Acta Microscópica, Vol. 1, Nº 1, May 1992, pp 52-57

Fractographic study of a sensitized AISI 304 type austenitic stainless Steel

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ABSTRACT

An investigation has been made into the effect of a sensitization treatment at 850 °C, on the tensile fracture mechanism at room temperature in AISI 304 type austenitic stainless steel. A partially microvoid coalescence mechanism intercalated with intergranular secondary cracking was observed. It is believed that the $M_{23}C_6$ type carbide promotes the formation of the secondary intergranular cracks which stopped the development of the main transgranular crack, being the later formed by microvoid coalescence mechanism. Both, strength and ductility were increased in the sensitized condition.

KEY WORDS
Stainless steel, sensitization treatment, fracture mechanism.

INTRODUCTION

Despite the fact that 304 austenitic stainless steel is an important engineering material in several energy systems and is used considerably at elevated temperatures, the fractographic features associated with practical work conditions, which could lead to sensitization, are not been well established. Austenitic stainless steels are the major structural materials for currently operating and planned fast breeder reactors all over the world [1]. Among this group of materials, type 304 is between the most used.

The four classical modes of fracture mechanisms according to several authors [2-5] are: cleavage, quasi-cleavage, intergranular separation and void coalescence. An additional fracture mode was described by Thompson et al [6], namely "Tearing Topography Fracture". Rarely one of this fracture modes encompass the entire surface. Normally, in fractographic work the fractographs presented focused on an area where micromechanisms developed locally and is not intended to be representative of the surface as a whole. On the other hand, El Soudani [7] proposed a classification of fracture surfaces, based on the concept of "dividing surface of a fracture surface", and quite recently, Wojnar et al [8], proposed a new classification, based on the modified degree of orientation. None of the last two approaches were used in the present work, since both are more useful from the point of view of quantitative analysis. Instead, this work reports on "classical" observations made in fracture surfaces of sensitized 304 stainless steel with emphasis on the competing fracture modes, which could lead to variations in some mechanical properties, with regard to the solution treated condition.

MATERIALS AND METHODS

Three smooth axisymmetric tensile specimens (Fig.1) were prepared from a commercial rolled bar, (chemical composition in Table I), homogenized at 1050 °C during 1 hour and quenched in water. The specimens were machined with a 2.54-cm gage length and a 0.635-cm gage diameter, then heated to 850°C during 24 hr and air cooled. Tensile tests were carried out at room temperature at a constant crosshead speed of 4.2×10^{-4} cm/seg. The fracture surfaces were examined with a scanning electron microscope, operated at 20 kV.

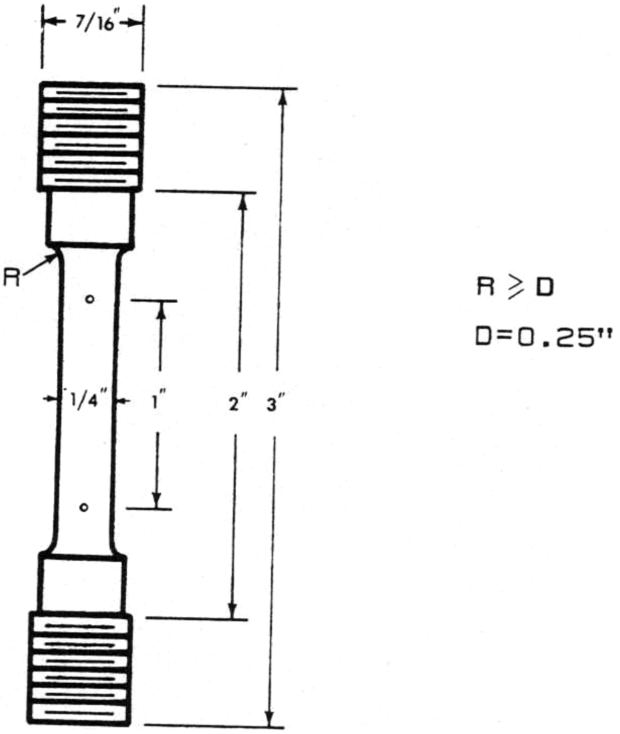

Fig. 1. Tensile test specimen geometry.

RESULTS AND DISCUSSION

Table I Chemical Composition of the 304 Stainless Steel Used (Wt %)

C	Cr	Ni	Si	P	S	Cu	Mo	Fe
0.070	17.89	9.69	1.45	0.35	0.022	0.09	0.20	balance

Fig.2 shows a general view of a typical fracture surface, in which various modes of fracture are present. The main fracture path was predominantly transgranular. However, the fractographic study indicated in all the specimens, numerous secondary cracks of a branched character. The showed fracture surface ocurred by the operation of various combinations of fracture mechanisms. In this figure are indicated:

(1) An intergranular separation, producing a well defined secondary crack.

(2) A secondary crack produced by an intergranular separation, plus microvoid coalescence.

(3) and (4) Microvoid coalescence areas. This kind of micromechanism dominates great part of the overall surface, i.e., the nature of the main fracture path was transgranular.

(5) A dimple rupture zone associated to an intergranular separation i.e., to a branch of a intergranular secondary crack.

(6) An internal wall of a intergranular zig-zag secondary crack.

(7) A dimple rupture zone which looks depressed respect to the portion of the fracture at the upper-left part of the fractograph, (A). This zone has been "stopped" by the intergranular secondary crack at (6), and

(8) A portion of a grain which has been transgranulary separated by microvoid coalescence, but showing laterally a wall of an intergranular secondary crack. This grain looks elevated respect to the zone portion of the main transgranular fracture path showed in B.

The zone between arrows, shows a surface covered with oriented dimples which represent the presence of a local shear mode of rupture.

The general geometry overwieved, suggests that intergranular secondary cracks stopped the development of the main transgranular crack, which continues to

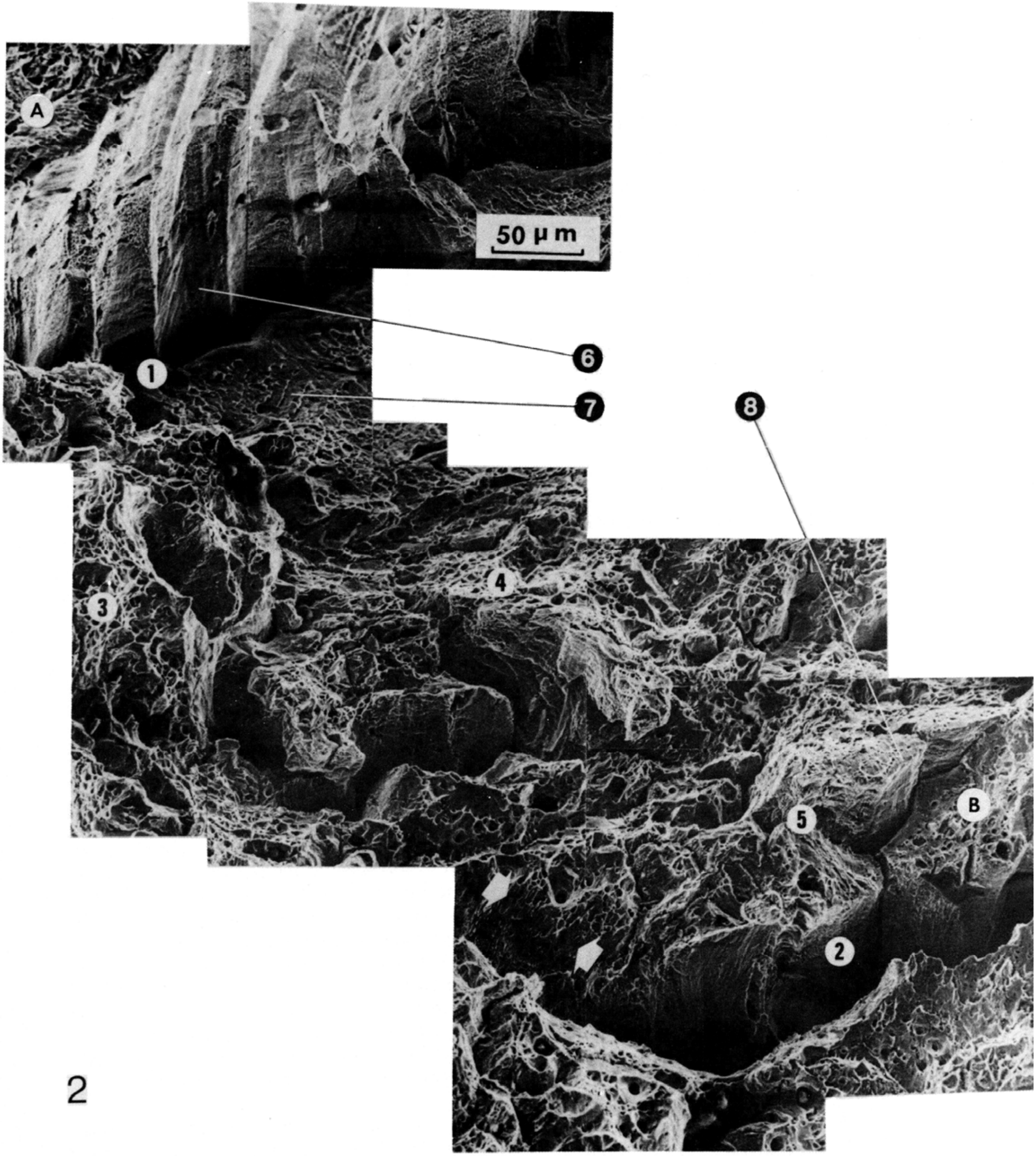

Fig. 2. Montage of SEM fractographs showing the nature of the micromechanisms of fracture, corresponding to the sensitized condition. (For details see text)

Fig. 3. Fracture appearance (SEM) of a representative zone which has been failed by microvoid coalescence mechanism.

propagate in step-by-step manner to from the overall fracture surface.

Figure 3 shows a detailed picture of a representative normal dimple rupture, like the one shown in 3 on Fig.1. Figure 4, on the other hand, reveals the main features of the intergranular separation similar to that showed in 1 and 6 on Fig.1. Both detailed fractographs, 3 and 4, reveal the very different nature of the micromechanisms which contribute together to the complex topography of the fracture surface.

It is believed, that the sensitization products, i.e., $M_2\ _3C_6$ carbides, alter the balance between the conditions which promotes pure microvoid coalescence mechanism in the solution treated condition, at room temperature, as suggested by Ashby[9], in favor of a partially microvoid coalescence mechanism intercalated with intergranular secondary cracking in the sensitized condition.

Typical mechanical properties at room temperature for the sensitized condition were:

0.2% proof stress: 285 MPa, tensile strength: 581 MPa and %elongation: 63%. In the solution treated state, the corresponding values are: 242 MPa, 539 MPa and 49%. This agree with the observation that the precipitation of $M_{23}C_6$ carbide does not necessarily correlate directly with detrimental effects resulting from such precipitation [10]. The intergranular corrosion lags considerably behind the initiation of

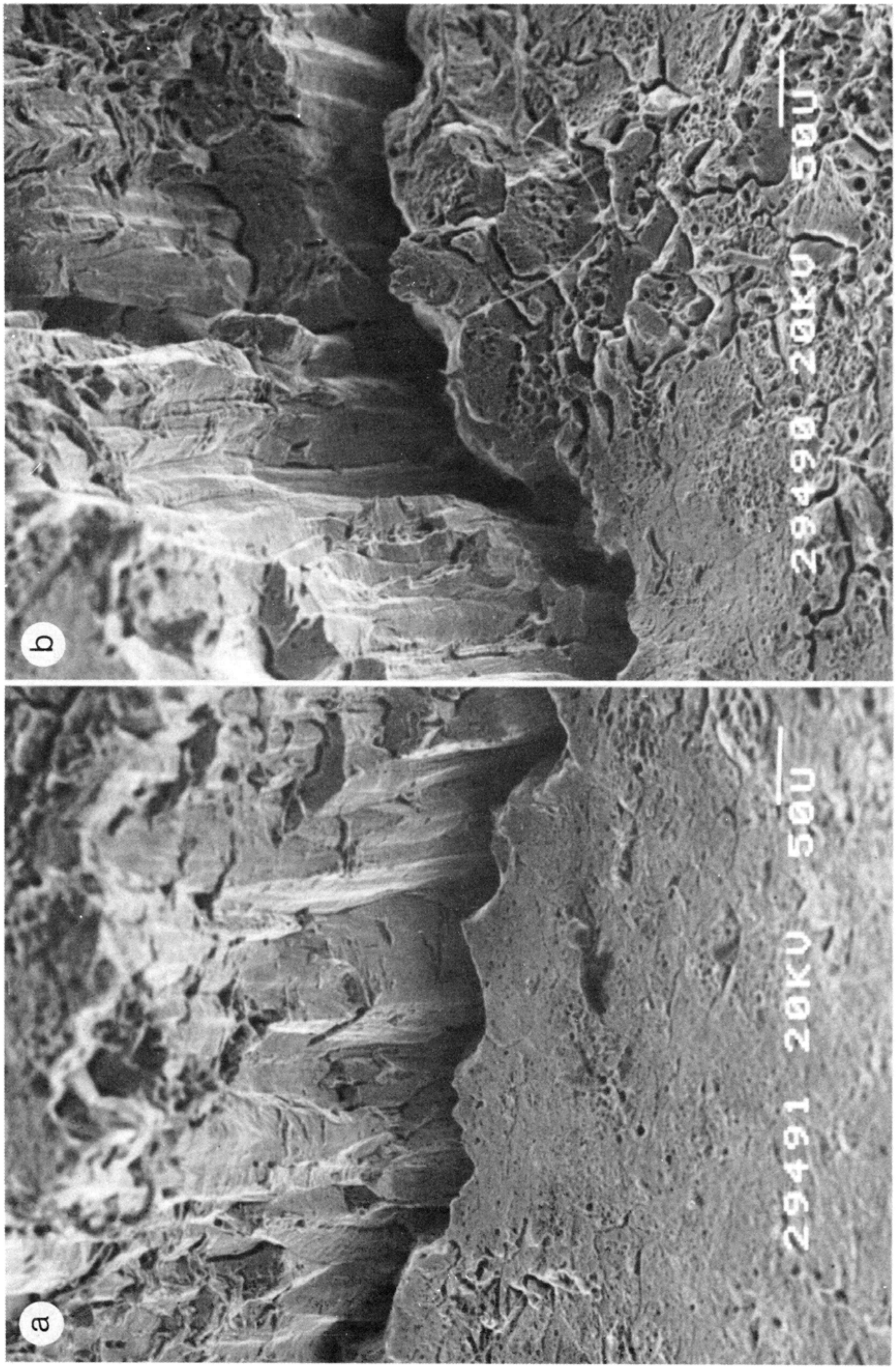

Fig. 4. (a) and (b). Development of intergranular secondary cracks (SEM)

carbide precipitation.

CONCLUSION

The observations made in this work, may have general validity for the complex fracture topography studied, but further observations and techniques can be used to elucidate the complete machanisms. For example, profiles of fracture surfaces can be correlated with the local fracture topography [11], or a relationship between local microstructure and fracture surface could be established [12].

In general, some insight has been gained into the combined mechanism of fracture in the sensitized AISI 304 stainless steel, and image-analysis methods are currently been carried out to enterely characterize the fracture surfaces. Among others, two of the more promising parameters, which could lead to complete the information about the micromechanisms of fracture, are the linear roughness R_l, [13,14], and the fractal dimension [15,16], both related to the fracture profile.

ACKNOWLEDGMENTS

This work was supported by the Scientific and Humanistic Development Council of the Central University of Venezuela, and the Organization of American States.

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