Journal of the Nigerian Association of Mathematical Physics,
***Volume 8* (*November 2004*).**

On the kinetics of martensite formation in a duplex stainless steel

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Abstract

Studies have been made of the kinetics of martensite transformation in a duplex stainless steel of composition 21Cr-6.6Ni, 2.5M$_0$, 1.6Cu, <.0.03C (wt.%) Solution treatment at 1050^{0}C for 1 hr was followed by deformation at the subzero temperatures of –70 and –196^{0}C. The kinetics of the $\gamma \rightarrow \alpha^1$ transformation in the duplex stainless steel is confirmed to be sigmoidal in nature by the results obtained. Nearly constant rate of transformation occurs up to 50% reduction, then a stimulating effect thereafter. Saturation of the transformation would occur in reduction range of 50-80%.

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1.0 Introduction

The stainless steels, in solving most corrosion problems, have assisted the development of numerous industrial sectors. In such applications as chemical and nuclear energy industries, corrosion resistance has to be combined with high strength, good weldability and formability as well as appreciable level of toughness. The single phase alloys would not provide this combination.

Ferritic steels exhibit yield strengths superior to those of austenitic steels. The former also have the advantage of being cheaper [1]. However in terms of work hardening, formability, tensile duclility and welding, the austenitic steels are superior. Of corrosion resistance, the austenitic steels are superior in reducing media and more severe conditions. Two-phase, austenite (γ) + ferrite (α) or duplex alloys provide an advantage solution over austenitic and ferritic steels having, essentially, the best combination of the properties exhibited by the single phase alloys [2-4].

The general level of mechanical properties and forming characteristics of high-chromium stainless steel can be equaled or exceeded by many other types of steels at a lower cost [1]. However a measure of improvement can be achieved by suitable alloying additions and control of microstructure through deformation.

The deformation characteristics of these steels have not been extensively reported. Cooke [5] studied the deformation (at room temperature) and annealing behaviour of 26Cr – 6.5 Ni and 28Cr – 10.5Ni duplex alloys and Blickarski [6] studied a 25.5Cr, 6.6Ni, 0.007C alloy, also rolled at room temperature. The authors [5-6] did not report the formation of martensite (α^1).

The emphasis of the work reported in this article is on formation of martensite, in a duplex stainless steel, induced by deformation (by rolling) at sub-zero temperatures, and essentially the kinetics of such $\gamma \rightarrow \alpha^1$ reaction.

2.0 Experimental procedure

The analysed composition of the duplex stainless steel is shown in Table 1

Table 1: Alloy Composition

C	C_r	Ni	Mn	Si	M_0	C_u	S	P
0.026	20.60	6.62	1.60	0.46	2.45	1.64	0.018	0.031

The alloy was supplied as 4mm thick plate. Samples of the alloy were solution treated for 1 hr at 1050^{0}C followed by water quenching. They were then cold rolled at –70^{0}C and –196^{0}C to reductions in thickness in the range 10-80%. The reductions were carried out in series of small passes, the samples being re-equilibrated in the baths after each pass. The –70^{0}C and –196^{0}C baths were made of acetone+ liquid nitrogen and liquid nitrogen respectively.

Transmission electron microscopy was used for structural studies. For this, 3mm discs were punched and thinned electrolytically using 10% perchloric acid in ethanol at 12V, 0.5 amp and ice water temperature. Changes in ferromagnetic content were measured using a Suchsmith magnetic balance [7].

3.0 Results and discussion

3.1 Ferromagnetic phase change:

In estimating the ferromagnetic change resulting from the deformation-induced α^1 it was noted that the ferrite phase (α) is ferromagnetic i.e. the ferromagnetic content after deformation is of two components: wt.% α^1 and the constant wt.% α. The amount of α^1 formed was then calculated as percentage of the non-magnetic γ originally present. This is designated % ($\gamma \rightarrow \alpha^1$).

$\gamma \rightarrow \alpha^1$ transformation occurs at reductions as low as 10% reduction, increasing with amount of reduction. The -196^0C rolled samples have more α^1-content. A typical structural feature is shown in plate 1. In this plate martensite with lath morphology is seen in the original γ domain. Plate 1 is High Resolution Dark Field (HRDF); the dark regions correspond to untransformed inter-lath austenite.

Plate 1**: HRDF** showing typical martensite laths. The ample was reduced 20% by rolling at -196^0C.

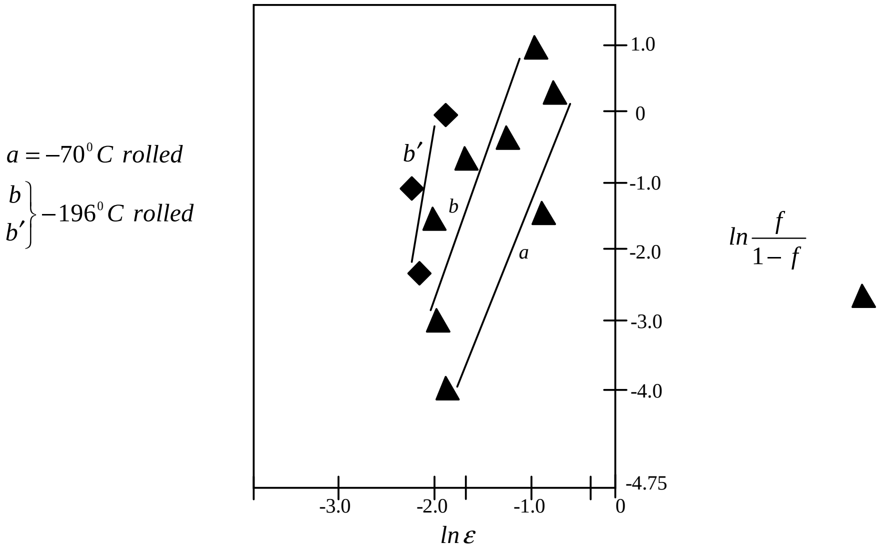

Figure 1: Graph of $ln\frac{f}{1-f}$ **vs** $ln\,\varepsilon$

3.0 Kinetics of martensite formation

For strain-induced martensite formation at constant temperature the relationship between strain and degree of martensite transformation is known to be of sigmoidal nature [8-9]. The relationship proposed by Olson and Cohen [8] is as follows:

$$f = 1 - exp\left\{\beta - \left[1 - exp(\alpha\varepsilon)\right]^n\right\} \qquad (3.1)$$

where f = fractional amount of martensite formed,
ε = strain
n = a fixed exponent, and
α and β are temperature-dependent parameters.

Equation (3.1) relates the kinetics of the α^1-transformation to initial formation of shear bands as observed in the present work but because α and β are not known, reducing this equation to a useful form will involve a lot of oversimplification. However a simpler relationship, which has shown a good fit to experimental data, is that proposed by Angel [9]:

$$ln\,\frac{f}{1-f} = n\,ln\,\varepsilon + K \qquad (3.2)$$

where
n and K are constants;
n is independent of temperature and alloy composition , while
K is dependent on these parameters.

The graph of $\ln \dfrac{f}{1-f}\ vs\ \ln\varepsilon$ is seen to be approximately linear (Figure 1). The slopes for -70^0C and -196^0C are similar being about 2.5 (Figure 1, a & b). Angel [9] reported a value of 3 for the slope. A limiting value (M_T) of degree of α^1 transformation was then assumed as Angel did. Based on observations in this work $M_T \sim 70\%$. Then f was recalculated as

$$\frac{M}{M_T}$$

where
M = degree of α^1 transformation at a lower reduction.

The resulting graph, Figure1, *b′*, has a slope of ~3 and is in good agreement with Angel. A sigmoidal relationship between martensite formed and strain is thus indicated. Infact the ferromagnetic content of the samples deformed at -70^0C showed an increase of only about 5% up to 40% reduction. At 80% reduction the content has increased to ~70%, suggesting a stimulating effect. Saturation would have occurred in reduction range of 50% - 80%. That saturation was not observed is explained by lack of reductions between 50% and 80%.

4.0 Conclusion

Martensite is induced by rolling the duplex alloy at sub-zero temperatures.

The kinetics of the $\gamma \rightarrow \alpha'$ reaction is unaffected by any interaction between γ and α coexisting in the duplex. Infact the $\gamma \rightarrow \alpha'$ transformation is of sigmoidal nature.

A nearly constant rate of transformation precedes a stimulating effect, and saturation of the transformation is reached at higher reduction levels.

Acknowledgement

Acknowledgements are made to Professor D.R.F. West for supervision, Professor D.W. Pashley for provision of research facilities, University of Benin for a research grant and the Creusot Loire Steel Co. for supplying the alloys.

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