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INFLUENCE OF SEVERE PLASTIC DEFORMATION OBTAINED BY WARM ROLLING ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF THE FERRITIC STAINLESS STEEL

Luana Alves Barbosa[1], Estevesson Ferreira Miqueletti[2], Eric Marchezini Mazzer[3], Dagoberto B. Santos[4] , Wagner Reis Costa Campos[5] e Jefferson José Vilela[6]

[1] Comissão Nacional de Energia Nuclear/Bolsista IC CNPq (CNEN/CDTN)
Av. Avenida Antônio Carlos, 6627.
31270-901 Belo Horizonte, MG.
luana_alves_barbosa@hotmail.com

[2] Universidade Federal de Minas Gerais (UFMG)
Av. Avenida Antônio Carlos, 6627.
31270-901 Belo Horizonte, MG.
estevess@demet.ufmg.br

[3] Universidade Federal de Minas Gerais (UFMG)
Av. Avenida Antônio Carlos, 6627.
31270-901 Belo Horizonte, MG.
marchezini@demet.ufmg.br

[4] Universidade Federal de Minas Gerais (UFMG)
Av. Avenida Antônio Carlos, 6627.
31270-901 Belo Horizonte, MG.
dsantos@demet.ufmg.br

[5] Comissão Nacional de Energia Nuclear (CNEN/CDTN)
Av. Avenida Antônio Carlos, 6627.
31270-901 Belo Horizonte, MG.
wrrc@cdtn.br

[6] Comissão Nacional de Energia Nuclear (CNEN/CDTN)
Av. Avenida Antônio Carlos, 6627.
31270-901 Belo Horizonte, MG.
jjv@cdtn.br

ABSTRACT

Generation IV reactors require research on new materials. For example, materials that will be used in the reactor vessel must be resistant to creep and have high toughness. Grain refining is a technique used to improve toughness. This grain refinement can be achieved by severe plastic deformation. In this work, the stainless steel 409 was used to simulate the EUROFER one type of ODS steel. The rolling process was applied to make the severe plastic deformation. The rolling was performed at 600°C which corresponds to the warm working condition in the absence of dynamic recrystallization. The rolling schedule studied allowed a logarithmic strain accumulation of 3.16. The rolled sheet had a yield stress of 822 MPa and a hardness of 302 HV. The grains became quite elongated characteristic of a severe plastic deformation. The recrystallization temperature of the rolled sheet was approximately 500°C. It was obtained by heat treatment and hardness measurement.

Keywords: Severe plastic deformation, Ferritic Stainless Steel, Rolling

1. INTRODUCTION

Generation IV reactors have been developed with some improvement over current reactors. Generation IV reactors are more economical, sustainable, safe, reliable, resistant to proliferation and safety. In the early 2000s, a panel of international experts selected six families of reactors to meet these expectations: the sodium-cooled fast reactor (SFR), the lead-cooled fast reactor (LFR), the gas-cooled fast reactor (GFR), very-high-temperature reactor (VHTR), the supercritical water-cooled reactor (SCWR) and the molten salt-cooled reactor (MSR) [1]. ODS (oxide dispersion-strengthened) steels are candidates to be applied to the pressure vessel of these generation IV reactors. But more research on the mechanical properties of these steels is needed.

EUROFER is a type of steel ODS. It is an alloy of iron and chrome. Yttrium oxide is dispersed in the grain boundary. These grains have nanometric dimensions. Several iron and chromium alloys do not change phase in the solid region. Severe plastic deformation (SPD) associated with a heat treatment can be used to refine the grain size in these situations. Some SPD techniques are being investigated as equal channel angular pressing (ECAP), high pressure torsion (HPT), accumulative roll bonding (ARB), asymmetrical rolling and multiaxial forging [2] [3]. The 409 ferritic stainless steel has a chemical composition similar to EUROFER. In this work, a high level of plastic deformation was applied by traditional rolling on 409 steel. The objectives of this work were: to perform a severe plastic deformation by warm rolling on 409 steel and to assess the effect of SPD on mechanical properties and microstructure.

2. METHODOLOGY AND DEVELOPMENT

The 409 steel studied in this work came from hot rolling. The plate was a semi-finished product. The thickness was 28.2 mm. The chemical composition of stainless steel 409 is shown in table 1.

Table 1: Chemical composition of 409 ferritic stainless steel (% weight).

C	Mn	Si	P	S	Cr	Ni	Mo	N
0.03	1.0	1.0	0.04	0.0015	10.50 a 11.7	0.50	-	0.030

* Quantitative chemical from catalogue of Aperam South America.

2.1. Experimental Procedure

2.1.1. Warm rolling

The sample was cut in the dimensions: 30 x 28.2 x 60 mm. The warm rolling was made in the two-high laboratory rolling mill mills, with a diameter roll of 200 mm, a mill table of 250 mm, capacity of 400 kN and FROHLING mark. The sample was heated to 600 ° C and then a soaking time of 15 minutes was made to homogenize the temperature. The sample was

deformed in 12 passes. At each pass, the sample was returned to the furnace at 600°C for 10 minutes. After the last pass, the sample was air-cooled to room temperature.

2.1.2. Mechanical test

The tensile tests were done on 409 steel as received and after severe plastic deformation. They were made a universal machine, Instron, model 5882, capacity of 100 kN. The tests were done according to E8 / E8M [4].

Hardness tests were performed on the 409 steel with severe plastic deformation which then received the different thermal treatments to define the static recrystallization temperature. They were made in a digital durometer, the DIGI-TESTOR 930 / 250N model. The tests were done according to ASTM E92 [5].

2.1.3. Metallography

The microstructures were analyzed by optical microscopy. Metallography was done on 409 steel as received and after severe plastic deformation. The electrolytic attacks with oxalic acid 5% were made with 5 volt electrical potential difference for 240 seconds.

2.1.4. Heat treatment

The recrystallization temperature was defined by means of heat treatment. One of the samples was heated to 300°C and the soak time was 30 minutes, and then cooled to 0°C to freeze the microstructure. The other samples followed the same scheme but at different temperatures: 400, 500, 600 and 700°C [6].

3. RESULTS

3.1. Warm rolling

Rolling was performed at 600°C. The initial thickness of the plate was 28.2 mm and the final thickness was 1.20 mm. Table 3 shows the rolling scheme. The accumulated logarithmic deformation was 3.16.

3.2. Mechanical properties

The results of tensile tests of the steel as received are shown in Table 3. And Table 4 shows the results of steel with severe plastic deformation. The yield stress and ultimate tensile strength of the rolled steel 409 increased in relation to the material received, but the elongation decreased. Figure 1 shows the stress-strain curve of steel 409 as received. Figure 2 shows the stress-strain curve of the rolled steel 409. When the thickness has reached 1.20 mm, the rolling mill cannot reduce the 409 steel plate.

The Vickers hardness of the 409 steel as received and with severe plastic deformation are shown in Table 5. The hardness of the rolled steel 409 increased relative to the material as received.

Table 2: Rolling scheme.

Number of Passes	Reduction (%)	ε
1	2.19	0.02
2	4.15	0.04
3	11.68	0.12
4	12.15	0.13
5	15.29	0.17
6	18.34	0.2
7	23.16	0.26
8	30.14	0.36
9	34.77	0.43
10	46.69	0.63
11	30.09	0.45
12	29.4	0.35
∑ε= 3,16		

*The results of rolling processes made in the Metal Forming Laboratory of UFMG.

Table 3: Mechanical properties of the 409 steel as received

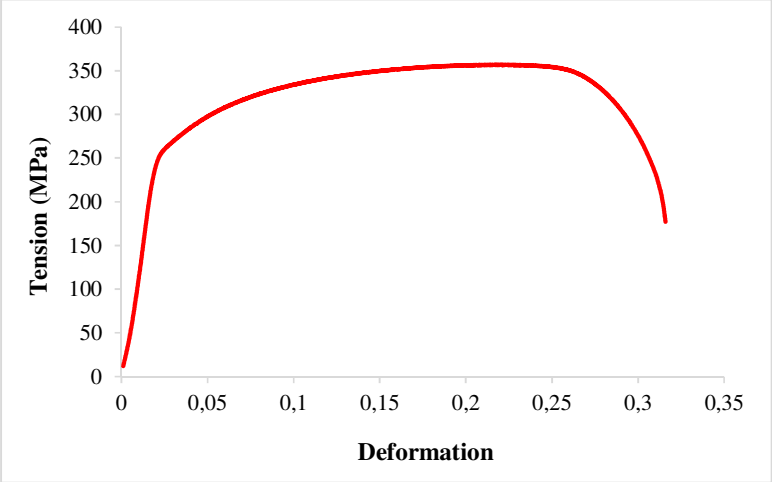
409 STEEL AS RECEIVED			
Specimens	**Ultimate tensile strength (MPa)**	**Yield stress (MPa)**	**Elongation (%)**
1	356.88	247.63	22.39
2	327.79	247.35	28.54
3	344.84	240.62	33.39
Average	343.17	245.2	28.11
Standard deviation	14.62	3.96	5.51

* The results of tensile tests made in the Mechanical Tests Laboratory of CDTN/CNEN.

Table 4: Mechanical properties of the 409 steel with severe plastic deformation.

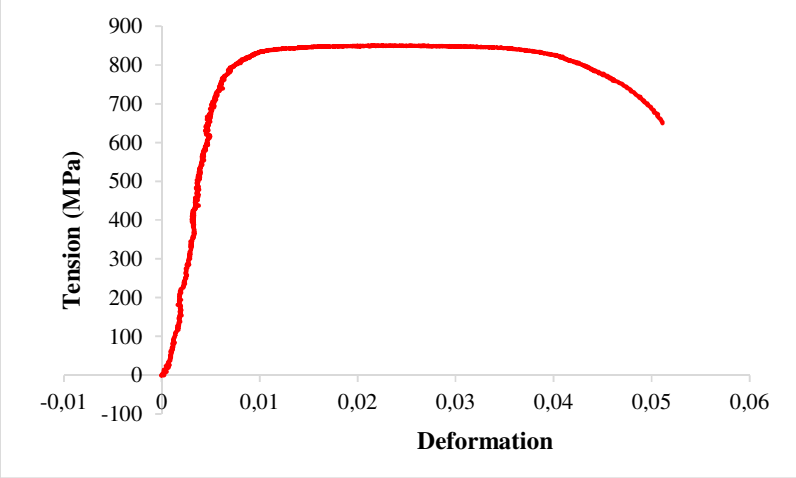
409 STEEL ROLLED			
Specimens	**Ultimate tensile strength (MPa)**	**Yield stress (MPa)**	**Elongation (%)**
1	854.72	835	2.16
2	831.81	816	5.31
3	849.28	816	5.11
Average	845.28	822.33	4.19
Standard Deviation	11.98	10.97	1.76

* The results of tensile tests made in the Mechanical Tests Laboratory of CDTN/CNEN.



* The curve obtained in the Mechanical Tests Laboratory of CDTN/CNEN.

Figure 1: Curve stress-strain of 409 steel as received.



* The curve obtained in the Mechanical Tests Laboratory of CDTN/CNEN.

Figure 2: Curve stress-strain of 409 steel with severe plastic deformation.

Table 5: Hardness HV of material as received and laminated

TOUGHNESS VICKERS	MATERIAL AS RECEIVED (HV)	LAMINATE MATERIAL (HV)
1	175.2	299.8
2	169.9	300.5
3	167.9	304.7
Average	171	301.67
Standard Deviation	3.77	2.65

* The results of Vickers hardness tests made in the Mechanical Tests Laboratory of CDTN/CNEN.

3.3. Microstructure

Figure 3 shows the microstructure of the steel 409 as received. The size of the grain was very large because the plate was a semi-finished product. The microstructure of the 409 steel with severe plastic deformation is shown in Figure 4. The grains were elongated grains in the direction of rolling and indicated absence of dynamic recrystallization.

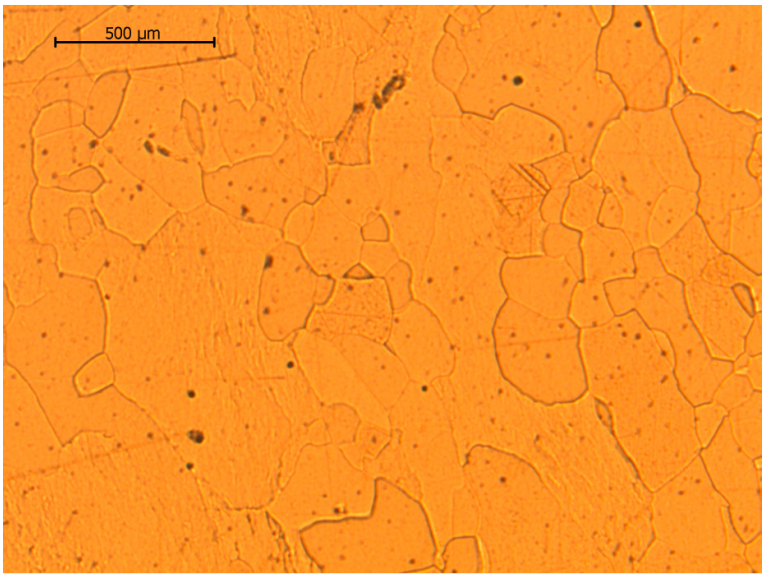


Figure 3: Microstructure obtained from the optical microscope of 409 steel as received.

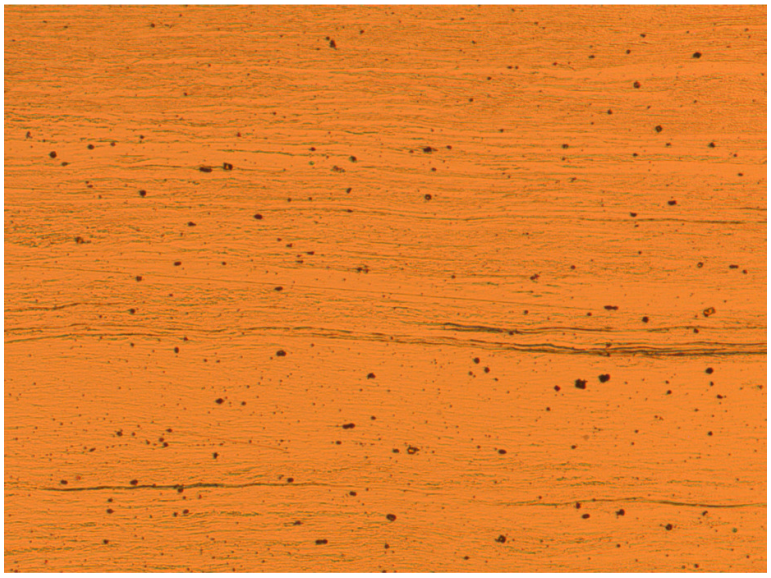
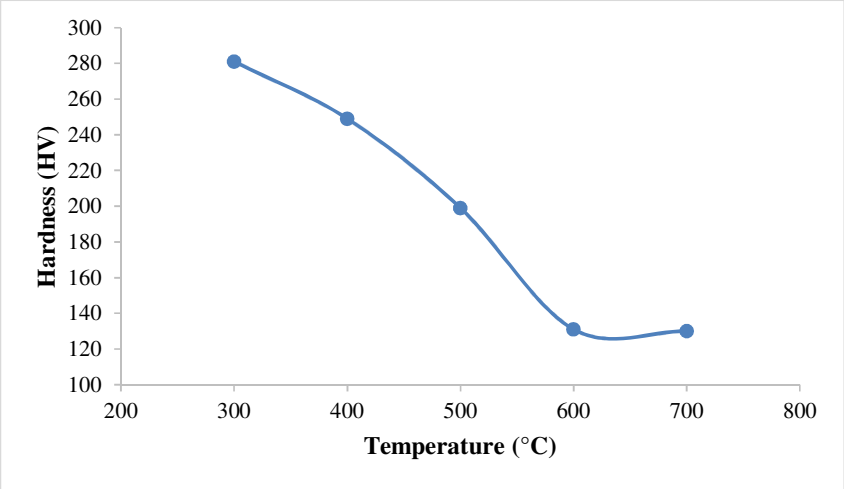


Figure 4: Microstructure obtained from the optical microscope of 409 steel with severe plastic deformation.

3.4. Heat treatment

Figure 5 shows the hardness versus temperature curve. The heat treatment indicates that the recrystallization temperature of the 409 steel with severe plastic deformation was approximately 500°C.



* The curve obtained in the Mechanical Tests Laboratory of CDTN/CNEN.

Figure 5: Curve temperature versus hardness.

4. CONCLUSIONS

In the rolling process the temperature of 600 ° C, the accumulation of logarithmic deformation was 3.16. When the thickness has reached 1.20 mm, the rolling mill cannot reduce the 409 steel plate.

The mechanical properties of the 409 steel with severe plastic deformation increased in relation the material received. The rolled steel had the yield stress of 822 MPa, ultimate tensile strength of 845 MPa and hardness of 302 HV.
The microstructure of the 409 steel with severe plastic deformation showed elongated grains with absence dynamic recrystallization.

The temperature of the curve with respect to hardness indicated that the recrystallization temperature was approximately 500 ° C for steel 409 with severe plastic deformation.

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