Microstructure of Duplex Lamellar Phases in an Fe-37.3wt. %Ni-3.58wt. %Al-3.3wt. %Ti-0.2wt. % C Alloy

J. Kim, W. Choo

► To cite this version:

J. Kim, W. Choo. Microstructure of Duplex Lamellar Phases in an Fe-37.3wt. %Ni-3.58wt. %Al-3.3wt. %Ti-0.2wt. % C Alloy. Journal de Physique IV Proceedings, 1995, 05 (C8), pp.C8-329-C8-332. 10.1051/jp4:1995847 . jpa-00254096

HAL Id: jpa-00254096

<https://hal.science/jpa-00254096>

Submitted on 1 Jan 1995

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Microstructure of Duplex Lamellar Phases in an Fe-37.3wt.%Ni-3.58wt.%Al-3.3wt.%Ti-0.2wt.%C Alloy

J.H. Kim and W.K. Choo

*Korea Advanced Institute of Science and Technology, Dept. of Materials Science and Engineering,
373-1 Kusong-dong, Yusong-gu, Taejeon, Korea*

Abstract. A mode of grain boundary precipitation in Fe-37.3wt.%Ni-3.58wt.%Al-3.3wt.%Ti-0.2wt.%C alloy aged at 823K has been investigated by transmission electron microscopy. Fine γ' particles of $L1_2$ -type ordering firstly precipitated within the γ matrix during ageing treatment at 823K. The aged matrix phases (γ and γ') were later encroached on by the grain boundary lamellar phases. Quite uniquely, these duplex fine lamellae are composed of alternately aligned ferrite and γ' platelets. These two phase constituents in the lamellae are separated by the interface parallel to both $\{110\}_\alpha$ and $\{111\}_{\gamma'}$ planes.

1. INTRODUCTION

Since the age-hardening phenomenon was recognized in austenitic (γ) Fe-Ni-Al-C alloys [1,2], more investigations have been carried out on the microstructure and phase constitution of these alloys [3,4]. Low carbon alloys of this system can be fairly ductile although they are age-hardenable [5]. The age hardenability is ascribed to the matrix precipitates which have ordered $L1_2$ or $L'1_2$ structure depending on the degree of interstitial carbon supersaturation in the fcc γ matrix. In the low carbon alloys, the predominant precipitate is of the $L1_2$ -ordered γ' phase.

In addition, heterogeneous grain boundary precipitation of cubic carbides on ageing of γ phase Fe-Mn-Al-C alloys has been observed [6,7]. In rapidly solidified Fe-31.3wt.%Mn-8.7wt.%Al-2.0wt.%C alloy aged at 923K, colonies composed of lamellae of alternately arranged cubic κ' carbide and γ phase platelets encroached on the γ matrix dotted by metastable κ' precipitates after a lengthy ageing [7]. The crystallographic orientation relationship between the two phases in the lamellae has the cube-to-cube correspondence. This is quite understandable because κ' carbide is an $L'1_2$ -ordered intermetallic in which a carbon atom occupies the body center position in the $L1_2$ -ordered γ' unit cell. A fine lamellar structure was also reported in rapidly solidified Fe-5wt.%Ni-8wt.%Al-2.0wt.%C alloy on ageing at 823K [3]. The constituents of the grain boundary lamellae in the latter alloy were ferrite (α) and κ' phases, but no clear-cut epitaxial relationship could be established. Recently, in an Fe-42.4wt.%Ni-4.15wt.%Al-0.45wt.%C alloy aged at 823K, cementite and γ' phase constituting the grain boundary lamellae were reported to have the Pitsch's orientation relationship with respect to each other [6].

The scope of the present work is directed toward clarifying the epitaxial aspects of grain boundary precipitates in Fe-37.3wt.%Ni-3.58wt.%Al-3.3wt.%Ti-0.2wt.%C which is high in austenite stabilizing nickel content, but low in carbon content within the matrix.

2. EXPERIMENTAL PROCEDURE

An Fe-Ni-Al-Ti-C ingot was prepared by air induction melting using high purity materials. The ingot was homogenized at 1473K for 4 hours and subsequently hot- and cold-rolled to 1mm-thick sheets. After the

oxide scale was removed, test specimens cut from the sheets were solution-treated at 1473K for 1 hour. The chemical composition of the alloy was found to be Fe-37.3wt.%Ni-3.58wt.%Al-3.3wt.%Ti-0.2wt.%C by wet chemical analysis. Heat treatments were carried out in a 50NaNO₂-50KNO₃ salt bath at 823K. All the specimens were sealed in vacuum and water-quenched after the ageing treatment. Thin foils for electron microscopy were prepared in a 10 perchloric acid - 90 ethanol electrolyte and examined on a JEOL 200CX operating at 160kV.

3. RESULTS AND DISCUSSION

From previous x-ray diffraction studies, it could be confirmed that the matrix of the as solution-treated Fe-37.3Ni-3.58Al-3.3Ti-0.2C alloy is solely austenitic. In the diffraction, TiC lines were identified. It is believed that TiC particles were formed during solidification.

In a specimen aged at 823K, grain boundary reaction is noticeable in the transmission electron image. Fig. 1(a) shows a bright field (BF) image in the vicinity of a grain boundary of such a specimen after 100 hour ageing treatment at 823K. In this image, colonies of grain boundary lamellar precipitates of different crystallographic orientation are visible in the right hand half of the figure as marked A. Fig. 1(b) is a selected area diffraction pattern (SADP) in [011]_γ zone of the left hand side of the image as marked B. The region around B is believed to be a part of a grain which is not intruded by the penetrating precipitate boundary front. Ordering superlattice spots, which were absent in the as solution-treated condition, are observed in the SADP. This pattern indicates that {100} type ordering leading to the ordered L₁₂ structure (γ'-Ni₃Al type) has taken place, and hence γ' particles of L₁₂ structure are seen to be present in the matrix after ageing.

Fig. 1 BF image of Fe-37.3Ni-3.58Al-3.3Ti-0.2C aged at 823K for 100 hours in the vicinity of a grain boundary (a). Its SADP in [011]_γ zone (b) taken from the retained matrix region marked as B shows the L₁₂-type ordering in the matrix. No diffraction pattern other than that of {100} ordering is observed.

In order to investigate the crystallographic relationship among the grain boundary lamellar phases, a more detailed phase analysis was conducted in the lamellar region. Fig. 2(a) is an SADP of a colony of the lamellae of a specimen aged at 823K for 28 hours. At a first glance, it can be interpreted as an diffraction pattern of a lattice modulated structure. The squeezed hexagonal fundamental pattern of the fcc structure or γ' phase in [011] zone is readily seen. We can see first and higher order satellites of rather strong intensity flanking the fundamental spots like {111}_{γ'} and {200}_{γ'} and weak {100}_{γ'} ordering spots. By x-ray diffraction, we have previously determined the lattice constant of γ' phase as 0.3516 nm. From the result, the lattice spacing between {111}_{γ'} planes have been calculated to be 0.2030 nm. From Fig. 2(a), we can independently determine the relative satellite separation $\Delta g / g(1\bar{1}1)$ as 0.327. By combining the last two results we can determine the modulation wavelength which is the inverse of Δg as 0.62 nm. Additionally, we

may now say that the modulation wave is in the near $[3\bar{2}2]$ direction as can be seen in Fig. 2(a) and its wavelength is roughly 3 times the lattice spacing between $\{111\}$ planes. The above observation may be stated in a different context after a careful re-examination of Fig. 2(a).

Fig. 2 SADP (a) in superimposed zones, $[001]_{\alpha}$ and $[011]_{\gamma'}$ and the corresponding schematic diagram (b) of a grain boundary lamellae shown in the BF image (c) of a specimen aged at 823K for 28 hours ; centered DF image (d) obtained from the reflection, $(\bar{1}10)_{\alpha}$ spot marked by an arrow in (a).

In the diffraction pattern schematic, Fig. 2(b), we could first identify the squeezed diffraction pattern in $[011]_{\gamma'}$ zone of γ' structure. We could further notice a square pattern identifiable to the $[001]_{\alpha}$ zone pattern of bcc ferrite with the lattice constant 0.2880 nm which was previously determined by x-ray diffraction. All the other diffraction spots in Fig. 2(a) can now be classified as multiple diffractions. In the schematic, the multiple diffraction spots are deleted for brevity.

Fig. 2(c) is a BF image of a colony of the grain boundary lamellae associated with the diffraction, Fig. 2(a). Fig. 2(d) is a centered dark field (DF) image using the $(\bar{1}10)_{\alpha}$ spot marked in Fig. 2(a). Fig. 2(c) shows narrow α platelets (bright image) now seen to be embedded between a little wider γ' platelets (dark image). From the fact that $(110)_{\alpha}$ spots overlaps with $(\bar{1}\bar{1}1)_{\gamma'}$ in Fig. 2(a), we may state that $(110)_{\alpha}$ and $(\bar{1}\bar{1}1)_{\gamma'}$ planes are nearly parallel, and further state that the α/γ' interface is nearly parallel as well since the striation-like images of platelets lie normal to the $[1\bar{1}1]_{\gamma'}$ direction. These two planes happen to be close packed planes for α and γ' phases respectively, and hence we can expect the closest lattice matching between the two phases on $\{110\}_{\gamma'}$ and/or $\{111\}_{\alpha}$.

The duplex lamellae in austenitic Fe-Mn-Al-C and Fe-Ni-Al-C alloys formed *via* the discontinuous precipitation process accompanying grain boundary migration [3,4,7]. This process may now be compared

to bainite transformation in low-carbon steels. Herein, the lamellae composed of alternating α and cementite plates can also be formed *via* so called upper-bainitic transformation in which the atom movements for transformation are at least partially military in character [8]. To determine the accurate precipitation mechanism of lamellar phases, it is indispensable to examine the crystallographic relationship between the pre-transformed matrix and the product phases as well as among the product phases themselves. Henceforth, further studies are necessary to clarify the formation mechanism of the lamellae in the present alloy.

4. SUMMARY

The following concluding remarks may be made on 823K ageing of austenitic Fe-37.3wt.%Ni-3.58wt.%Al-3.3wt.%Ti-0.2wt.%C alloy. Fine γ' phase particles of $L1_2$ structure firstly precipitated uniformly within the γ matrix during 823K ageing treatment. Then the matrix composed of γ and γ' were later intruded upon by colonies of very fine duplex lamellae composed of α and γ' platelets. The scale of platelet size is very fine indeed. Observing the electron diffraction alone, we may easily lead to consider the product phase being incommensurate. Therefore, we need more indepth studies of this alloy to understand the phase transformation behavior.

References

- [1] James P.J., *J. Iron Steel Inst.* **207** (1969) 54-57.
- [2] Kayak G.L., *Met. Sci. Heat Treat.* **2** (1969) 95-97.
- [3] Choo W.K. and Kim D.K., *Metall. Trans.* **18A** (1987) 759-766.
- [4] Lee J.S. and Choo W.K., *Metall. Trans.* **24A** (1993) 1039-1047.
- [5] Kim J.H. and Choo W.K., to be published.
- [6] Han K.H. and Choo W.K., *Metall. Trans.* **14A** (1983) 973-975.
- [7] Yoon J.C. and Choo W.K., *Mater. Res. Soc. Symp. Proc.* **122** (1988) 175-179.
- [8] Bhadeshia H.K.D.H., *Bainite in Steels* (The Institute of Materials, London, 1992) pp. 20-26.