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# Thermomechanical treatment of a Fe-Mn-Al alloy

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**Resumo:** Análises da dureza e da estrutura metalografica mostraram em uma liga de Fe-Mn-Al a existencia de fase γ e de precipitado β pela ativação do Si, durante o rapido esfriamento do material fundido. Durante o tratamento térmico nas temperaturas de recuperação e de recristalização são formadas franjas, grãos maiores do precipitado β e da fase recristalizada γ. O tratamento termomecânico dá ao material excelentes propriedades de resistência mecânica e de ductilidade, sem a colaboração do precipitado β.

**Palavras-chave**: liga, tratamento termomecânico, metalografia, microscopia óptica

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**Abstract:** Analysis of the hardnees and the metalographic struture, show in a FeMnAl alloy the existence of a γ fase and a β precipitate, activitate by Si during the casting processes. During the recovery and recrystalisation temperatures there are the formation of fringes, coarsed grains of γ fase and β precipitate . The thermomechanical treatments give to the material excellent properties of mechanical resistance and good ductility, without the β collaboration.

**Keywords:** alloy, thermomechanical treatment, metallography and optical microscopy

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## INTRODUCTION

Studies of ordered alloys Fe3Al and Fe3Si [6,12] has enabled the development of the Fe-(5w%Al)-(1.5w%Si) magnetic alloy itself, with excellent resistance to corrosion and high resistance to oxidation at high temperatures, by forming a thin surface layer of alumina, Al2O3.

The composition limit for the alloy is 1.5w%Si and 5w%Al [1,17], which allows their use as well as resistors (80 μΩcm), combined with moderate mechanical strength properties and resistance to oxidation.

Their mechanical fragility is attributes to the structure BCC and to the interstitial defects of the alloy.

Because their FCC structure the (55w%Fe-35w%Mn-10w%Al) alloy [1,16], presents at high temperatures a better mechanical and a good plasticity properties.

A combination of (35w%-40w%Mn) and 15w%Al of that alloy produces an improper structure β-Mn, and a lamellar ferritic structure B2 that do not maintain their austenitic structure at high temperature [2,13,17].

The addition of Carbon to the alloy [8] stabilizes the austenite, gives inoxidizable property up to 650◦C, similar to the inox steel Fe-Ni-Cr, and superior mechanical conditions up to 815C [7,10] to the carbon steels 304 AISI and 347 AISI.

During cold rolling operation that alloy hardens quickly wanting intermediate thermal anneals.

Today a nominal composition proposal to agree mechanical properties and corrosion resistance for the alloy [1,2,3], is 53w%Fe, 35w%Mn, (8 - 9w%)Al, 2w%Si, (0.7-1.0w%)C.

Addition of 3w% of elements as B, Cr, Mo, Ni, Nb, Ti, do not improve the best properties of this alloy [3,14,1518]. *corresponding

The table 1 shows for example some mechanical properties of different Fe cast-alloys,

**Table 1** (weight%)

| Fe-Cast-Alloy | σR(MPa) | σE(MPa) | Elong. (%) | Hv | Refer. |
|---|---|---|---|---|---|
| 30Mn-10Al-1.3Si | 605 | ------ | 10 | 381Vickers | 9 |
| 30Mn-7Al-1.25Si | 550 | ------ | 11 | 166Vickers | 9 |
| 30Mn-8Al-1C* | 890 | 495 | 54 | ------------- | 9 |
| 31.22Mn -7.54Al-1.34Si-0.93C | 738 | 401 | 50 | 234Vickers | 10 |
| 30Mn-8Al-1.5Si-1C | 800 | 574 | 72 | -------------- | 3 |

Some properties of the austenitic alloy (56w%Fe. 30w%Mn, 10w%Al, 3w%Si, 1.0w%C) [4] are presented here:

remarkable corrosion resistance to boiling sea water during 118 hours [9], what is adequate to use as helix for vessels long journey;

imperceptible superficial corrosion after to be into sea water during 32 days at room temperature, as show similar works [1,5,9,10];

their properties σR (MPa), σE(MPa), between 24° C and 815° C, and of cold reduction increment, are higher than that austenitic Fe-Ni-Cr steels [10];

their ductility is similar to traditional inox steels, which permits various percentages of reduction;

the σE of the alloy can reach to high values of 1660(MPa) for 80% of cold reduction [10];

studies of that Fe-Mn-Al-Si-C austenitic steel, at three dynamic strain aging rates in the range of 172-345◦C, show the occurrence of peaks in strength, in ductility and work hardening parameters, the three well-defined peaks for the work hardening were displaced to higher temperatures with increase in strain rate, and the activation energy involved was determined and the possible mechanism of strain ageing was proposed [4];

the oxidization resistance of the alloy at 700° C for 70 hours is almost the same for the inox AISI 304 at 800° C for 40 hours with an stable oxidized superficial layer [11];

their electrical resistivity varies from 168 μΩcm to 180 μΩcm between 80◦C and 800° C, values that are superior on the Ni-Cr and Kanthal alloys [11].

## MATERIAL & METHOD

The following alloy was cast using purest components,

**Fe(58.8w%)-Mn(30.2w%)-Al(8.6w%)-Si(1.30w%)-C(0.63w%)-Cr(0.40w%)-Ni(0.05w%)**

Chemical analysis of the cast-alloy indicated a composition close to the nominal one, with Cr, Ni as main impurities.

The existence of two metallographic structures β and γ, was revealed by the optical metallography and the Scanning Electronic Microscope (SEM-Instituto de Quimica-UNESP), having the β phase a little concentration of Cr and a smallest concentration of Fe and Mn than in the γ phase.

The existence of β phase it is attributed to the Si influence on the casting procedure.

These two phases stay inside the (γ+β) band of the Horizontal Section at 7600C of the Fe-Mn-Al Ternary Equilibrium Diagram [2].

## ANALYTICAL PROGRAMS

Two programs were settled, trough micro hardness and micrographic analysis, to determine the temperatures of stress relief, and of re-crystallization, as well as to evaluate the mechanical properties for technological applications.

**1º) Program** – Sequence of thermomechanical treatments;

a)Cold rolling to 40% of reduction (0.2 cm thickness), b) Anneal at 1473K, 1 hour and quench to normal temperature, c) Anneal from 300K to 1200K, in successive steps of 100K for 1 hour to measure the respectives micro-hardness, figure 1, and metallographic structure observation, Table 2.

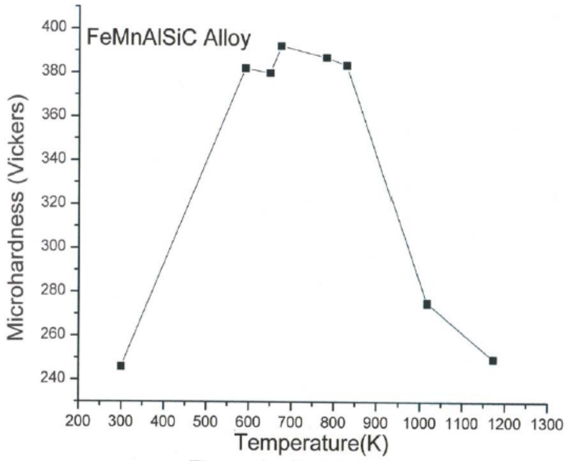

Figure 1 - (1st Program)

**Table 2** - Micrographic observation of annealed samples

| Temperature (K) | GamaPhase(γ) | Beta Phase (β) | Observation | Micrography (Figure) |
|---|---|---|---|---|
| 300 | Coarse grains with L of 44μm to 800 μm | Few grains bordering γ phase Lm=30 μm | Fine fringes drawn on all the optical field Lengths L and medium Lm | III |
| 640 | Larger granulation than at the 300K Lm=44 μm | More grains bordering γ phase | Idem | IV |
| 660 | Some sub-grains Lm=150 μm | Spreaded and bordering γ Lm=60 μm | Long size due on the pre-cold rolling | V (3) |
| 800 | Decomposition of grains and creation of sub-grains | Idem | Idem | VI (4) |

| | | | | |
|---|---|---|---|---|
| 1000 | Decomposition of more grains Lm≈150 μm | Long and cracked in various parts | Decomposition of fringes into spheres and small batons | VII |
| 1180 | Scattered decomposition Lm≈15 μm | Scattered decomposition Lm≈15 μm | ____________ | VIII (5) |

Figures 3, 4, 5 respectively micrographics of V,VI,VIII from table 2

**2◦) Program –** Sequence of thermomechanical treatments;
a) Cold rolling to 40% of reduction (0.2 cm thickness), b) Anneal at 1473K, 1 hour and quench to normal temperature, c) Another cold rolling to 40% of reduction (0,2 cm of thickness), d) Anneal from 300K to 1200K, in successive steps of 100K for 1 hour to measure the respectives micro hardness, figure 2, and metallographic structure observation, Table 3.

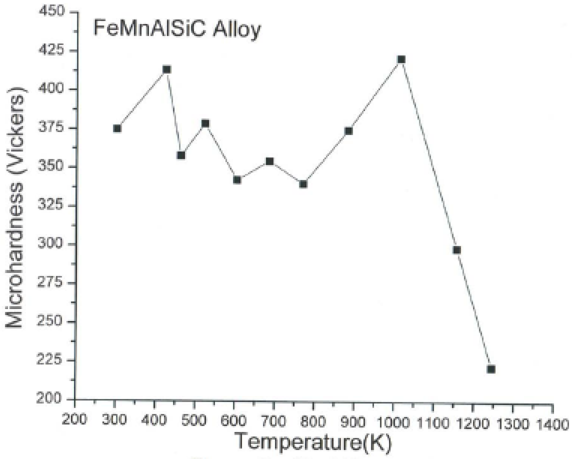

Figure 2 - (2nd Program)

Table 3 - Micrographic observation of annealed samples

| Temperature(K) | Gama Phase (γ) | Beta Phase (β) | Observation | Micrography (Figure) |
|---|---|---|---|---|
| 423 | Grain boundary not observed | Lengthened by initial cold rolling Lm =70 μm | Fringes at some regions. Lengths L and Medium Lm | ______ |
| 461 | Idem | Idem | Fringes and initial cold rolling with directions of 90◦ | ______ |
| 521 | Small numbers of grains with Lm=500μm Dm=150 μm | Some grains bordering the γ phase | Existence of depressed γ phase with internal fringes Lüders bands? | XI |
| 683 | Large grains | Idem | Nitid fringes or Lüders bands! | XII |
| 768 | The number of grains is greater than that at 683K | Idem | In some places an high density of fringes | XIII-XIV |

| | | | | |
|---|---|---|---|---|
| 880 | Poly crystals Lm=800µm | Interstitials grains on the γ phase borderline | Elongated black fringes filaments | XV |
| 1010 | More Poly- crystals Lm = 400 µm - 450 µm | Interstitials cracked grains on the γ phase borderline Small Lm | Black filaments inside the γ phase and Serrated traces | XVI |
| 1155 | Decomposition of grains with Lm<5 µm to 15 µm in distints regions | Cracked grains | Ausence of fringes | XVII (6) |
| 1245 | Polyhedrical crystals Lm ≈ 12 µm and twins bands | Decayed with Lm≈60 µm | Idem | XVIII |

## CONCLUSION

**Under the metallographic point of view**

The component Si during the cooling speed of the molten state alloy produces a blend of γ phase and β precipitates [2]. The calculated grain proportion of γ and β was γ ⁄ β = 522.

Micrographic photos, of (1◦) and (2◦) programs, show that the heat treatments produce, coarse grains of γ and β phases , fringes during the stress relief, figures 3, 4, 5 and re-crystallized γ, figures 6, 7.

By collaboration of the fringes the re-crystallization of γ phase grains starts at temperature of 800K (1◦) program) and at 1000K (2◦) program) with dimensions less than 12 µm.

The β phase starts to be multi-fractured at 1000K and no collaborates on the hardness of the material.

**Under the technological point of view**

1◦) Program - In the range of 600K- 800K the heat treatment ensures to the alloy an excellent strength, hardness of 385Vickers, with a adequate grain sizes, and at 1180K, an hardness of 250 Vickers, a favourable mechanical conditions to produce by cold rolling process, plates blades, wires, nuts or bolts.

2◦) Program - Internal stress relieves is proven in the heat treatment (range 600K - 700K), because the low hardness, 337Vickers.

The alloy hardens from 800K (337Vickers) to 1000K (422Vickers), and softens to 1250K (220Vickers), which recommends to be good for cold metal-forming.

For technical applications the higher hardness recommended is 422Vickers, despite of more energy consumption and less resistance to oxidation, figure 4

General hardness values, here marked, agree with the data contained in the works cited on the bibliography.

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