

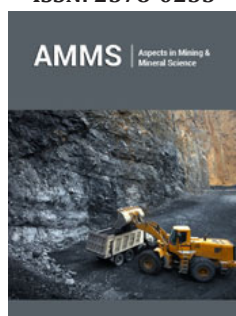
# Effect of Solution Annealing on Alpha Prime Martensitic Microstructure of Cold Rolled AISI316L Stainless Steel

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## Abstract

The effects of solution annealing on alpha prime ( $\alpha$ ) martensitic microstructure of cold rolled AISI316L austenitic stainless steel have been studied using XRD and corrosion analysis technique. Based on the good compatibility to high temperature water environment, AISI316L austenitic stainless steel is widely used for internal structural materials of light water reactors. However, recently, Stress Corrosion Cracking (SCC) was detected in the stainless steels for the applications in some commercial PWR plants. In this paper, the root cause of the SCC and its countermeasure are discussed on the basis of martensitic transformation in relationship with solution annealing and alpha martensitic microstructure. The martensitic contents of cold rolled AISI316L stainless steel decreased as solution annealing time increased with higher temperature. The mode of martensitic content change was deeply related to the solution annealing time and temperature. Therefore, it is considered that solution annealing and alpha prime martensitic microstructure play an important role in SCC resistance of cold rolled AISI316L. This leads us to conclude that the SCC resistance of AISI316L can be enhanced by the optimal solution annealing.

**Keywords:** Alpha prime martensitic phase; Solution annealing; Stress corrosion cracking; AISI316L; Austenitic stainless steels

## Introduction

Intergranular attack in austenitic stainless steels has been of great interests and investigated for about one century [1]. Specifically, intergranular corrosion and sensitization have been focused in relation to chromium depletion at the grain boundaries [2-8]. Austenitic stainless steels have been commonly used for internal structural materials of light water reactors and heavy water reactors, due to its good compatibility to high temperature water environment. However, in early 1970s, intergranular cracking (IGC) was observed in the 25%Cr-20%Ni austenitic stainless steel of the parts of fuel assembly for steam generating heavy water reactor [9] and the Cr depletion and Ni, Si enrichment were detected near the grain boundaries of this material. The material flow during plastic deformation process considerably affects the product quality-its structure and properties, the process efficiency and the deformation force amplitude. The changes of basic properties (resistance and plasticity) of the deformed material present importance to ensure the final mechanical characteristics of the parts for an appropriate behavior in working condition [10-11]. The increase of  $\alpha$ (110) martensitic structure by martensitic transformation induced by plastic deformation causes a change in physical properties of austenitic stainless steels. The martensitic transformation is expected to change by stress states. Even though stainless steels are known having a good resistance to general corrosion because they form a thin chromium rich passive surface film, they are susceptible to localized corrosion attack such as pitting, intergranular corrosion, and stress corrosion cracking [12-17]. We study the effects of solution annealing and load reversals on  $\alpha'$  martensitic phase of cold rolled AISI316L. The SCC resistance of AISI316L can be enhanced by the solution annealing. The advantages of using solution annealing indicate the new contributions about SCC resistance since there are many papers related to the martensitic transformation is expected to change by stress states.

## Experimental Procedure

The material used in our study was an AISI316L austenitic stainless steel with its chemical composition shown in Table 1. AISI316L samples were cold rolled as 10% and 20%, producing average grain size of 50 $\mu$ m. Residual martensitic contents were detected using XRD after solution annealing. Table 2 shows the specimen conditions used for the solution annealing tests. Fourteen

distinct specimens numbered from 1 to 14 were then analyzed for their martensitic intensity. Fourteen specimens numbered from 1 to 14 were then analyzed using XRD and corrosion tested. The centers of specimen surfaces exposed to the XRD test were observed by an optical microscope system (OLYMPUS BX51M), scanning electron microscope (NOVA NANO SEM) and transmission electron microscope (JEM 2000F).

**Table 1:** Chemical composition of the AISI316L austenitic stainless steel (wt. %).

Elements	Measured	AISI316L
C	0.011	0.03max
Si	0.34	0.75max
Mn	0.558	2.00max
P	0.0296	0.045max
S	0.0017	0.030max
Ni	12.222	10.00~14.00
Cr	17.612	16.00~18.00
Mo	2.054	2~3
Co	0.098	0.100max

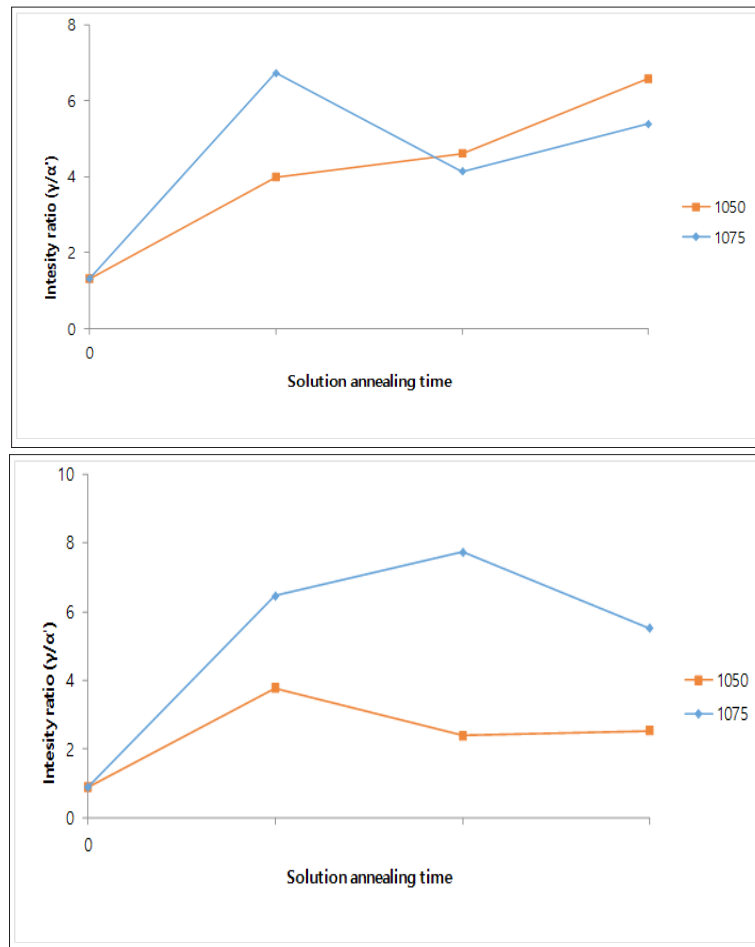
**Table 2:** Conditions of specimens for the solution annealing tests.

Specimen No.	Cold Rolling (%)	Annealing Time (min)	Annealing Temperature (°C)
1	-	-	-
2	10	-	-
3	10	10	1050
4	10	20	1050
5	10	30	1050
6	10	10	1075
7	10	20	1075
8	10	30	1075
9	20	10	1050
10	20	20	1050
11	20	30	1050
12	20	10	1075
13	20	20	1075
14	20	30	1075

## Result and Discussion

We evaluate solution annealing of cold rolled specimens. Figure 1 shows the martensitic phase measurement results for AISI316L specimens. It is revealed that the martensitic phase properties depend only on solution annealing time, possibly due to microstructure transfer processes at the grain boundaries. As shown in Figure 1, the similarity of both properties for different specimens also indicates that cold rolling mechanism is influential for the annealing time of all specimens. The intensity ratio as

shown in Figure 1 exhibits a flat line that decreases from the cold rolled specimens to the low annealing temperature specimens. We employ the salt technique in order to quantitatively evaluate the intergranular corrosion resistance of the AISI316L. Corrosion occurs more at all grain boundaries and this shows the susceptibility to corrosion as cold rolled. The results show that the annealing treatment increases the intergranular corrosion resistance of the specimens. The salt tests confirm the other results, showing the susceptibility to intergranular corrosion [3,17].



**Figure 1:** XRD properties measurement in relationship with intensity ratio ( $\gamma/\alpha'$  face) for AISI316L specimens:

10% cold rolled specimens

20% cold rolled specimens

## Conclusion

Based on the good compatibility to high temperature water environment, AISI316L austenitic stainless steel is widely used for internal structural materials of light water reactors. However, recently, intergranular cracking was detected in the stainless steels for the applications in some commercial PWR plants. The susceptibility to intergranular corrosion of the cold rolled AISI316L stainless steel was highly affected by alpha martensite and cold rolling. The resistance to intergranular corrosion increased by more than a factor of two when the optimal solution annealing is applied. The corrosion characteristics of the test specimens may be attributed to the transfer of microstructures. Consequently, the corrosion resistance of AISI316L can be improved with the optimal annealing time and temperature and decreasing IGC in AISI316L stainless steel.

## Acknowledgment

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