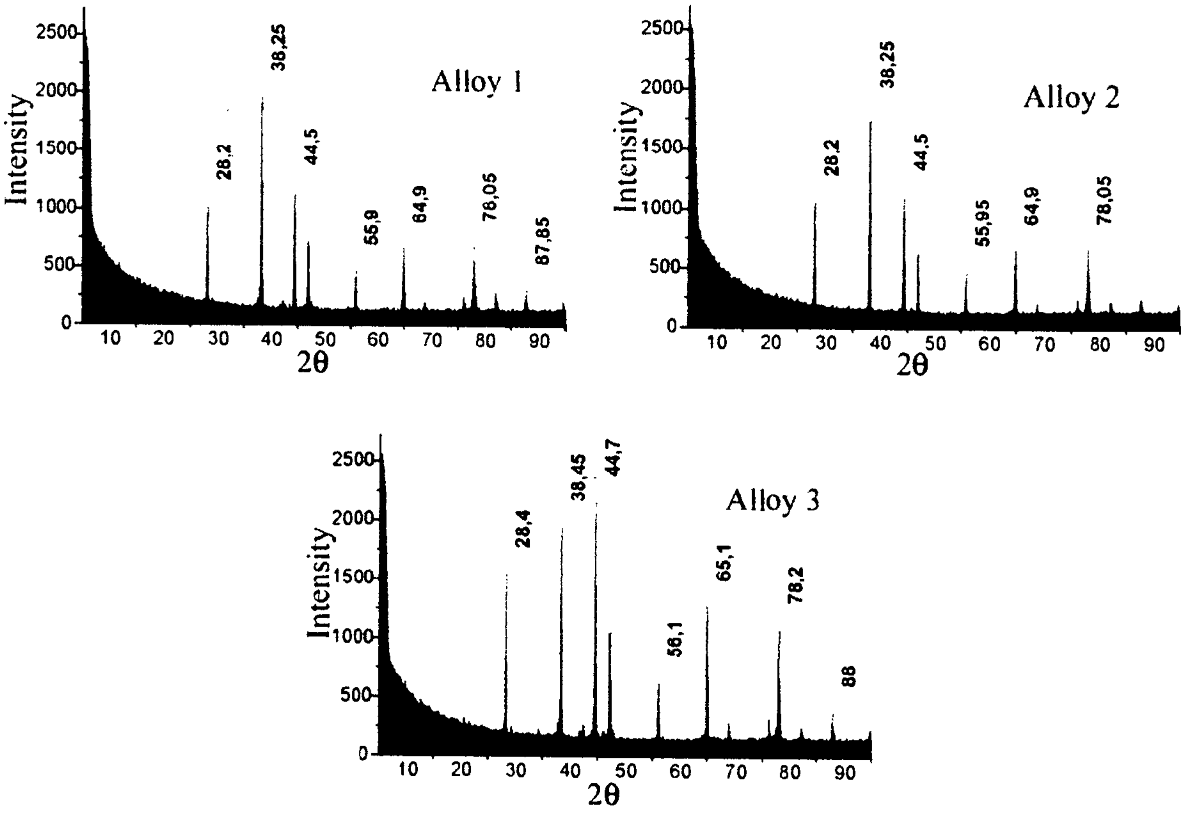


Figure 10


Alloy 1
Intensity
2500
2000
1500
1000
500
0
28,2
38,25
44,5
55,9
64,9
78,05
87,85
10 20 30 40 50 60 70 80 90
2θ
Alloy 2
Intensity
2500
2000
1500
1000
500
0
28,2
38,25
44,5
55,95
64,9
78,05
10 20 30 40 50 60 70 80 90
2θ
Alloy 3
Intensity
2500
2000
1500
1000
500
0
28,4
38,45
44,7
56,1
65,1
78,2
88
10 20 30 40 50 60 70 80 90
2θ

IPEN/CNEN-SP
BIBLIOTECA
"TEREZINE ARANTES FERRAZ"

Formulário de envio de trabalhos produzidos pelos pesquisadores do IPEN para inclusão na Produção Técnico Científica

AUTOR(ES) DO TRABALHO:
H.O. SANTOS;F.M. M . SERNA; N.B.DE LIMA; J.L.ROSSI; I. Costa

LOTAÇÃO: CCTM

RAMAL:9359

TIPO DE REGISTRO:

art. / periód.: ☐
cap. de livro ☐
Publ. IPEN ☐
Art. conf ☒
. resumo ☐
outros ☒
(folheto, relatório, etc...)

TITULO DO TRABALHO:
SPRAY FORMED HYPEREUTETIC ALUMINIUM ALLOYS- CRYSTALLOGRAPHIC ORIENTATION

APRESENTADO EM: (informar os dados completos - no caso de artigos de conf., informar o título da conferência, local, data, organizador, etc..)
PTECH 2003
19 A 31 de Novembro de 2003 - Guarujá- Brasil

PALAVRAS CHAVES PARA IDENTIFICAR O TRABALHO:
SPRAY FORMING; CYLINDER LINERS; Al-Si HYPEREUTECTIC ALLOYS

ASSINATURA: ______________________

DATA: 10/12/2003