Mechanical Properties of Nanocrystalline and Ultrafine Grained Steel Obtained by Mechanical Milling

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ABSTRACT- The stress-strain response of steel (0.05 and 0.6 wt.% C) obtained by a warm consolidation process from mechanically milled powder has been studied by means of compression tests. The samples were consolidated and subsequently heat treated at different temperatures in order to obtain ferritic grain sizes within the nanocrystalline and ultrafine grained regimes.

INTRODUCTION: In recent years, the mechanical behavior of nanocrystalline (NC) and ultrafine grained (UFG) iron (Khan et al [2000]; Ma et al. [2003]) and steel (Zhao et al [2006]; Murty al. [2006]) has been studied. High strength and low ductility were observed, especially in the NC regime and UFG iron. In the case of UFG steels with medium carbon content (0.45-0.6 wt.%), a small amount of tensile uniform elongation can be achieved.

PROCEDURES, RESULTS AND DISCUSSION: Iron powder of commercial purity was severely deformed in a ball mill for 52 hours together with a small amount (0.8 wt.%) of EBS wax (Benito et al. [2007]). In the case of the 0.05 wt.%C steel specimens, the same iron powder was deformed for 17 hours with no presence of wax. The both kind of powders were first cold compacted at 1300 MPa and subsequently warm consolidated at temperatures between 425ºC and 500 ºC under a pressure of 850 MPa for 1 hour. Subsequent heat treatments were applied in both cases to obtain the desired ferritic grain sizes. All the consolidation and heat treatment temperatures are listed in Table 1 together with the corresponding grain sizes and mechanical properties. In all cases the relative density of samples was above 96%.

In NC samples the ferrite grains were randomly oriented and quite homogeneous in size (Fig. 1A and 1C). In the UFG samples a wider distribution of the ferrite grain size was found, so grains larger than the average were easily observed (Fig. 1B).

The true stress-strain curves obtained by compression test are shown in Fig. 2. The NC 0.6 wt.%C steel samples showed high strength and low ductility as the samples failed with low plastic deformation. However, the NC 0.05 wt.%C steel showed a better response since it was deformed up to a plastic strain of 42%. The samples underwent work hardening up to a strain level of 3.5%. From this point, a slight flow softening appeared until the end of the test. This effect has been related to the beginning of dislocation annihilation in the deformed NC grains (Wei et al [2004]). In the low UFG regime, the steel samples showed an increase in the total plastic strain (80%) although the work hardening capacity was not enhanced. Only when the ferritic grain size was around 1 μm the steel showed large strain hardening.

References:

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Figures:

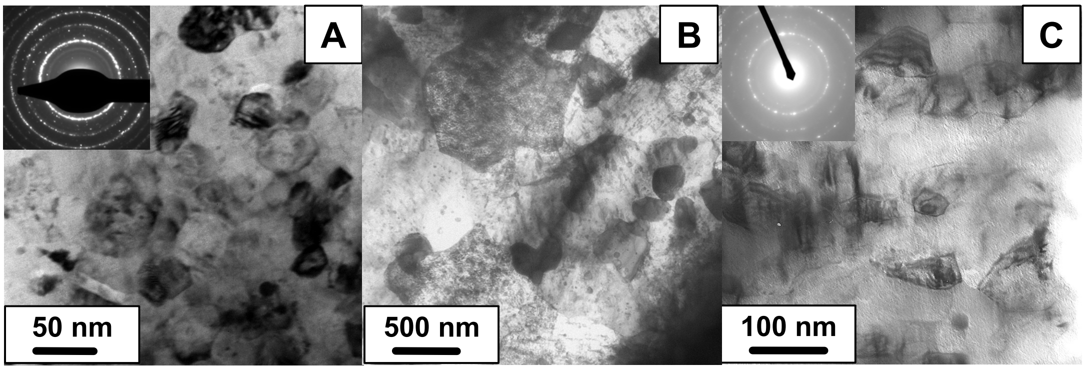

Figure 1. TEM micrographs showing the microstructure of A) 0.6 wt.%C steel with average grain size of 46 nm; B) 0.6 wt.%C steel with average grain size of 1 μm; C) 0.05 wt.%C steel with average grain size of 96 nm.

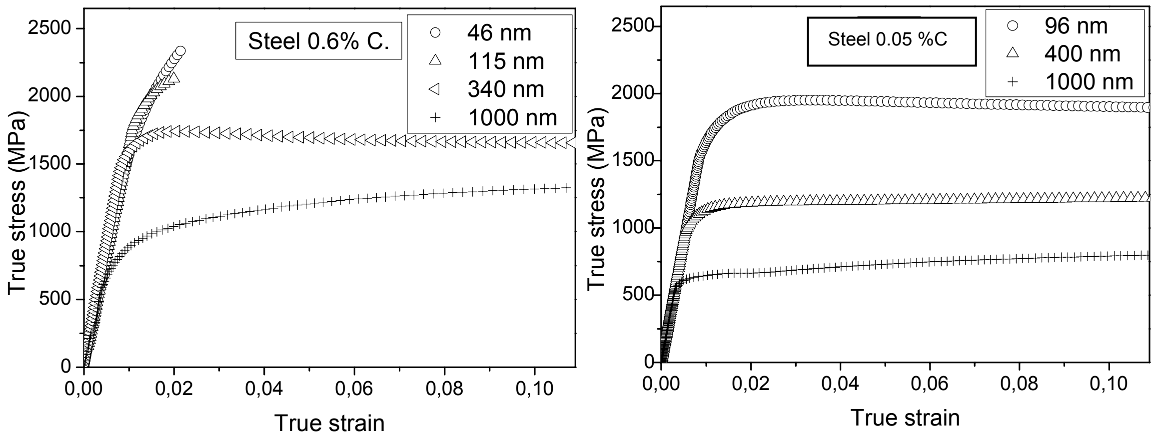

Figure 2. True stress-true strain curves obtained by compression tests for nanocrystalline and ultrafine grained samples.

Table 1: Consolidation and Heat Treating Temperatures, Ferritic Grain Size and Mechanical Properties for the 0.05 and 0.6 %C Steel Samples. WC: Warm Compaction, HT: Heat Treated, Y.S.: Yield Strength, M.S.: Maximum Strength.

Steel	Consolidation Procedure	Average grain size (nm)	$HV_{0.2}$ (GPa)	Y.S (MPa)	M.S (MPa)	Plastic Strain (%)	Strain Hardening (%)
0.6 %C	WC 460 °C	46 ± 21	8.4 ± 0.4	2040	2340	2.35	2.35
0.6 %C	WC 500 °C	115 ± 45	6.4 ± 0.4	1880	2140	2.1	2.1
0.6 %C	WC 500 °C + HT 700ºC	340 ± 220	4.7 ± 0.2	1635	1740	80	2.2
0.6 %C	WC 460 °C + HT 775ºC	~1000	4.1 ± 0.2	720	1390	80	35.2
0.05 %C	WC 500 °C	96 ± 36	6.0 ± 0.4	1724	1951	42	3.5
0.05 %C	WC 500 °C + HT 700ºC	400 ± 215	4.2 ± 0.3	1095	1238	80	22.8
0.05 %C	WC 460 °C + HT 750ºC	~1000	2.5 ± 0.2	620	870	80	47.9