

**MORPHOLOGICAL CHANGES DURING MARTENSITIC  
TRANSFORMATION IN FE-Ni AND Fe-Ni TERNARY ALLOYS**

**I. I. T. LIBRARY DELHI**

*by*

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## CERTIFICATE

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The thesis entitled " **MORPHOLOGICAL CHANGES DURING MARTENSITIC TRANSFORMATION IN Fe-Ni AND Fe-Ni TERNARY ALLOYS**" is being submitted by **Mr. P.Visvesvaran** to Indian Institute of Technology, Delhi for the award of degree of Doctor of Philosophy.

He has been working on this problem since January 1988. In the opinion of the Departmental research Committee, the work reported in this thesis is his bonafide work, and has not been submitted elsewhere for the award of any other degree. Further the committee feels that the work is worthy of consideration for the award of the degree of Doctor of Philosophy.

(Prof. N.K.Gupta)

Chairman, DRC

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## Abstract

The factors that determine the transformation kinetics, morphology and substructure in martensitic transformation are poorly defined. However the fundamental factors, such as the transformation temperature ( $M_s$ ), the relative strength of austenite and martensite, the critical resolved shear stress for slip and twins in martensite and the stacking fault energy of austenite are considered to be important along with basic geometrical factors such as grain size and the formation sequence of the plates during the progress of the transformation. A lot of interest has been shown in recent years to measure plate dimensions using quantitative metallographic techniques adopted by Fullman and Smith and Guttman. Though systematic study on the plate dimensions in Fe-Ni alloys has been carried out by earlier workers, a concrete conclusion about the factors responsible for the drastic change in the plate dimensions could not be drawn on the basis of experimental results.

Attempts are made in this thesis work to examine whether the factors related to the transformation temperature or composition are responsible for various morphological features and the changes in the plate dimensions. A systematic study is carried out in Fe-Ni binary alloy and three sets of ternary alloys such as Fe-Ni-X where X = Cr, Mo and Co. In the case of Fe-Ni-Cr and Fe-Ni-Mo alloys the composition of both Ni and the ternary addition (Cr or Mo) are chosen in such a way that their  $M_s$  are maintained within a narrow range, and in Fe-Ni-Co alloys. Study is done by keeping Ni content constant at 33.3% and varying cobalt content from 0 to 10%. In order to make sure that the basic

factors did not affect the  $M_b$  temperature, a coarse grain structure is selected for all the alloys.

Electrolytically pure powdered Fe, Ni and Co, Cr beads and Mo rods were used as starting materials. The powdered metals were separately hydrogen treated at 1223 K for an hour to remove the oxide inclusions which might hinder like a grain boundary during the progress of the transformation. About 50 alloys of 20 g each were prepared in a non-consumable electrode argon arc furnace. The alloys were homogenized at 1473 K for 48 hours and the final dimension of 4 X 4 mm<sup>2</sup> rods were obtained by rolling. The intermediate anneals were given at 1173 K whenever the deformation was about 50%. The grain size of all the alloys was more or less same and coarse (around .14 mm) by giving same final anneal of half an hour at 1473 K. The  $M_b$  of all the alloys were found to be within  $\pm 2$  K. A chemical mixture of 80% H<sub>2</sub>O<sub>2</sub> (30% volume), 5% HF and 15% distilled water was used to reveal the microstructural details. The quantitative measurements of grain size, volume fraction and the mean dimensions of martensite plates were carried out directly at 625X magnification. The dimensions of the plates are represented through mean semithickness [ $\bar{c}$ ], mean radius [ $\bar{r}$ ], mean semithickness to mean radius ratio [ $\bar{c}/\bar{r}$ ] and mean semithickness to radius ratio [ $\overline{(c/r)}$ ]. These parameters are evaluated using Fullman equations. The measurements were made in samples which showed only plate morphology.

Various morphological features such as interface characteristics, butting of plates, parallel plate formation, mid-rib characteristics, retained austenite and characteristics of internal twins that are commonly observed in all the alloy systems are discussed.

In Fe-Ni alloy system, compositions ranging from 29 to 34 Ni Wt% are studied. Lath martensite is the dominant morphology at lower Ni contents and at higher transformation temperatures. The transition from lath to plate morphology takes place at the very narrow range of temperature between 268 K and 255 K corresponding to alloys of composition 29% and 29.5% Ni. Such transition was reported earlier at around 29% Ni ( $M_b = 258$  K). In alloys with Ni content 31% and above, plate martensite is the only morphology seen. The martensite plates appear to thin down gradually with increasing Ni content. Fine internal twins are observed on both sides of the midribs in all the samples. With increasing Ni content and correspondingly decreasing transformation temperature, the austenite-martensite interface smoothen and becomes straight, and the extent of transformation twinning also increases. The  $(d\lambda)$ ,  $\bar{c}$  and  $\bar{r}$  appear to decrease with increasing Ni content and correspondingly decreasing transformation temperature. The plates thicken to a lesser extent as the plates tend to grow radially.

In Fe-Ni-Cr alloy series, a new procedure has been adopted to prepare a set of alloys with  $M_b$  close to 135 K. A plot of Cr in Wt % and Ni equivalent ( $Ni_{eq} = Ni_{removed}$  in Wt% / ( $Cr_{added}$  in Wt% in lieu of  $Ni_{removed}$ )) shows a linear relationship indicating that Cr replaces more and more Ni with its further additions, while keeping the  $M_b$  constant. With increasing Cr and at the same time decreasing Ni content, the following are noticed. The shape of the plate which seemed to be lenticular become more planar. The extent of irregularities in the austenite-martensite interface gradually increase and many plates show irregular interfaces in both sides. The appearance of small plates with smooth interfaces are observed along with irregular plates. The small plates increase

in number and the irregular plates which appeared relatively big are rarely spotted. The small plates appear like a butterfly martensite. Finally, very thin needle-type plates are seen which lead to lath martensite. The aspect ratio does not show any systematic variation with the variation in composition of a set of alloys with same  $M_b$ , whereas the plot of  $\bar{c}$  and  $\bar{r}$  show a linear relationship against the same. Here, the plates thicken proportionately along with their radial growth.

In Fe-Ni-Mo alloys, a set of alloys with the transformation temperatures slightly in the higher range ( $M_b = 170$  K) was prepared. The plot of Mo versus Ni equivalent show a linear relationship indicating Mo also replaces more and more Ni (though with different proportion) with its further additions, while keeping the  $M_b$  constant. Observations on the morphological features and the trend of plate mean dimensions with compositional variations are seen to be similar to that observed in Fe-Ni-Cr alloys.

It is found that the initial additions of Co to Fe-Ni raised the burst temperature where as further additions suppresses the same. The temperature and Co content at which the reversal effect takes place depend on Ni content. With increasing Ni content, the reversal effect takes place at a lower cobalt concentration and at a lower transformation temperature. The presence of lath or butterfly martensite has not been noticed with the alloys containing 33.3%Ni and above. Through out the series of cobalt alloys containing same Ni content, a wide range of plates, long to short and thick to thin, are noticed in every alloy irrespective of cobalt content. With increasing Co content, the fraction of thick plates to thin plates decreases, the austenite-martensite interface becomes smoother, the number of plates showing twins and the extent of twinning decrease. The  $(d/h)$  ratio and  $\bar{c}$  decrease while  $\bar{r}$  appears to increase with increasing

Co content. The comparative study of  $(d/\lambda)$  in Fe-Ni series and Fe-Ni-Co series of alloys with their burst temperatures reveals that they follow the same trend with temperature.

A comparative analysis is done on various features studied in all the systems and conclusions are made. In the case of Fe-Ni alloys, while increasing the Ni content, the burst temperature decreases and consequently this makes factorial identification difficult whether the factors related to composition or the transformation temperature ( $M_b$ ) are responsible for various morphological features. But in the case of Fe-Ni-Cr and Fe-Ni-Mo alloys, by confining the burst temperature of a set of alloys same, it has been noticed that different morphologies and the variations in the substructural features of plate morphology are closely related to composition, and the aspect ratio seems independent of the compositional variations. In the case of Fe-Ni-Co alloys, though the effect of the addition of Co to Fe-Ni on transformation temperature is quite different from that of Ni addition, the aspect ratio varies with the transformation temperature in the same way. So, it appears that the factors related to the transformation temperature are responsible for the huge changes in the aspect ratio.

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