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Microstructural and Mechanical Properties of a 304 Stainless Steel Fiber

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Steel fiber combines flexibility of a traditional textile fiber with high temperature resistance of steel. Stainless steel fibers are also resistant to mechanical stresses, in particular to shearing stress, contrary to glass, ceramic or carbon fibers, and resistant to corrosion. Steel fibers are obtained by successive wire bundle-drawings [1]. Annealed wire, which is commonly specified for sizes over 0.75 mm, in the 3*xx* series commonly has a tensile strength of 655 to 860 MPa and an elongation (in 50 mm) of 35 to 60% [2]. Austenitic stainless steel has a typical Young´s modulus of 193 GPa [3]. Fracture of metallic filaments differs in many respects from fracture of bulk samples. Particular fabrication processes, such as drawing, melt spinning or crystallization from the vapor phase for fibers, that are needed to obtain their small lateral dimensions, may introduce specific defects and textures, and have influence on the fracture behavior [4].

In this work the tensile mechanical behavior of a 304 austenitic stainless steel was investigated in fiber and bulk presentation. Single stainless steel fibers (~45 μm in diameter) were subjected to uniaxial tensile tests at room temperature using a Universal Fiber Tester [5], equipped with a load cell of 250 g calibrated from 0 to 100 g, with a precision of 0.01 g. The specimen gauge length was 30 mm and the fiber was gripped between two sets of jaws. The tests were conducted at a strain rate of 4.05×10^{-3} s^{-1} and 30 fibers were broken. Data acquisition used a PC linked to the fiber tester via a National Instrument interface card and WinATS 6.2 software from Sysma. In order to normalize the stress, the diameter of each fiber was systematically measured before each test by using a Mitutoyo LSM-500S laser apparatus, with an accuracy of 0.01 μm. Three bulk stainless steel specimens have been subjected to tensile tests at a strain rate of 8.33×10^{-3} s^{-1} and at room temperature, using an Instron Model 4400 Universal Testing System, according to the ASTM-E8 Standard. Scanning electron microscopy (SEM) characterization was performed using two JEOL microscopes, a JSM5800-LV and a JSM7401F operated at 15 kV and 5 kV, respectively; secondary electron emissions were used to obtain the images. For porosity measurements, an optical microscope Olympus PMG3 and an Image-Pro Plus image analyzer were used; before measuring the samples were metallographically prepared and 30 measurements were performed for both the fibers and the bulk specimens.

The mechanical properties were determined from tensile stress-strain curves; their values are shown in table 1. The low mechanical properties obtained for the fibers are attributed to their higher porosity percentage; the fibers porosity percentage is 3 times superior to that of the bulk material and the fiber pore diameter is 2.4 times higher than that of the bulk, as shown in table 1. From figures 1a and 2a it can be seen that the microstructure of both the fibers and bulk specimens is similar, with irregular austenite grains and dispersed carbide particles. However, it is evident that the pore size of the fibers (Fig. 1b) is bigger than that of the bulk specimens (Fig. 2b). Figure 1c presents the fracture surface of a stainless steel fiber. The inset in this figure reveals a cone-like fracture with inter- and transgranular portions; the quantity and size of the pores can be seen. Figure 2c shows the typical fail by necking during the tensile test of a stainless steel bulk specimen; at high magnification, the fracture surface showed to contain many deep dimples homogeneously distributed like honeycombs.

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Table 1. Mechanical properties, porosity percentage and pore size of stainless steel fibers and bulk.

Properties	Fibers	Bulk
Tensile strength (MPa)	522.57 ± 9.96	719.77 ± 1.16
Breaking strain (%)	21.56 ± 2.83	49.55 ± 0.79
Young´s modulus (GPa)	91.98 ± 19.26	121.52 ± 20.62
Porosity (%)	6.54 ± 1.75	2.13 ± 0.71
Pore diameter (µm)	4.48 ± 1.17	1.85 ± 0.55

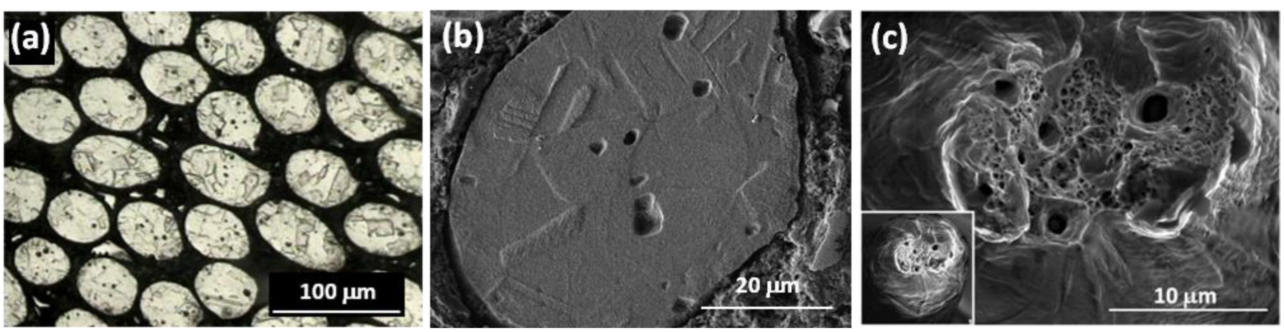

Fig. 1. (a) Optical micrograph of the stainless steel fibers showing their microstructure. SEM micrographs showing (b) the porosity within a fiber and (c) the tensile fracture morphology of a fiber.

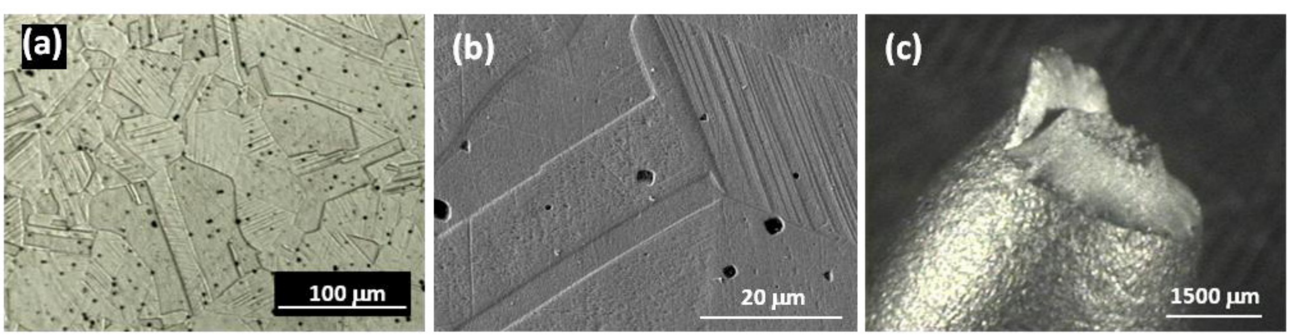

Fig. 2. (a) Optical micrograph of the stainless steel bulk material showing its microstructure. SEM micrographs showing (b) the porosity and (c) the tensile fracture morphology of the material.