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V. VODOPIVEC
Institute of Metallurgy, Ljubljana, Yugoslavia

The role of twin boundary/grain-boundary intersections on microcracking behaviour of AISI 304 stainless steel deformed in slow tension and creep at 650°C

Studies of intergranular crack formation in metals at elevated temperatures have shown that triple points may provide both preferential sites for the nucleation of cracks and barriers to their propagation [1-5]. Although it has been shown that the growth of cracks originating at grain-boundary triple junctions may be arrested or interrupted at twin boundary/grain-boundary intersections [6, 7] relatively little is known concerning the influence of these intersections on the crack propagation process is austenitic stainless steel.

Recent work has shown evidence for the formation of cracks and cavities along twin boundaries in 304 stainless steel [8]. These results suggest that the twin boundaries may behave in a manner similar to grain boundaries under the proper conditions.

The purpose of this communication is to report quantitative observations concerning the influence of twin boundary/grain-boundary intersections (hereafter referred to as TGI) on the intergranular cracking behaviour in AISI 304 stainless steel deformed in the slow tension and creep rupture modes at a test temperature of 650°C. The experimental test data and the chemical analysis of the alloy are available in [5].

Fig. 1 shows the crack morphology that will be used in this analysis. In addition to those cracks whose lengths, in terms of grain-boundary facets, fall in the interval $l \leqslant 2$ and are not terminated at TGI [5], a non-negligible number of triple-point cracks were also observed to terminate at TGI (See Fig. 1c and e). Cracks not associated with triple junctions but associated with TGI's were also observed. These cracks are shown in Fig. 1i to k. Secondary cracks [9] are defined as those which are not associated with triple points (Fig. 1g to k). The cracks in both these groups were, therefore, evaluated in a manner similar to that used for the triple-point cracks previously discussed [10]. Relatively few cracks with lengths $l > 2$ were observed to terminate at TGI [10].

The distribution of triple-point cracks terminated at TGI's, as well as secondary cracks associated with TGI's, is plotted in Fig. 2 as a function of deformation rate. It is apparent that both the intergranular cracks related to TGI's and the secondary cracks increase with decreasing deformation rate (i.e. decreasing stress levels). This observation is consistent with the overall intergranular crack results for these specimens where triple junctions are involved [5] and suggests a correlation with the tendency for strain associated with grain-boundary sliding.

There is a strong indication that the propagation of triple-point cracks may be interrupted at TGI's. This is mainly based on the observation that there are non-negligible number of triple-point cracks which occupy sites between triple points and TGI (as shown in Figs. 1c and e, and 2). Although it is difficult to visualize the actual cracking process, it can be safely assumed that the intergranular cracks have a greater tendency to nucleate at or near the triple point and then proceed toward the TGI and the next triple point. This circumstance may be explained by the fact that the surface energy [11] and stress concentration due to the applied stress at triple junctions are higher than those at TGI's. The majority of cracks observed are triple-point cracks which again supports this idea. Fig. 3a shows the angular incidence with respect to the applied stress of triple-joint cracks which are filled between the triple junction and TGI (Fig. 1c). Cracks with a length of less than one boundary facet are plotted in Fig. 1c. The

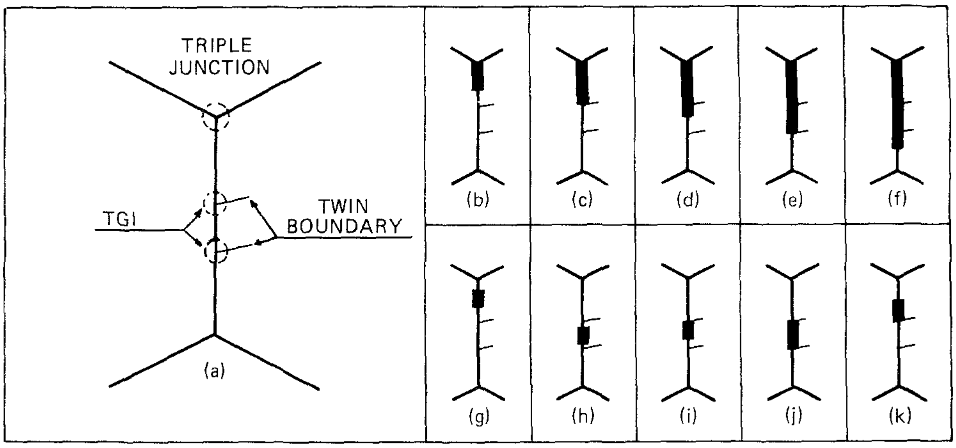

Figure 1 Schematic drawing showing various types of cracks.

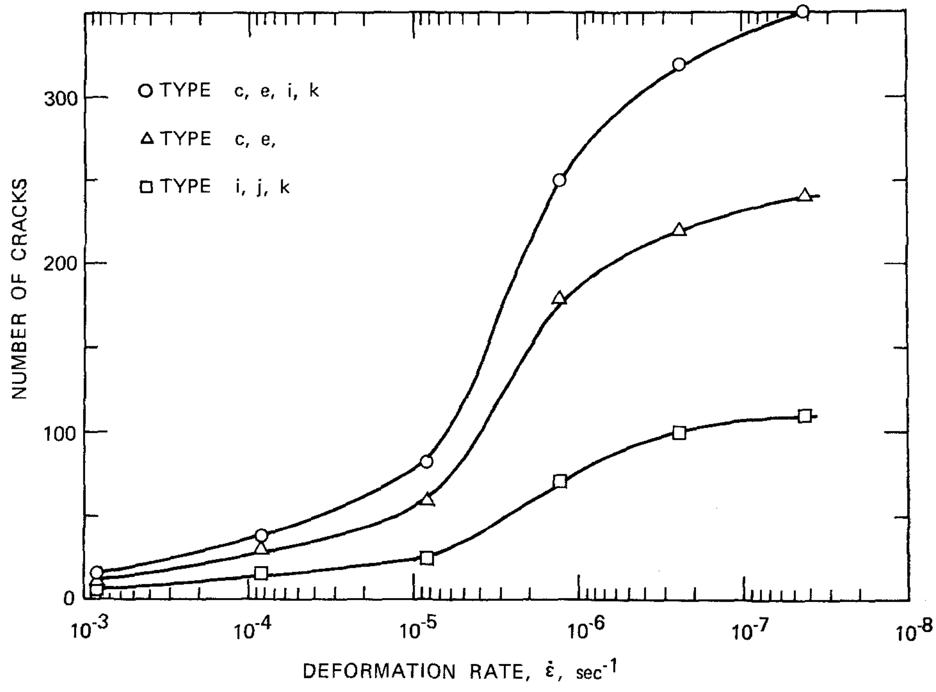

Figure 2 Number of intergranular cracks associated with twin boundary/grain-boundary intersection (TGI) as a function of deformation rate.

angular orientation of these cracks is consistent with those triple-point cracks which are not associated with TGI [5].

There is a further experimental result indicating that the secondary cracks appear, at times, to originate from TGI. Approximately 1 to 3% of the total population of cracks observed in each specimen are found to be secondary cracks which occupy sites between TGI. 1 to 4% are found to be those lying between TGI and boundaries not associated with TGI (Fig. 1i and k). From the above observations, it is concluded that the role of the TGI appears to be similar to that of the triple-point junction in the normal cracking process.

However, the extent of the role of TGI acting as a barrier to crack growth as well as being a nucleation site for cracks in the creep fracture behaviour is certainly dependent on many factors such as the grain size, temperature,

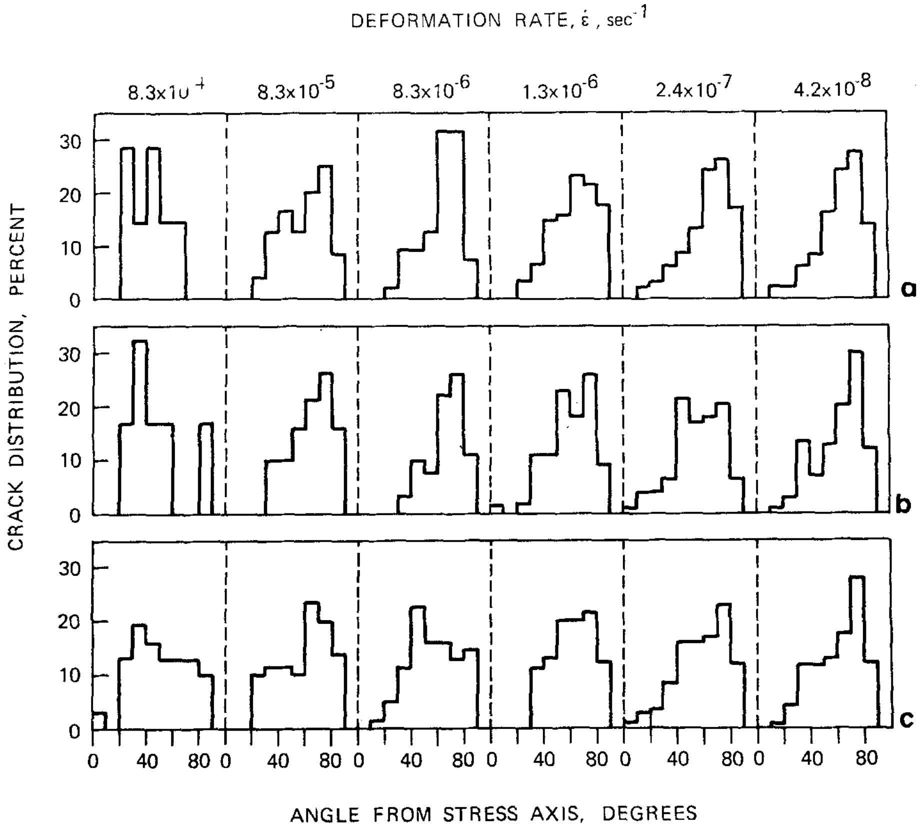

Figure 3 Angular percentage distribution of the different types of intergranular cracks shown in Fig. 1. 1: (a) types c and e; (b) types i, j and k; (c) types g to k.

deformation rate, impurity levels, etc. along with the surface energy and the grain orientation relative to the applied stress for both the grain boundary and the twin boundary considerations.

Slow deformation at elevated temperature has been known to be a competitive process between intergranular deformation and grain-boundary sliding. In the 304 stainless steel employed in this study, it is found that the ratio of grain-boundary sliding strain to total elongation is increased when the deformation rate (i.e. stress level) is decreased [10]. This is consistent with the results shown in Fig. 2 in the sense that the number of triple-point cracks and secondary cracks, regardless of their relationship with TGI, is increased when the grain-boundary sliding component of the strain is increased with the decrease in the deformation rate.

In one study of secondary cracks which were formed in copper, Gittins and Williams [9] suggested that the secondary cracking may be affected by the triple-point cracking because of the plastic strain field ahead of the triple-point cracks. However, in this study of 304 stainless steel, careful examination shows that there is a predominance of secondary cracks formed along the boundary facet where no triple-point cracks were observed to occur. Furthermore, as shown in Fig. 3b and c, the angular orientation of secondary cracks shows the same behaviour as that of triple-point cracks [5]. From the preceding observations together with the result that the considerable number of secondary cracks are related to TGI, it appears that the secondary cracking mode is essentially the same as the triple-point cracking mode. It is a reasonable conclusion since the role of TGI is quite similar to that of triple junction in the cracking behaviour. It would be especially true in the case of coarse grain size materials such as the 210 μm size employed in this study. This cracking behaviour could be different in fine grain size materials because there are more triple-point sites available for cracking.

It is worth noting that approximately 5% of the intergranular cracks are found to be pure secondary cracks (Fig. 1g and h). This clearly demonstrates that the triple points and TGI's are not necessarily the only nucleation sites for crack formation. The degree of cracking follows from triple point junctions, TGI, grain boundary, to twin boundary. It is interesting to note that the interfacial energies most likely also follow in that order.

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H. NAHM
J. MOTEFF
Department of Materials Science and Metallurgical Engineering, University of Cincinnati, Cincinnati, Ohio, USA

A correlation between dielectric breakdown and mechanical strengths of alkali halides

Alkali halides represent a class of "simple" ionic solids which lend themselves to theoretical investigations attempting to correlate their fundamental properties, such as dielectric breakdown fields and mechanical strengths, with some of their basic parameters, e.g. chemical composition, magnitudes of electrostatic binding, lattice parameters and lattice energies. The purpose of the present note is to point out that the magnitudes of the experimental dielectric breakdown fields for alkali halides are directly related to their mechanical strengths as represented by their elastic modulii. The possible theoretical basis of this correlation will also be indicated.

The dielectric breakdown in an alkali halide is a field-induced phenomenon [1] and the parameter characteristic of the dielectric strength is thus the experimental value of the dielectric breakdown field; these values for various alkali halides have been critically reviewed [1] and used recently in another study [2]. The mechanical breakdown strength for a solid may be represented by the experimental value of its elastic modulus and the elastic modulii of alkali halides have been reported by Gilman [3]. The magnitudes of these two parameters for those alkali halides for which the data are available are given in Table I. A plot of dielectric breakdown fields against the elastic modulii shows a good straight line correlation (Fig. 1) in which high dielectric strength is associated with high mechanical strength. This correlation would tend to suggest that the basic factors determining the dielectric and mechanical strength for alkali halides are probably the same.

It has been shown recently [4] that the dielectric breakdown fields for these alkali halides (Table I) are inversely related to their lattice constants. Gilman [3] has shown that the elastic modulii of alkali halides are inversely related to their interatomic distances (lattice constant for an alkali halide is twice the interatomic distance between its constituent atoms). It is not surprising, therefore, that the dielectric breakdown fields for alkali halides are directly related to their elastic modulii (Fig. 1); it should perhaps be added that this rather important point has not