



October 30th - 31st 2014, Bandung, Indonesia

MATERIAL PROCESSING
MAP.03

International Seminar of Chemical Engineering in Minerals and Materials Processing
In conjunction with Seminar Teknik Kimia Soehadi Reksowardojo 2014

Microstructural Evolution of Fe-Ni-Al Alloy

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Abstract. Iron-nickel-chromium based alloys has been considered as commercially important materials either for aqueous as well as high temperature oxidation and corrosion environment such as in power plant and metallurgical processing equipment. The replacement of Cr with Al as alloying elements are of great interest in the studies of high temperature oxidation of the Fe-Ni-Al based alloys. These relatively new materials are relatively cheaper, lighter and stronger as a result of the dispersion of second phase intermetallic compound precipitates of B2-(Fe,Ni)Al. This study investigates the effect of aluminum addition on the microstructural evolution of the alloys at high temperatures. The materials were made from low carbon FeNi shot produced by PT. Antam Tbk. and pure aluminium ingot obtained from PT. Inalum Indonesia. The source materials were melt in a single arc furnace purged with high purity argon. The homogenized and annealed samples were then aged at 900°C at atmospheric condition with 2 variation of time. Optical microscope and scanning electron microscope in which an energy dispersive x-ray analysis apparatus is attached were used to analyze the microstructures of the substrates. The results show that the size of the B2 precipitates changed with times. The Al additions to Fe-20Ni promoted transition of the precipitates, varied from NiAl, FeAl, and (Ni,Fe)Al.

Keywords: *Fe-Ni-Al alloy, α phase, γ phase, B2 phase, microstructure evolution*

1 Introduction

The efficiency of conventional boiler/steam turbine fossil power plants is a function of the steam temperature and pressure. Research to increase both has been pursued worldwide since the increasing of awareness about clean energy. Viswanathan [4] has predicted that steam temperatures will rise 50 to 100°C in the next 30 years. Thus there is considerable interest in the development of high-temperature materials capable of operating under high stresses at every increasing temperature.

Much of this research centers on the development of Ni base superalloy strengthened by intermetallic compound. However, this alloy is too expensive for most application due to high cost of Ni. Fe base alloy has been used as high-temperature structure materials but their high-temperature mechanical

properties limit the operational temperature to about 600°C. Precipitation strengthening method is one of the methods to increase the high-temperature mechanical properties of Fe base alloy.

Fe-Ni-Al alloy with duplex microstructure is of the interest since it may offer a combination of good mechanical properties both in room temperature and high temperature. Duplex microstructure is composed of B2 ordered phase (NiAl or called β' phase) and disordered FCC phase (essentially Fe, called γ phase) which both phases has very similar lattice parameters and are coherent and coplanar, a characteristic as same as nickel base superalloy strengthened by intermetallic compound.

This study examines the influences of chemical composition on microstructure evolution of Fe-rich Fe-Ni-Al alloys in 900°C with two aging time, 6h and 24 h. Alloy composition is selected according to the chemical composition of Fe-Ni shot produced by PT Antam Tbk which contain Fe-21%wt Ni and pure aluminium ingot obtained from PT Inalum Indonesia.

2 Experimental

Three Fe-Ni-Al alloys were made by arc melting with composition based on ternary diagram [2] with the aim to obtain two-phase materials consists of (Ni,Fe)Al precipitates in ferrite matrix. The nominal chemical compositions are listed in Table 1. The melting process took place in a water-cooled copper plate under argon atmosphere thus the solidification happened relatively quickly due to fast heat extraction from the small sample size. Following casting, these alloys were homogenized at 1200°C for 24 h to ensure that all components are distributed evenly in the alloy. The alloys were machined into specimens with dimension of about $1 \times 2 \times 7$ mm.

Table 1 Chemical composition of the alloys (atomic%).

Alloy name	Fe	Ni	Al
C1	65	21	14
C2	62	21	17
C3	59	21	20

These specimens then annealed at 1100°C for 1 h followed by water quenching and aging at 900°C for 6 and 24 h, again followed by water quenching. Microstructures were examined firstly by optical microscope then continued with scanning electron microscope (SEM). The chemical analysis is performed using energydispersive x-ray spectrometry (EDS). Three points were chosen from different regions of each sample for composition identification.

3 Results

The microstructural evolution of the material will be presented in conjunction with the ternary phase diagram for Fe-Ni-Al system. Fig. 1 shows two isothermal sections through the Fe-Ni-Al system at 1100°C and 900°C. The examples of microstructure at various stages are shown in Fig. 2.

The as annealed microstructure of C1 alloy seen in Fig 2(a) shows a light brown colored dendritic phase inside a light phase. The chemical composition of alloy determined by EDS indicates that the dendritic phase is B2 phase while the lighter one is γ phase. Followed by aging at 900°C, fine dendrites occur inside the γ phase regions (Fig 2(d)). This microstructural evolution can be understood by ternary phase diagram (Fig. 1(b)) where it is clear that on lowering the temperature from 1100 to 900°C there is a significant change on the morphologies of B2 phase while smaller change happens in γ phase. Prolonging the exposure time on 900°C from 6 hours to 24 hours reveals another microstructural evolution, the growth of γ precipitate inside B2 phase dendrite. Fig. 3 shows inside B2 dendrite there are coarse precipitates which by further analysis using SEM-EDS, has same composition with γ phase.

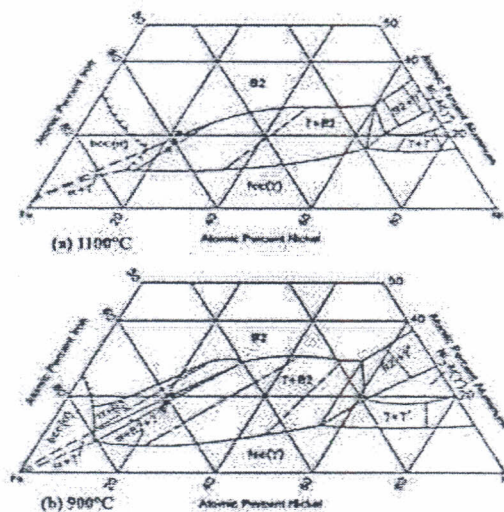


Figure 1 Isothermal section through the Fe-Ni-Al diagram at (a)1100°C and (b)900°C. The composition chose in this work is indicated with circle.

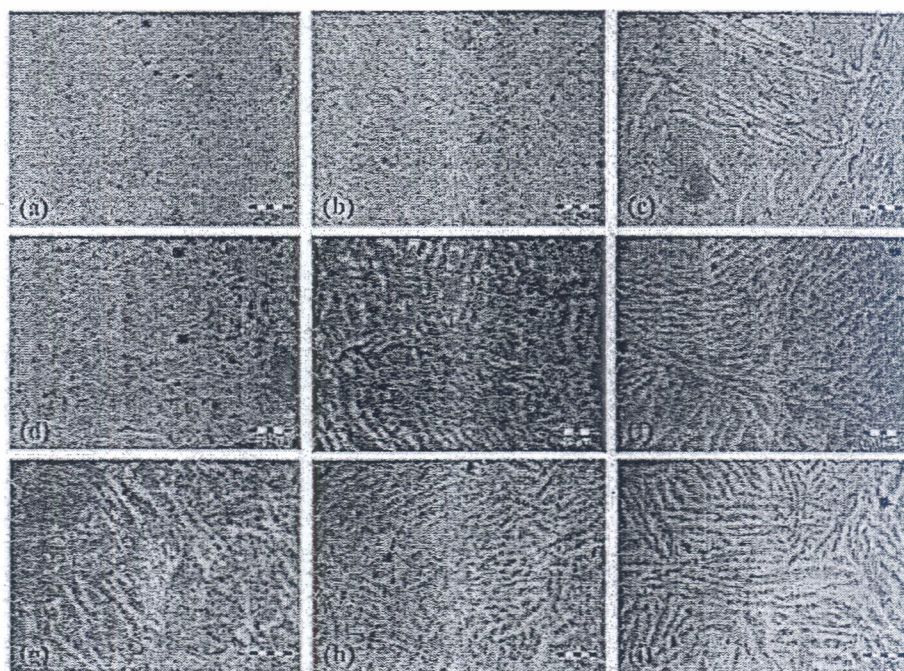


Figure 2 Optical microscope images with 1000 times magnification shows (a), (b), (c) as annealed microstructure of C1, C2, and C3 alloy; (d), (e), (f) microstructure of C1, C2, and C3 alloy after aged on 900°C for 6 hours; and (g), (h), (i) shows the microstructure after aged on 900°C for 24 hours.

Fig.2(b) shows the microstructure of C2 alloy. From the picture it can be seen that C2 has different morphological appearance with C1 alloy. In this sample, the dendritic phase is regularly distributed throughout the matrix phase without distinctive boundaries as in C1 alloy. SEM-EDS results, summarized in Table 2 the matrix is γ phase while the dendritic is B2 phase. This result is different with results from ternary diagram. C2 alloy lies between area of $B2+\alpha+\gamma$ and area $B2+\gamma$. When this alloy is aged, α and γ competes to grow inside B2 dendrite. Because of the chemical composition, the growth of γ is more favorable than α . As a result, there are more γ precipitates than α precipitates. Aging this alloy for 6 h and 24 h produces bigger fraction of precipitates inside the dendrite. As seen in Fig. 3(b), the precipitates have cuboid like shape that resembles the intermetallic phase in Ni-based superalloy.

C3 alloy has same morphologies with C2 alloy except C3 alloy has wider area of α phase. It can be explained using isothermal diagram of Fe-Ni-Al alloy

which shows that C3 alloy located between B2+ α + γ area and B2+ α area. As described in previous paragraph, α and γ competes to grow inside dendrite and because the growth of α is more favorable, the number of α inside B2 is bigger than γ . Extending the aging time shows a coarsening mechanism in both C2 and C3 alloy. The precipitates became bigger in size, as shown in Fig. 2(b) and (c).

Table 2 EDS Analysis of 24 h-aged samples

Alloy	Point	Fe(%at)	Ni(%at)	Al(%at)
C1, 900°C, 24 h	1	68.87	20.17	10.97
	2	70.26	20.95	8.8
	3	29.55	39.28	31.17
C2, 900°C, 24 h	1	60.25	21.89	17.86
	2	61.7	24.61	13.69
	3	43.57	29.32	27.11
C3, 900°C, 24 h	1	76.27	14.08	9.65
	2	70.29	16.63	13.07
	3	33.02	34.52	32.46
	%at	Fe	Ni	Al

Note: Point 1 is light phase inside the dendrite
Point 2 is dark phase inside the dendrite
Point 3 is phase outside the dendrite



Figure 3 SEM images of (a) C1, (b) C2, (c) C3 alloy aged for 24 h



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4 Discussion

SEM-EDS analysis on precipitates shows that precipitates grow on three samples is different. C1 alloy has B2 with NiAl as the main composition, C2 alloy has FeAl as its B2 phase, and C3 has (Fe, Ni)Al phase for B2 phase. These three types of B2 have different mechanical properties (Ref. 5). For application in energy, NiAl has bigger advantage than the other two types. This type also has moderate addition of alloying element to the Fe-Ni as the main composition. By applying intermetallic strengthened mechanism using NiAl as the intermetallic, the utilization of Fe-Ni alloy can be expanded into high temperature application as in energy industry.

5 Summary

Fe-Ni-Al has a big potential to be applied in energy industry. This material is relatively cheaper and lighter than Fe-Ni-Cr alloy. By substituting Cr with Al, this material develops strengthening mechanism by dispersion of intermetallic precipitates named B2. B2 phase exhibits same properties as precipitates in precipitates-strengthened Ni-based superalloy. Al addition into Fe-Ni alloy promotes formation of B2 precipitates. The bigger the amount of Al added into the alloy, the precipitates produced has relatively equal atomic percentage of Fe, Ni, Al atom thus produces (Ni,Fe)Al type precipitates.

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Nomenclature

<i>B2</i>	=	ordered bcc phase: NiAl, FeAl, (Ni,Fe)Al
α	=	disordered bcc phase
γ	=	disordered fcc phase



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PROCEEDING BOOK I



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