On the nucleation of the martensite transformation

THE standard description of the austenite–martensite transformation includes the statement that once the material reaches the martensite start temperature, or below, then the transformation occurs immediately[1]. Hence, if a nucleus is present in the material, then growth occurs to an extent determined by the transformation temperature. We expect, therefore, that there should be no time delay in this transformation and that the amount of martensite should depend on the transformation temperature, for a given grain size and composition[2]. If there is a time delay in the appearance of martensite, again at a temperature at or below the martensite start temperature (M_S), then it is important to show this by establishing that no growth of martensite occurs while a specimen is held at or below M_S. We show here that the nucleation event and not the growth behaviour of martensite can be affected by a common metallurgical treatment. The experiment is carried out at a constant grain size and composition with the result that we can unambiguously relate the change in nucleation rate to the present procedure.

The experiment was carried out as follows: samples of Fe–30% Ni were arc melted into rods, swaged to a final size of 0.7 mm and then annealed at 1,200 °C for 20 h. In this way we obtained a constant grain size and also homogenised the structure. Thin samples, treated as described, were cooled from 1,200 °C to a series of temperatures, held another 2 h at the respective temperatures and then quenched to room temperature. Samples treated in this way were subsequently cooled to temperatures at and below M_S, held for various lengths of time and then kept at room temperature for various observations. While samples were cooled to the respective transformation temperature—typically the bath was a precooled alcohol bath—the acoustic emission which accompanied the transformation was recorded. This procedure ensured that: (1) the only independent variables in the procedure were the temperature the sample was quenched from, the temperature the sample was transformed at and the time at this temperature. All other variables were held constant. (2) The recorded acoustic emission signal registered the time necessary for the transformation to start. This, as we shall show, was a yes or no situation because when an acoustic emission signal is recorded, then martensite can be observed by optical microscopy. Conversely, if an acoustic emission signal were not recorded, then no martensite platelets would be observed in those samples.

These experiments gave the following results. The acoustic emission which accompanies the austenite–martensite transformation is found to be a function of time at transformation

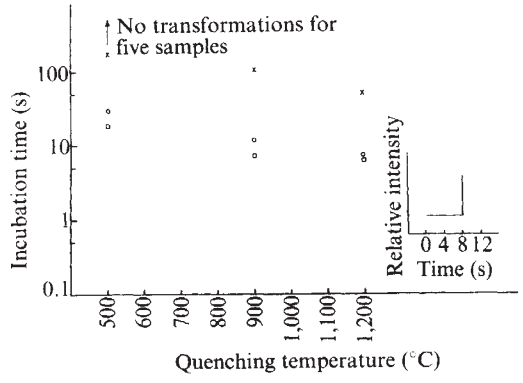

Fig. 1 Incubation time, as defined in inset for various samples which have been quenched from various high temperatures. The inset shows a typical acoustic emission pattern for Fe–30% Ni sample previously heated to 1,200 °C for 20 h then quenched to room temperature and transformed at −28 °C. Transformation temperatures: ×, −25 °C; ○, −28 °C; □, −30 °C.

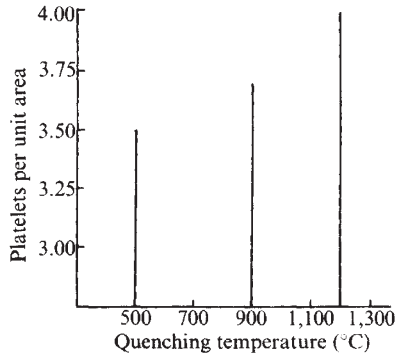

Fig. 2 Observed density of martensite platelets in samples quenched from various high temperatures.

temperature, with this time depending on the previous high temperature at which the sample is equilibrated (Fig. 1). As these data show, the higher the temperature from which the sample is quenched the shorter the time, t_0, for the transformation to start. Also, as the transformation temperature is lowered, t_0 decreases.

In conjunction with the acoustic emission studies we have also measured the occurrence of martensite as a function of quench temperature at constant transformation temperature (Fig. 2). These data showed that, consistent with the acoustic emission data, the higher the temperature the more abundant the martensite. The density of martensite was obtained by standard optical microscope techniques, which involved counting the number of martensite platelets intersecting lines drawn on several optical micrographs—the standard method of assessing the density of a second phase.

Finally, in samples quenched from various temperatures, and held at the transformation temperatures for times $< t_0$, that is, where no acoustic emission signal was observed, we repeatedly observed no martensite platelets in the samples. This showed, under the ordinary definition of a transformation in this system, that no nucleation event had occurred, as once a nucleus is formed it is expected to grow. This proves that this procedure can distinguish between the nucleation event and the growth process in the martensite transformation.

An obvious interpretation of the present results, taking into account quenching studies in other metals and alloys, is that as we decrease the quenching temperature, we retain less vacancies. This can lead to fewer dislocation loops in those samples quenched from lower temperatures. Dislocation loops have already been suggested as possible nuclei for the transformation[3], but very little has been done to exploit this approach. Small dislocation loops can provide a nucleus for the transformation, as loops, such as Shockley loops, can introduce regions of shear.

The present experiments show that there is a delay time in the transformation process and that this delay is affected by the temperature from which the sample is quenched. We have also shown that during this delay time no observable transformation occurs. A more quantitative and complete version of the present experiments will be reported elsewhere.

J. M. GALLIGAN
T. GAROSSHEN

Department of Metallurgy,
Institute of Materials Science,
University of Connecticut,
Storrs, Connecticut 06268

Received 9 May; accepted 2 June 1978.

1. Christian, J. W. *The Theory of Transformations in Metals and Alloys* (Pergamon, Oxford, 1975).
2. Entwisle, A. R. & Feeney, J. A. *The Mechanism of Phase Transformations in Crystalline Solids*, 156 (Institute of Metals, Spec. Publ. No. 33, 1969).
3. Cottrell, A. H., *An Introduction to Metallurgy*, 2nd edn, 383 (Crane Russak, New York, 1975).