KINETICS AND PLATE DIMENSIONS OF ISOTHERMALLY FORMED MARTENSITE IN AN Fe-Ni-Mn ALLOY

by

GAUTAM GHOSH

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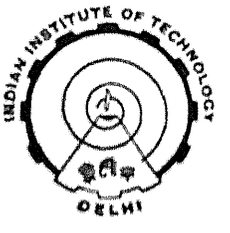

Department of Applied Mechanics
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
1985

CERTIFICATE

This is to certify that the thesis entitled "Kinetics and Plate Dimensions of Isothermally Formed Martensite in an Fe-Ni-Mn Alloy" by G. Ghosh submitted to the Indian Institute of Technology, New Delhi (India) for the award of the degree of Doctor of Philosophy in Applied Mechanics Department is a record of bonafide research work carried out by him under my supervision and guidance. The thesis work, in my opinion, has reached the standard fulfilling the requirements for the Doctor of Philosophy Degree. The research report and results presented in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma.

V Raghavan 23/9/85

(V. Raghavan)
Professor
Department of Applied Mechanics
Indian Institute of Technology
New Delhi-110016 (India)

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(G. Ghosh)

ABSTRACT

The kinetics of isothermal martensitic transformation is influenced by the test temperature, a superimposed elastic stress, prior plastic strain of the austenite and the grain size of austenite. The isothermal mode of transformation provides an ideal opportunity to measure the plate dimensions on a firm basis, as the reaction temperature can be controlled accurately and also the transformation rate is measurable as a function of time. In the present work, the isothermal kinetics as well as the plate dimensions have been studied as a function of reaction temperature, a superimposed elastic stress, grain size and prior plastic strain of the austenite.

An Fe-23.2Ni-2.3Mn alloy is used here for all experiments. The experimental procedures include homogenization, rolling and wire drawing, austenitization, doping, plastic deformation of austenite at room temperature, optical and electron metallography. The virgin austenite is transformed to martensite at nine isothermal test temperatures from -70°C (203K) to -196°C (77K). The effect of a superimposed elastic stress field has been studied at three test temperatures: -85°C (188K), -143°C (130K) and -196°C (77K). The plastically deformed specimens are transformed at -85°C (188K), -100°C (173K), -140°C (133K) and -196°C (77K). The kinetics of the transformation is followed by measuring the electrical resistance of the samples by means of an Autobalance Universal Bridge. The change in resistance is calibrated in terms of the

volume fraction of martensite determined by point counting. The microstructures have been characterized using the optical microscope as well as the TEM. The Fullman method has been used extensively to evaluate the mean dimensions of the martensitic plates. The fraction of the partially transformed grains (G_g) and the extent of plate association (EPA) are obtained by areal and lineal analysis respectively.

The alloy exhibits a typical C-curve behaviour with the nose of the C-curve around -110°C (163K). The kinetic parameters such as the autocatalytic parameter and the activation energy for nucleation are obtained by using the Raghavan-Pati-Cohen approach. The autocatalytic parameter increases slowly but continuously with decreasing reaction temperature. The activation energy for nucleation decreases with decreasing temperature. The computed transformation curves obtained by the above approach agree well with the experimentally observed transformation curves upto a significant extent of transformation. For a particular test temperature, the reaction progresses by a combination of the spreading out of clusters of plates and filling-in of the pockets, both occuring simultaneously. The mean semithickness-to-radius ratio ($\overline{c/r}$) is found to increase with increasing martensitic fraction at any test temperature, but it decreases with decreasing temperature for a given martensitic fraction. The initial $(\overline{c/r})_i$ ratio i.e. ($\overline{c/r}$)

at ~ 0% martensite decreases by a factor of 2, as the test temperature decreases from -70°C (203K) to -196°C (77K). This indicates that a fraction of the transformational strain energy is to be released which decreases with decreasing reaction temperature. This fraction estimated to be about 0.50 at -70°C (203K) and 0.04 at -196°C (77K).

The effect of a superimposed elastic stress on the transformation kinetics and the plate dimensions have been studied by applying various levels of uniaxial tensile stress at three test temperatures. At a given test temperature, with the increasing level of applied stress, the initial nucleation rate and the autocatalytic parameter increase, whereas the activation energy for nucleation decreases. However, the increase in nucleation rate or the decrease in activation energy is more at higher temperatures than at lower temperatures. Three linear equations with different slopes are obtained between the activation energy for nucleation and the total driving force at the three test temperatures, where the elastic stress experiments are carried out. From these slopes, the activation volumes for the dislocation motion associated with the nucleation process are obtained. The activation volume for nucleation is found to decrease by a factor of 15 as the test temperature decreases from -70°C (203K) to -196°C (77K). The activation energies for nucleation at

different stress levels have been calculated by applying the concept of thermally activated motion of dislocations. Also, the activation energies for nucleation at different test temperatures (where no stress was applied) are calculated from the Olson-Cohen model. In most of the cases the calculated and the observed activation energies are in good agreement. The $(\overline{c/r})$ ratio is found to increase with the increasing level of applied stress at any test temperature. The calculated (c/r) agrees reasonably well with the experimental $(\overline{c/r})_i$.

The effect of prior plastic strain of austenite on the transformation kinetics and plate dimensions have been studied at various plastic strains from 0.005 to 0.05. For any test temperature, the initial nucleation rate and the autocatalytic parameter decrease, whereas the activation energy for nucleation increases. At higher temperatures, the decrease in the initial nucleation rate or increase in the activation energy is more than at lower test temperatures. By taking into account the increase in flow stress due to work hardening at the corresponding test temperatures and plastic strains, the activation energies for nucleation are calculated with the help of the temperature dependence of the activation volume. As before, the assumption is that the nucleation of martensite involves a process of dislocation motion. The calculated and the experimental activation energies are in satisfactory agreement. The work hardened

matrix is found to restrict the growth of the martensite plates. The $(\overline{c/r})$ ratio decreases with the increasing degree of prior plastic strain at any test temperature and martensitic fraction. The (c/r) ratio is calculated as a function of prior plastic strain and test temperature by taking into account the increase in the flow stress due to work hardening. The calculated (c/r) and the experimentally observed $(\overline{c/r})_i$ values are found to be in good agreement.

Using three grain sizes 0.019 mm, 0.048 mm and 0.09 mm (mean linear intercept), the effects of grain size on the transformation kinetics and plate dimensions have been studied. Both the activation energy for nucleation and the autocatalytic parameter are found to be independent of grain size at any test temperature. This confirms that the autocatalytic parameter is uniquely related to the driving force. The observed nucleation rates are found to increase by a factor of 2-3 with increasing grain size from 0.019 mm to 0.09 mm. At any reaction temperature and martensitic fraction f, the fraction of the austenitic grains G_g partially transformed to martensite increases with increasing grain size. Also, for any given grain size and f, G_g increases with decreasing reaction temperature. At any test temperature, the extent of plate association (EPA) is independent of f and grain size. However, EPA is found to increase with decreasing test temperature and in the presence of a superimposed elastic stress but decreases in the prestrained austenite.

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