# INFLUENCE OF COLD ROLLING AND ANNEALING ON SUPERPLASTIC CONDITION OF A FE-MN-AL AUSTENITIC STEEL[1]

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## Abstract

The first approach to characterize the superplastic behavior of solubilized and cold rolled austenitic Fe-Mn-Al steel was obtained with elongation around 300% at temperature of 850℃, which compared with a similar steel, that shows better promising results around 500%, whose work showed potential of superplastic condition elongation. So this referred work was undertaken to show the results of a chemical composition Fe -24.5Mn –6.5Al -1.5Si -1.1C(weight%) material, which was prepared by different thermo mechanical processing route, as to obtain around 1 mm thickness sheets having a fine grain (~3 µm) equiaxial dual phase austenitic/ ferritic structure. The material was submitted to tensile and creep tests at temperature range from 600℃ to 1000℃, and strain rate range from $10^{-4}$ to 1 $s^{-1}$. The parameter m (strain rate sensitivity) could be determined in both cases. Maximum elongation at rupture ($\varepsilon_r$) values could be also observed from the results obtained of the tensile and creep tests. These results from tensile and creep test procedures were compared, showing good agreement to each other. The largest $\varepsilon_r$ around 600% associated to the largest m, around 0.54 was observed in the tensile test case at temperature of 800℃ in the strain rate range from $10^{-4}$ to $10^{-3}$ $s^{-1}$. The creep test case with the largest $\varepsilon_r$ around 700% (without rupture) for applied stress in the range from 20 to 50 MPa.

**Key words**: Fe-Mn-Al steel; Superplasticity; Creep test; Strain rate sensitivity.

## INFLUÊNCIA DA LAMINAÇÃO A FRIO E RECOZIMENTO NA CONDIÇÃO SUPERPLÁSTICA DE UM AÇO AUSTENÍTICO Fe-Mn-Al

## Resumo

A primeira abordagem para caracterizar o comportamento superplástico de um aço austenítico Fe-Mn-Al solubilizado e laminado a frio foi obtido com um alongamento do material de 300% a uma temperatura de 850℃, comparado a um trabalho com aço similar, que apresentou resultados promissores em torno de 500%, e mostrou o potencial do alongamento superplástico destes materiais. Este presente trabalho foi realizado com um aço de composição química Fe -24,5Mn -6,5Al -1,5Si -1,1C (%peso) preparado por diferentes rotas de processamento termo-mecânico, de modo a obter chapas com espessura de aproximadamente 1 mm ,estrutura ferrita/austenita e granulação fina equiaxial com tamanho de grão em torno de 3 microns. O material foi submetido a ensaios de tração e fluência na faixa de temperatura de 600℃ a 1.000℃, e taxa de deformação na faixa de $10^{-4}$ a $1s^{-1}$. O parâmetro (sensibilidade à taxa de deformação) pôde ser determinado em ambos os casos. O valor observado do alongamento máximo até a ruptura ($\varepsilon_r$) também pode ser obtido tanto por ensaios de tração como de fluência. Os resultados dos dois métodos (ensaios de tração e fluência) foram comparados apresentando grande concordância entre ambos os procedimentos. Os maiores valores de $\varepsilon_r$ foram observados a temperatura de 800℃, no caso de ensaios de tração em torno de 600% para m ~0,54 e taxa de deformação na faixa de $10^{-4}$ a $10^{-3}$ $s^{-1}$ , e para ensaios de fluência com $\varepsilon_r$ máximo em torno de 700% (sem ruptura) para tensões aplicadas na faixa de 20 a 50 MPa.

**Palavras-chave:** Aço Fe-Mn-Al; Superplasticidade; Ensaio de fluência; Sensibilidade a taxa de deformação.

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[1] *Technical contribution to 64th ABM Annual Congress, July, 13th to 17th, 2009, Belo Horizonte, MG, Brazil.*

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## 1 INTRODUCTION

The austenitic Fe-Mn-Al steels may exhibit good combination of properties like mechanical strength, with relatively low density and light weight related to stainless steel. So it has been of considerable interest to substitute critical and expensive alloying elements as nickel and chromium for aluminum and manganese in a search for stainless steel.(1) The mechanical behavior of these alloys at high temperatures is largely unexplored. Thus the work done after a first superplastic performance for austenitic Fe-Mn-Al steel showing a set of previous reported result indicates a maximum elongation of about 320% at condition 850℃/$8.3 \times 10^{-5}$ $s^{-1}$. This previous work showed, for the first time, the possibility of further exploring the potential use of such materials in this regime at temperature higher than 700℃. So this present work was a second approach to study the superplastic behavior of an austenitic Fe-Mn-Al steel presented by Guanabara(2) with an austenitic structure of the same chemical composition: Fe -24.5Mn -6.5Al -1.5Si -1.1C (wt %).

The most important superplastic characteristic occurs in region II, associated to high elongations, of a usually three stage relationship obtained from both tensile and creep tests with the steady-state strain rate ($\dot{\varepsilon}$) dependence of the applied stress ($\sigma$), where the values of strain rate sensitivity exponent (m) in the range from 0.35 to 0.8. This is the range generally considered to produce superplastic behavior. Such sensitivity exponent are related with stress exponent (n) from creep test, through relationship $n=1/m$.(3)

This work was planned with the objective to undertaking a systematic study of the potential superplastic condition of this austenitic steel submitted to different thermo-mechanical processing routes, obtaining sheets with around 1 mm thickness having a fine grained equiaxial, dual phase austenite/ferrite structure and grain size around 3 µm. It was programmed to explore such occurrence with systematic hot tensile tests carried out on a constant crosshead speed machine in the range from 600℃ to 1000℃ involving initial strain rate in the range from 20 to 50 MPa. The largest elongation values observed until rupture of around $\varepsilon_r$ = 660% was associated to the largest m values around 0.54 at temperature of 800℃. It was performed for strain rates in the range from $10^{-4}$ to $10^{-3}$ $s^{-1}$ (case of tensile test) and applied stress in the range from 20 to 50 MPa (case of creep test).

## 2 EXPERIMENTAL MATERIALS AND PROCEDURE

The mechanical test used in early stage of this work were carried out with single specimens subjected to a sequence of crosshead speed changes, after ultimate tensile strength mainly at temperature of 600℃, 700℃, 800℃, 900℃ and 1000℃ with at least four crosshead speed levels namely: $V_C$ = 0.05; 0.5; 5 and 50 mm/min corresponding to initial strain rate of $8.3 \times 10^{-5}$; $8.3 \times 10^{-4}$; $8.3 \times 10^{-3}$ and $8.3 \times 10^{-2}$ $s^{-1}$ respectively. Due to obtain a more favorable characteristic of grain growth and annealing treatment condition, a set of experiment were performed using specimen of Fe-Mn-Al (SL - solubilized and laminated) and annealing treated material. Such material were treated during one hour at temperatures: 800℃; 850℃ and 900℃, according to each treatment, named as SLT1, SLT2 and SLT3 respectively. After heat treated on such conditions, the specimens were prepared from these materials. The samples were both tensile (with change crosshead speed ($V_C$)) and creep tested to obtain better superplastic condition, from which were chosen more favorable processing route based upon such result for the next set of experiment. Then it was performed with sample material of austenitic Fe-Mn-Al (SLT2) steel.

The material was prepared in form of ingots weighting about 3.5 kg with approximately 50x50x220 mm each. The ingot was submitted to the different thermo-mechanical processing routes named materials at SLT2 condition which consists of: first solution heat treatment at 1050°C / 24 hours followed by quenching in oil. After that, was used grinding operation to square all the faces before sectioning the sample in two slabs, each with about 25 x 50 x 200 mm. The slabs were subjected to three series of cold rolling deformation steps (of flow) followed by heat treatments of 1050°C /1hour. The accumulated deformation levels after each cold rolling stage corresponded to about 25, 50 and 75% reduction in thickness. After the last solution treatment the sample was cold rolled continuously until its final shape of a stripe with around 1 mm final thickness, then it was annealed treated at temperature of 850°C/1 hour. Tensile samples were machined from the stripes in the rolling direction having a nominal gauge length of $L_0$ = 5.0 mm and gauge width of w = 3.0 mm.

The sensitivity variation of stress with strain rate was first observed using *single specimens* subjected to several crosshead speed changes during a certain temperature level, then followed by experiments observed using *distinct specimens* for each combination of crosshead speed ($V_C$) with temperature.

Hot tensile test were carried out on a universal Instron machine model 5500R with a tubular electric resistance furnace. Temperature stability during all test was about ±1°C maintained by P.I.D. controllers. The flow stress was measured as function of strain rate related by the expression(3)

$$\sigma = C\,\acute{\varepsilon}^{\,m} \qquad (1)$$

here C is a constant including temperature, and m is the strain rate sensitivity exponent

$$m = d\mathrm{Log}\sigma \,/\, d\mathrm{Log}\acute{\varepsilon} \qquad (2)$$

So the set of experiment was performed first with tensile test of distinct specimens strained until rupture. Then conducted under different combinations of chosen crosshead speed and temperature. The sample finally were pulled until rupture under different combinations of crosshead speed from 0.01 to 20 mm/min. at temperature 800°C.Due to determine and confirm m value among other parameter, thus such set of experiments were followed by a new set of tensile and creep tests.

The systematic creep test were carried out on a MF-1000/STM constant load creep machine with a tubular electric resistance furnace, in this case the steady state strain rate is recorded for the imposed stress and data are logarithmically plotted as strain rate against stress ($\acute{\varepsilon}$ x $\sigma$). There was an interest in carrying out some systematic creep test in the early stage at temperature 900°C, due to good results obtained in first approach at this temperature, using applied stress in the range from 14 to 85 MPa, obtained from better results of the tensile test. After that were followed by systematic set of experimental creep tests carried out in the same range of applied stress, at temperatures of 600°C, 700°C; 800°C and 850°C, due to cover the same range of temperatures used in tensile tests. The data from these tests of austenitic Fe-Mn-Al (SLT2) material with different stress condition were used to plot an logarithmically Arrhenius relation

$$\mathrm{Ln}\ (\text{initial } \acute{\varepsilon}) \times 1/\,T \qquad (3)$$

so that

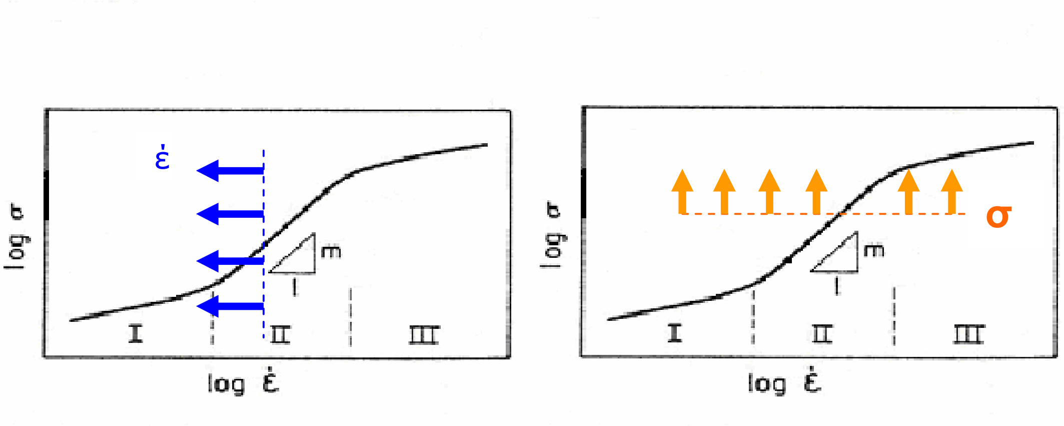
$$\dot{\varepsilon} = B.\, e^{-\frac{Qc}{RT}} \qquad (4)$$

here: $\dot{\varepsilon}$ – minimal $\dot{\varepsilon}$ ; B – coefficient considering $A'$, $\sigma^n$ ; $Q_C$ – activation energy; R – gás constant and T – temperature (K) rearranged as

$$\text{Ln}\ \dot{\varepsilon} = \text{Ln}\ B - \frac{Q_c}{RT} \qquad (5)$$

The stress exponent value (n) is so far the most important parameter for characterization of superplastic behavior through creep tests. It's because with this parameter one could compare and confirm, through the relationship $n = 1/m$, such m values obtained from the tensile tests(4) carried out in the same condition.

The performed test trend were verified at all experimental temperature used in both tensile and creep test, outline at Figure 1. Figure 1(a) shows the decreasing $\dot{\varepsilon}$ trend during tensile test with constant $V_C$. The decreasing $\dot{\varepsilon}$ trend during tensile test is growing with decreasing temperature, which necessary up righted computer to correct such trend. Figure 1(b) shows increasing σ during creep test with constant load, also with necessary up righted computer to correct such trend. So up righted were fulfilled due to eliminate such trends on both cases through experiment to keep constant $\dot{\varepsilon}$ during tensile test with constant $V_C$ until ultimate tensile stress (u.t.s.) at determined temperature. The same as compensate such increasing σ trend during creep test, here were performed through experiment with constant stress, and with up righted load based upon simulation designed for a specific experimental stress.



(a) (b)

**Figure 1.** Typical trends verified at all temperature used in both tensile and creep test where: a) $\dot{\varepsilon}$ is decreased during tensile test at constant $V_C$; b) σ is increased during creep test at constant load.(4)

## 3 RESULTS

The previous results, i.e. the researched parameter ($\varepsilon_r$) obtained at prior first step set of experiment,(2) were not the wished target to characterization superplastic behavior of austenitic Fe-Mn-Al steel alloy. So it was necessary a second step of research studies of such material with a sequence of experiments at several temperatures and time of recrystallization and grain growth treatment. Table 1 illustrates temperature and time values, which were used with chose 5 measured / hardness.

**Table 1.** Temperature and time used in study of sample 7x10 mm dimension of recrystallization and grain growth with average hardness HV10 take at room temperature(4)

| T ($^{o}$C) | AGEING TIME (min) | | | |
|---|---|---|---|---|
| | 5 | 20 | 60 | 180 |
| 25 | 514 | 514 | 514 | 514 |
| 600 | 576 | 588 | 689 | 798 |
| 700 | 598 | 624 | 653 | 694 |
| 800 | 667 | 486 | 459 | 399 |
| 900 | 336 | 365 | 325 | 333 |
| 1000 | 346 | 319 | 320 | 370 |

Hence, to subsequent thermo-mechanical treatment series were chosen, after data analysis, better treatment conditions of lower hardness value.

Figure 2 shows microstructure, after annealing at 900℃, of Fe-Mn-Al (SL) sample with time range treatment of grain growth and recrystallization (Table 1), standing out a fine structure of annealing treated material (Figure 2c), however stands out started of a new phase precipitation in grain boundary (5) and growth with coarse grain during treatment.

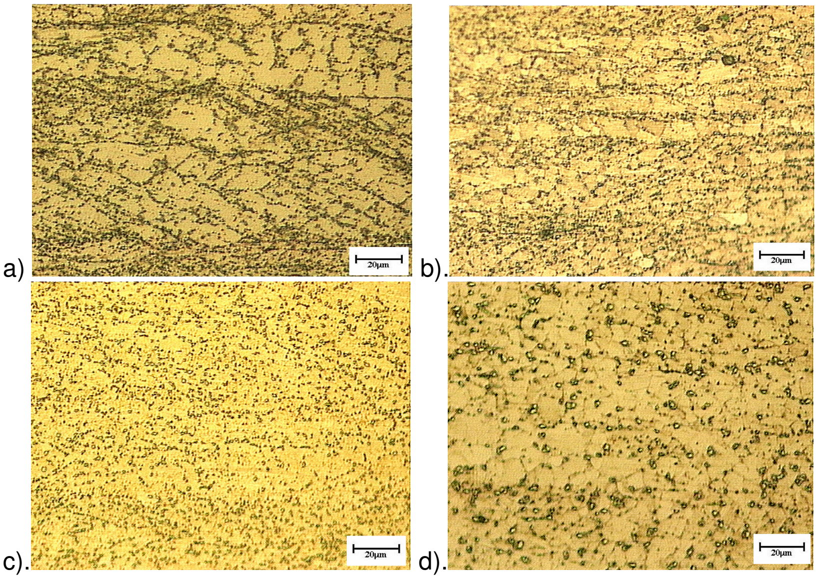


**Figure 2.** Sample Fe-Mn-Al (SL) austenitic steel heat treated at 900℃ with time: a) 5 min.; b) 20 min; c) 60 min. and d) 180 minute.(4)

These materials, on SLT condition were used in the next experimental set of experiments, performed at 3 annealing treatment (SLT1, SLT2 and SLT3) at temperatures respectively: 800℃, 850℃ and 900℃ for 60 minute each.

Figure 3 shows a typical true stress with strain rate curve of Fe-Mn-Al (SLT1) of tensile tested sample with change $V_C$ at temperatures 800℃, 900℃ and 1000℃.

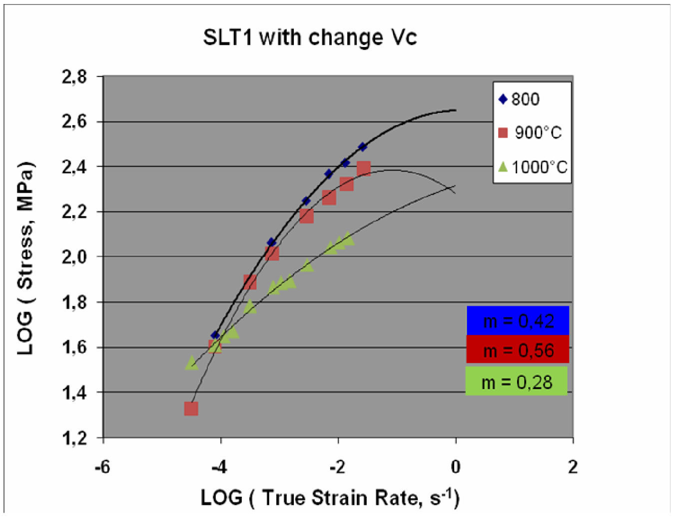
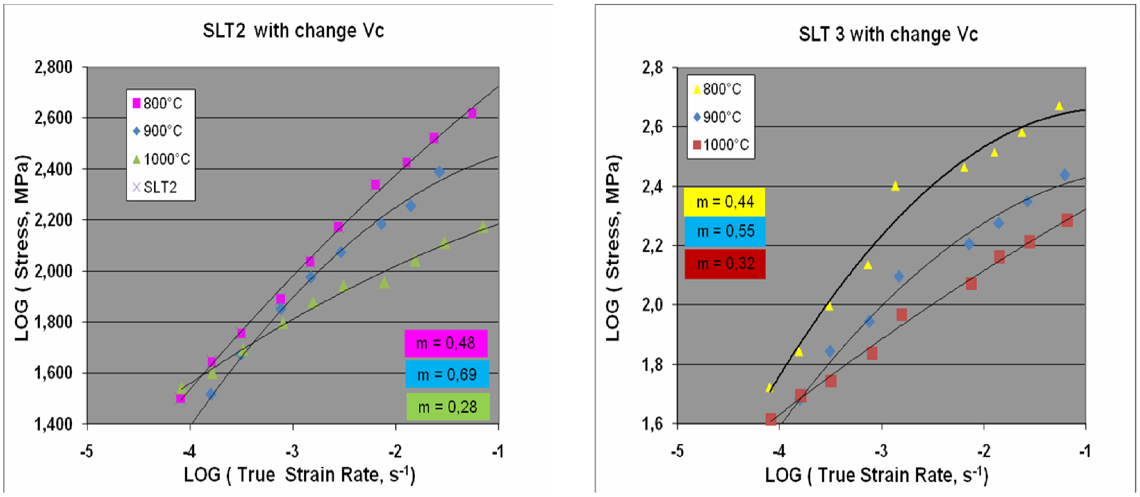


**Figure 3.** True stress with strain rate curve of Fe-Mn-Al (SLT1) of tensile tested sample with change $V_C$ at temperature 800℃, 900℃ and 1000℃ with respective average m value (4).

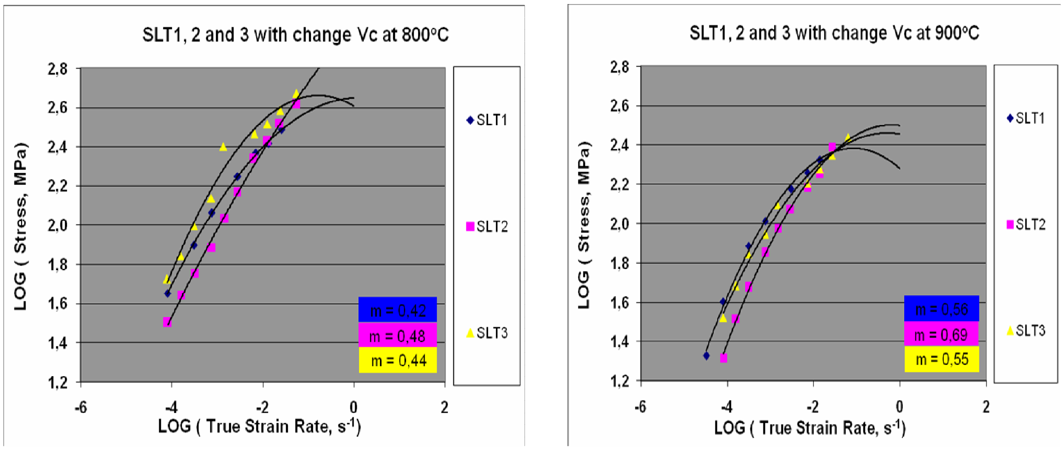
Figure 4 shows comparison result between true $\sigma$ with $\dot{\varepsilon}$ curve of hot tensile sample tested with different $V_C$ and temperature of: (a) of (SLT2), and (b) (SLT3) Fe-Mn-Al steel. Such curves show evolution of m value for each annealing treatment and experimental temperature.



(a) (b)

**Figure 4.** Comparison between true stress versus strain rate curve of hot tensile tested sample with different $V_C$ showing evolution of m value for each annealing treatment and experimental temperature. (4)

Figure 5 shows comparison of hot tensile test result with change $V_C$ for 3 different annealing treated Fe-Mn-Al steel samples (SLT1, SLT2 and SLT3) at 800℃ and 900℃, which presents better potential of superplastic behavior. These figure let see also both flow evaluation trend and respective m value for each SLT´s material curve.



(a) (b)

**Figure 5.** Comparison of hot tensile with change Vc test result for 3 different annealing treated SLT1, SLT2 and SLT3 Fe-Mn-Al steel sample with respective m values at temperature: (a) 800℃; (b) 900℃.[(4)]

Figure 6 shows example of typical hot tensile test result at true stress versus strain curve for Fe-Mn-Al (SLT2) steel, with different $V_C$ in the range from 0.01 to 200 mm/min., at temperature of 800℃. This Figure shows flow and ultimate tensile strength (u.t.s.) trend for each curve of $V_C$ values. The results at room temperature showed for a material at cold rolled condition, a very high yield and tensile strengths, the same results as reported by Toscano.[(6)] The more temperature increases the more strength becomes strain rate ($\acute{\varepsilon}$) sensitive. It could be observed in a very high flow stress and u.t.s. at room temperature. So as temperature increase, the material becomes more and more sensible to strain rate ($\acute{\varepsilon}$). The observed trend of curve to the left indicating as consequence, decreasing stress values and influence of strain hardening exponent (n`) with increasing predominance of strain rate sensitivity exponent (m). The appearance of tensile tested sample curve results at constant $V_C$ showed different elongation until rupture ($\varepsilon_r$). Such curve result with $V_C$ = 0.5 mm / min. at temperature of 800℃, observed result with $\varepsilon_r > 600$ %. This value is practically the double of such sample results obtained, without annealing treatment, with the first work [(2)]. The more pronounced result of the present work, with initial strain rate values was $\acute{\varepsilon} = 2.47 \times 10^{-4}\ s^{-1}$ with elongation until rupture ($\varepsilon_r$) of around 660%.

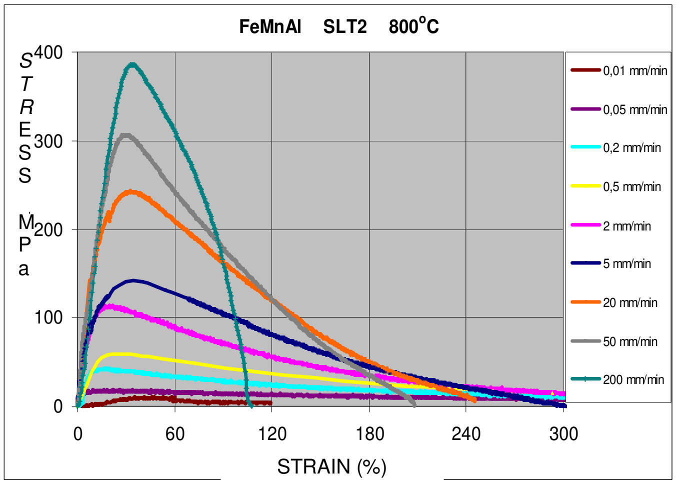
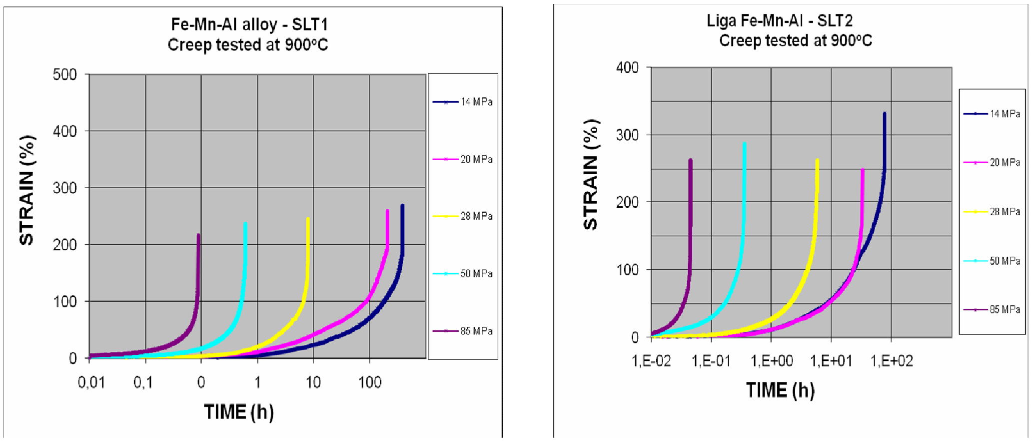


**Figure 6**. Typical True Stress versus Strain curves for austenitic Fe-Mn-Al (SLT2) steel with different crosshead speeds at same temperature 800°C.(2)

Due to stained out necessity to correction on both experimental methods (Figure 1) were also performed tension test with constant $\dot{\varepsilon}$, through $V_C$ correction, and performed creep test with constant σ, through load correction. It could be done a comparison of several sample results of Fe-Mn-Al steel (SLT2), after creep test with different stress at temperature 800°C, and among these sample, one shows constant $V_C \approx$ 0.1 mm/min. and $\dot{\varepsilon} = 2.47\text{x}10^{-4}\ s^{-1}$ with an elongation around $\varepsilon_{r\,=}$ 750%. Such value, if positioned among Figure 6 curves shows an ultimate tensile strength (maximum stress) of σ = 23.5 MPa of experiment with constant σ = 30 MPa, performed at temperature 800°C. Such constant stress experiment showed an elongation without rupture of 737%, when interrupted after a time test of 19.9 hours. These experiments with constant stress performed at others temperature, even if without correction, also showed higher deformation comparatively to previous results of creep test experiments with constant load. The comparison of creep tests performed with frontal load with those ones with constant stress, those tests with constant stress showed elongation with $\varepsilon_r$ value around ~ 500% after rupture in less than 3 hour of whole time.

Figure 7 shows strain with time curve of creep test with constant load Fe-Mn-Al (SLT1 and SLT2) sample results in the stress range from 14 to 85 MPa at temperature 900°. Figures 7(a) and 7(b) show creep test with constant load, performed with 5 prior adopted stress level values. The initial stress selected at temperature 900°C, and analyzed discretion were kept and used to associate u.t.s. from hot tensile test x $\dot{\varepsilon}$ curve with m values characteristic estimated of couple maximum stress / deformation. From these figures, were derived graph as: Norton; Monkman-Grant and Decreasing Creep strength with rupture Time. So such obtained graphs are used to compare the trend of stress exponent (n), with that stress level values performed at temperature 900°C, which comparative results are showed in the next figure.



(a) (b)

**Figure 7.** Curve of Strain with Time of creep tested sample with constant load in a range from 14 MPa to 85 MPa at temperature 900℃ here: (a) SLT1; (b) SLT2 condition.(4)

Figure 8 shows comparative graphs of SLT1; SLT2 and SLT3 Fe-Mn-Al steel from creep tested sample with constant load in stress range from 14 to 85 MPa at temperature 900℃ as: Norton; Monkman-Grant and Decreasing creep rate strength with time. The values, as Figure 8 (a) shows in Norton graph for temperature 900℃, could be initially obtained without correction of n values at several temperatures.

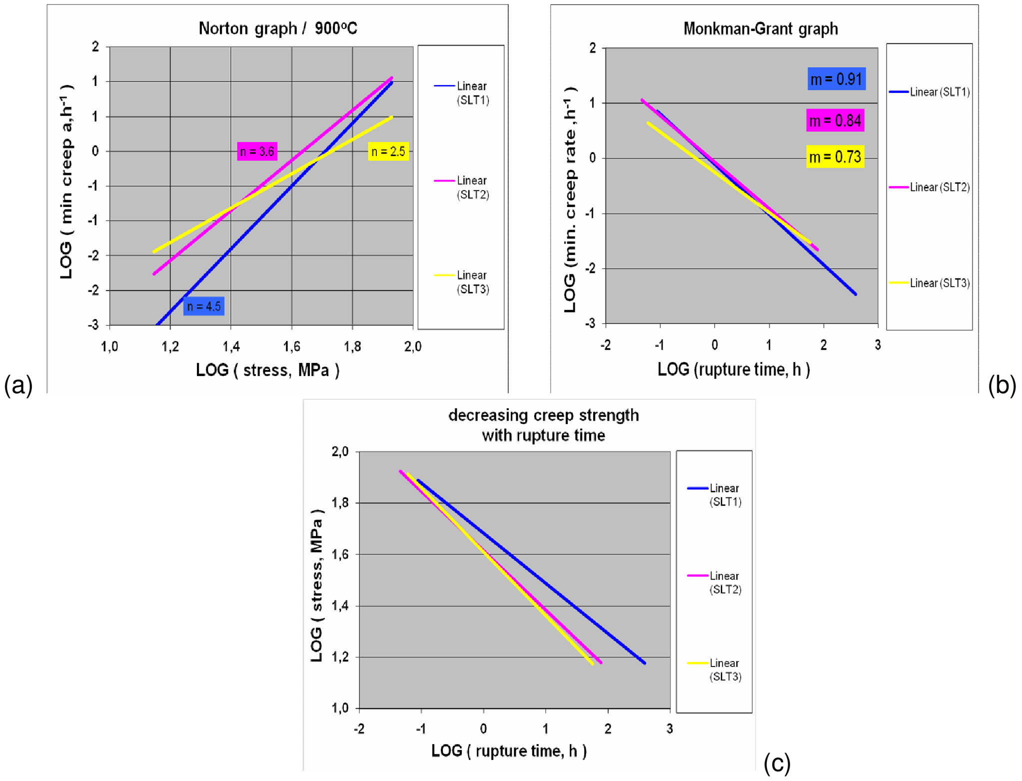


**Figure 8.** Comparative graphs of SLT1; SLT2 and SLT3 Fe-Mn-Al steel from creep tested sample with constant load in stress range from 14 to 85 MPa in such graph as: (a) Norton; (b) Monkman-Grant and (c) Decreasing creep rate strength with rupture time.(4)

Creep test of SLT2 Fe-Mn-Al steel were performed with constant load at test temperatures of 700℃ and 800℃, kept prior stress for comparison showing respective n values to Log (min. nominal creep rate, $h^{-1}$) x Log (nominal stress, MPa).

Stress exponent values obtained to 3 SLT´s condition, at different temperature to minimum and initial creep rate were grouped for the purpose of comparison.
Table 2 shows a comparative data of strain x rupture time curve from creep-tested samples with constant load, in terms of minimal creep rate values of stress exponent (n). The comparative graphs are composed with minimum nominal creep rate; true creep rate and initial creep rate curves used to show n data results grouped of SLT1; SLT2 and SLT3 austenitic Fe-Mn-Al steel at temperatures of 700°C; 800°C and 900°C. Thus letting more precise trend analysis of minimum creep rate and stress exponent (n) variation. The n values are closed to 2, as found in 3 comparative curves at temperature 800°C, to a minimum nominal and initial creep rate with $n \approx 2$. The corrected minimum creep rate, at the same temperature, increases stress exponent value to n=2.5. These three minimum creep rates at temperature of 900°C shows a very different values, which happens with meaningful increase of minimum true rate related to nominal one (see Table 2). Such comparatives of Table 2 also let to verify the influence of creep rate behavior related to both temperature and n exponent.

**Table 2.** comparative data of strain x rupture time curve of creep tested samples with constant load, in terms of minimal creep rate values of stress exponent (n) composed with minimum nominal; true and initial creep rate of SLT1; SLT2 and SLT3 austenitic Fe-Mn-Al steel at 700°C; 800°C and 900°C.$^{(4)}$

| | | **n Value** | | |
|---|---|---|---|---|
| MATERIAL | T (°C) | to Minimal Creep Rate **NOMINAL** | to Minimal Creep Rate **TRUE** | to Creep Rate **INITIAL** |
| **SLT1** | **700** | X | X | X |
| | **800** | X | X | X |
| | **900** | **4,51** | **7,32** | X |
| **SLT2** | **700** | **2,41** | **2,54** | **2,36** |
| | **800** | **2,00** | **2,41** | **2,00** |
| | **900** | **3,59** | **6,27** | **2,66** |
| **SLT3** | **700** | X | X | X |
| | **800** | X | X | X |
| | **900** | **2,47** | **4,50** | X |

So the data of austenitic Fe-Mn-Al (SLT2) steel at this comparative table were used to compose an Arrhenius graph, with several experimental temperature at different test stress which were plotted on Ln (initial rate, $h^{-1}$) x 1 / T ($K^{-1}$) condition. Such graph also associated to each curve the indicated test stress ($\sigma$) and creep activation energy ($Q_c$). This graph shows a detailed survey of initial and minimal creep rates. At first approach was found $Q_{c\ med.}$ = 226 kJ/mol, and in a second approach the value was $Q_{c\ med.}$ = 236 kJ/mol. Thus observing that both values were inferior of the ones found in analysis of minimum nominal creep rate performed in the range from 700 to 800ºC, according to Sordi & Bueno (7). Since these authors considered that the value of $Q_c$ =233 kJ/mol at temperature range from 500°C to 650°C is attributed to diffusion creep controlled by grain boundary.

## 4 DISCUSSION

Recrystallization model explains refined equiaxial structure formation with increase strain rate ($\dot{\varepsilon}$), let improve refined processing route, but not completely explain superplastic characterization. So as in present case to complex alloy could be possible that $Q_c$ values for diffusion creep through grain boundary should be bigger than simple self diffusion of Fe at Austenite. The obtained $Q_C$ data have good agreement with expected values to flow superplastic process, which occur through diffusion by grain boundary,(8) related as

$$Q_{gb} \approx \ ½\, Q_{sv}.$$

This activation energy data(9) agreed with the present work $Q_{c\ med.}$=226 - 236 kJ/mol values, which could be also associated to controlled diffusion creep by grain boundary characteristic of superplastic behavior. It is important to mention that a more precise $Q_{c\ med}$ value could be obtained only taking into account the activation energy correction, which is due to elastic module variation with temperature, according Barrett, Ardell & Sherby (10). These corrections cause a decrease of around 10% or more at found $Q_{c\ med}$ values. Such values were obtained without consider the temperature influence in material due to elastic module, thus indicated that a more correct value of activation energy creep should be around or least than $Q_c \approx 200$ kJ/mol value.

The mainly parameter used to characterize superplastic behavior were estimated m values, since only elongation is not sufficient to obtain such superplastic results, with better strain rate sensitivity (m) parameters obtained, from both techniques of tensile test with constant $\acute{\varepsilon}$ and creep test with constant $\sigma$, as showed results.

The were performed at Fe-Mn-Al (SLT2) steel a set of experiments based upon tensile test graph (Log ($\sigma_{Max}$ , MPa) x Log ($d\varepsilon / dt$ , $s^{-1}$)) indicated maximum m values plotted with tests with constant $\acute{\varepsilon}$ at temperature 800°C / $V_C$. Due to compare such results from both methods were carried out a superposing of this creep test data values with constant stress above a tensile test graph curve, in such a way that positioned plotted creep test data values were kept a little lower of the tension curve, as waited staying a little above in the same curve.

There were performed also a comparison of tensile test data values of Fe-Mn-Al steel (SLT2) at temperature 800°C / $V_C$, in the same way as above situation, superposing tensile data above the Norton graph of creep test. Here practically was observed the inverse situation of the first comparison.

So to verify that awaited agreement from both experimental methods was performed a comparison between corrected sample data results from tensile (with constant $V_C$) and creep (with constant load) test curves, thus with this last set of experiments were verified a very good agreement.

## 5 CONCLUSIONS

The result from both procedure, i.e. tensile and creep test showed good agreement with each other.

The new thermo-mechanical processing routes coupled with tensile tests (*with constant strain rate*) and creep tests (*with constant stress*) allowed improving the values of parameters of characterization.

The comparison between tensile with constant $\acute{\varepsilon}$ and creep with constant stress tests results at temperature 800°C/ $V_C$ based upon tensile test (Log($\sigma_{Max}$,MPa) x Log($d\varepsilon/dt$,$s^{-1}$)) after correction, comprise perfect symmetry between exponents m and n, since are related through $n = 1 / m$.

A tensile test performed at constant $\acute{\varepsilon} = 2.47 \times 10^{-4}\ s^{-1}$ produced a maximum elongation at rupture of $\varepsilon_r = 750\%$ and a creep test with constant $\sigma = 30$ MPa

produced a maximum elongation of $\varepsilon_f$ = 737 % (without rupture of the specimen) sensibly better data results than those obtained with the first work (2).
Both experimental tensile and creep tests allowed achieving better parameters, as m values at region of maximum m (strain rate sensitivity), thus confirming the superplastic behavior of this austenitic Fe-Mn-Al steel alloy.

## Aknowledgements

The authors are grateful to CAPES for a grant received during this research, to Mr. Rover Belo and Mr. José Luis dos Santos for carrying out the heat treatments, mechanical processing and hot tensile tests, to STM for carrying out creep tests and Prof. Luiz Carlos Casteletti from EESC/USP for supplying Fe-Mn-Al steel ingots.

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