INFLUENCE OF TEMPERATURE ON THE FINAL MICROSTRUCTURE OF MICROALLOYED STEEL SUBJECTED TO SEVERE PLASTIC DEFORMATION *

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Abstract

The aim of this work was to study the influence of temperature on the grain refining process from severe plastic deformations through the simulation of Accumulative Roll Bonding (ARB) by torsion tests. The assays were performed to simulate the ARB at three different temperatures of 550 ° C, 625 ° C and 700 ° C with 5 torsion cycles with equivalent strain of 0.8 per cycle at a rate of $0.1s^{-1}$, totalizing an accumulated deformation of 4.0. Grain refining was obtained with an average size of 2μm, 5μm and 6μm for the temperatures of 550 ° C, 625 ° C and 700 ° C respectively. There was a rise in Vickers hardness by 68%, from 119HV in the annealed sample to 175HV in the deformed sample at 550 ° C. In the deformations at 625 ° C and 700 ° C the value of 130HV E and 150HV respectively was obtained. Based on the obtained results, it can be stated that the severe plastic deformations in microliged steel, carried out at temperatures lower than the end of the austenite-ferrite transformation, produce refined grains of the order of 2μm and, consequently, increase the mechanical strength of the material.

Keywords: Severe plastic deformation; Torsion test; Grain refining; Microalloyed steel.

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1 INTRODUCTION

Currently there is a great effort in the development of more resistant materials in order to increase and energy efficiency and to reduce its consumption. Ultrafine granulation materials (UFG) generally have greater resistance than those of coarse grains (1). These can usually be produced by advanced thermomechanical processes or by severe plastic deformation (SPD). The former is based on phase transformations with the application of controlled deformations to obtain grain refining, whereas the latter is based on large plastic deformations applied at temperatures below half the melting point of the material (2).

1.1 SEVERE PLASTIC DEFORMATION

The materials with fine grains <2μm (2), have high mechanical strength and high tenacity with traditional chemical compositions and with low content of alloying elements. Additionally, they have the advantage of reducing and avoiding additional heat treatments (annealing, tempering and tempering) and also benefit the welding due to the lower carbon contents present in the alloy when compared to other high strength steels (3).
Methods of severe plastic deformation apply large accumulated plastic deformations (ε_a> 4) at temperatures below the recrystallization temperature, especially in the hot working regime. They are more effective in grain refining than controlled rolling with the ability to reach grain sizes in the nanometer range (<100nm). The main methods of severe plastic deformation are Equal-Channel Angular Pressing (ECAP), High Pressure Torsion (HPT) and Accumulative Roll-Bonding (ARB) (2-4).
With the increasing interest in the development of steels with high mechanical strength and toughness, SPD methods become the means to obtain these characteristics through the obtained grain refining. In this way, the simulation of the SPD methods becomes important for the development of the processing of the materials. The torsion tests are widely used for the simulation of laminations and deformations of the steels with simplicity in the control of the deformation rates and neck formation during the tests. They can be used to simulate SDP methods, especially the ARB method (5,6). According to the aforementioned points, the objective of this research was to analyze the influence of the temperature on the final microstructure of a low carbon steel microalloyed to the niobium by the process of severe to warm deformation.

2 MATERIAL AND METHODS

The material used in the work was a niobium microalloyed low carbon steel drawn from a rolling mill sketch of a steel industry with the chemical composition by weight described in table 1. The test bodies were machined in the rolling direction of the scaffold and are 5mm in diameter and 20mm in length useful. The tests were performed on a horizontal torsion machine. The equipment has a maximum speed of 120RPM and the mechanical effort is measured by a load cell with a maximum capacity of 22Nm of torque.

Table 1. Chemical composition of microalloyed steel (mass%)

C	Mn	Si	Nb	Al	Ni	Fe
0,067	0,515	0,012	0,025	0,047	0,003	bal

The samples were annealed at 1200 ° C for 5 min in order to homogenize the microstructures and ensure the solubilization of niobium carbides. This temperature is above 929 ° C and 1076 ° C calculated by the methods of Siciliano (7) and Dong et al. (8) respectively, based on the chemical composition of the steel. After annealing, the samples were heated to temperatures below A_{r1}, as determined by continuous cooling multiple-strain tests (9). The tests were performed at 550 ° C, 625 °

C and 700 ° C at a heating rate of 2°C/s underwent ε_{eq}= 0.8 deformation per cycle, totaling ε_a= 4.0 at a rate of $0.1s^{-1}$. After deformation, the oven is turned off and the samples are cooled. Throughout the process the samples are immersed in argon gas. This process is repeated until the sample is subjected to a cumulative deformation of ε_a=4.0, in which it approaches the tests carried out by ARB.

For metallographic analysis, the samples were prepared by removing the useful length of the specimen and preparing in the longitudinal direction of the axis with the purpose of analyzing the surface in which the highest stress levels are located during the torsion. Scanning electron microscopy and scanning electron microscopy were carried out to determine the grain size and temperature effect in the steel deformation process.

Additionally, VIckers microhardness tests were performed on the annealed samples and after the deformations. The test was performed with the application of a penetration charge of 0.5kgf for a time of 20s.

3 RESULTS AND DISCUSSION

From the data acquired in the tests tensile-strain graphs were constructed for each strain temperature, these graphs are shown in figure 1.

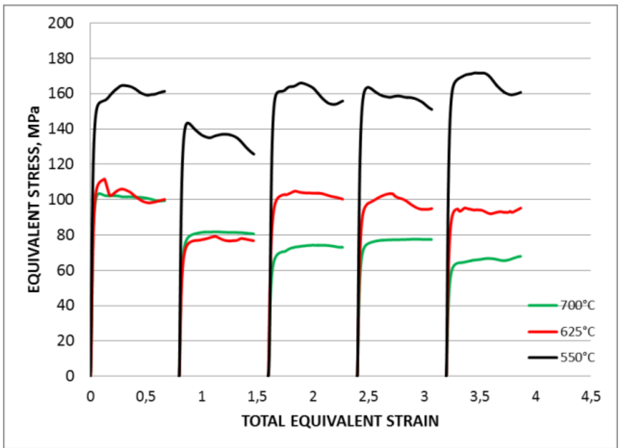

Figure 1. Tension-strain graph of the torsion tests performed at 550°C, 625°C e 700°C.

After deformation, at the temperature of 550 ° C, it is possible to observe in Figure 1, voltage peaks followed by a slight drop, characteristic of the occurrence of dynamic recrystallization. Note that at this temperature there were no steady-state regions of the stress during deformation. These results may indicate that there was grain refining in the deformed material at that temperature.

In the analysis of the deformation performed at 625 ° C it is possible to observe the smaller values of the peak voltage during the deformation passes due to the higher temperature at which the test was performed. However, the deformation peaks are not so clear in relation to the previous temperature. At this temperature can already be observed regions of steady state of the voltage, characteristic of dynamic recovery.

In the analysis of the deformations performed at 700 ° C, the lowest voltage value was observed in relation to the other tests performed at 550 ° C and 625 ° C. In addition, the voltage curve is stable without the presence of peaks, and with the evolution of the deformation the maximum values show a slight drop, in which they can indicate the occurrence of dynamic recovery in the material.

With the reduction of the deformation temperature of the material (700 ° C, 625 ° C and 550 ° C), there was an increase of Vickers hardness in relation to the annealed material, from 119HV to 175HV, an increase of 68%, as shown in the figure 2.

Initially the annealed samples presented the microstructure with distribution of the grains of varied and non-equiaxial sizes with average size greater than 30µm, shown in figure 3 with increase of 100x. This size may be associated with the annealing temperature at which samples were submitted. The steel has a ferritic matrix with a small fraction of perlite.

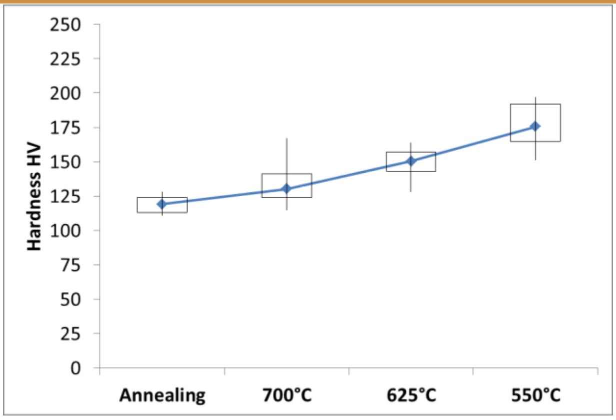

Figure 2. Relationship between hardness and material deformation temperature.

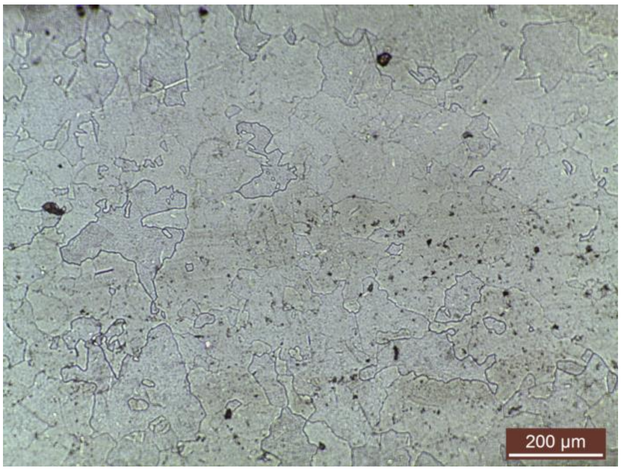

Figure 3. Initial microstructure of samples after annealing.

When comparing the microstructures obtained at each deformation temperature, as shown in Figure 4, the decrease of the grain size with the decrease of the deformation temperature is noticed. In Figure 4 (A) we can see some regions with larger grains and some with smaller grains. This difference may be due to the growth of larger grains that consume smaller grains and cause them to increase. Figure 4 (B) shows the microstructure of the sample subjected to deformation at 625 ° C. In this way, a smaller grain size was obtained in relation to the temperature of 700 ° C. At these two temperatures we can conclude that there was a dynamic recovery during deformation as observed in other studies (10,11), in which a steady state was reached. We can conclude that the diffusion is fast enough to allow the migration of grain boundaries and

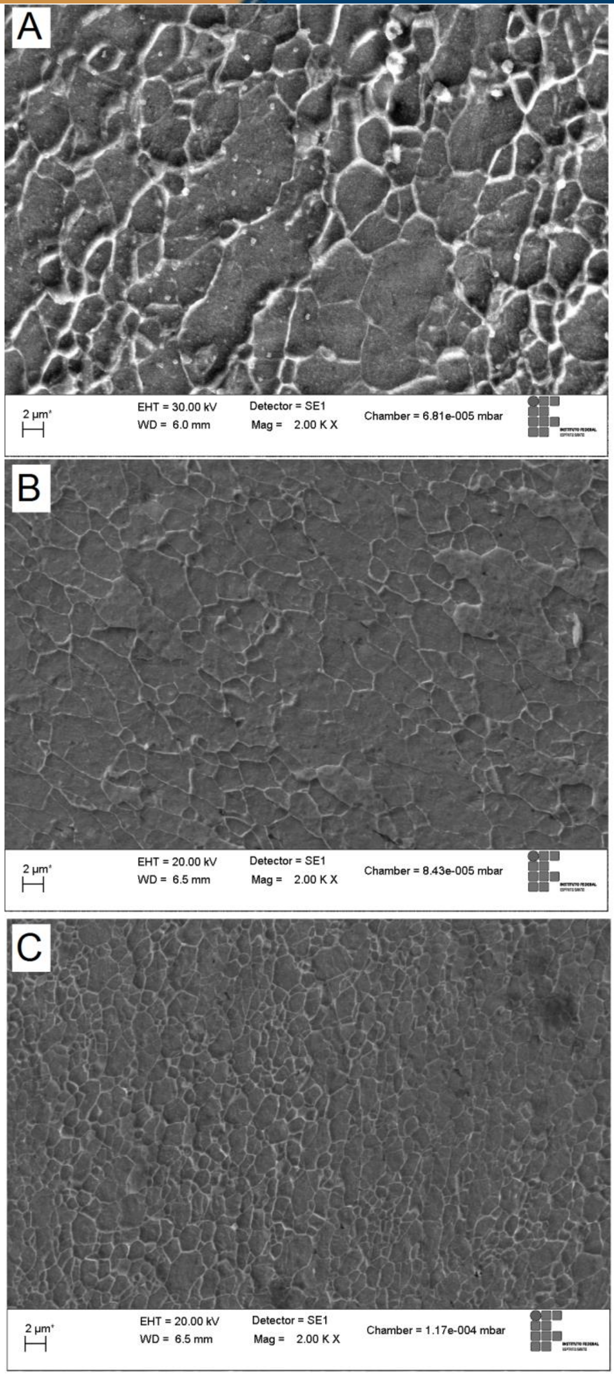

Figure 4. Scanning electron micrographs of microstructures obtained at the end of 5 cycles of microliged steel twist deformation. (A) subjected to deformation at 700 ° C. (B) subjected to deformation at 625 ° C. (C) subjected to deformation at 550 ° C.

dislocations. Finally at the temperature of 550 ° C there was the highest grain refining in relation to the other temperatures, as shown in figure 4 (C). At this temperature, most of the grains have equiaxial shape and size in the range of 2µm, size close to that obtained by other works (5,6).

Following the analysis of the strain-strain graph, we can observe the presence of peaks, which together with micrographs confirm the possibility of the occurrence of dynamic recrystallization during the process that resulted in the grain refinement and consequently the increase of the hardness of the material.
In Fig. 4 few regions of precipitation of perlite in the steel are observed. This may be justified by the low percentage of carbon present.
The process of severe plastic deformation causes the increase of the stored energy due to the introduction of new defects, in addition the niobium carbides can contribute to the hardening of the material despite the low density and to act in the limits of grain contouring, slowing its movement leading to the size of the ferrite (10). It occurs the formation of subgrains with the rearrangement of the dislocations and consequently the formation of contour of high angle due to the accumulation of the subgrains (11). With increasing deformation, new grains of ferrite are generated in the contours of the initial grains, these grains develop as a consequence of the gradual increase of disorientations between the grains (12). In addition, the final grain size of the ferrite is influenced by the residence time and the temperature of the deformation test.
Finally, the understanding of the grain refinement mechanisms involved during warm deformation becomes relevant to improve the production processes of low carbon microalloyed steels.

4 CONCLUSION

Through the results obtained it was possible to analyze the influence of the temperature on the severe plastic deformation of a microligado steel, simulating an ARB process.
It was observed that the decrease of the temperature during the deformation causes the greater grain refining, which reached the average size of 2μm to the temperature of 550 ° C.
The presence of niobium in the alloy may have contributed to refining by retarding the movement of grain boundaries. In addition to contributing to the occurrence of dynamic recrystallization in the material.
A hardness increase of 68% was obtained with respect to the annealed steel.
Finally, the torsion tests present good results in the ARB process simulation, which generates another form of analysis for severe plastic deformation methods.

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