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The influence of metallurgical factors on corrosion fatigue strength of stainless steels

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Abstract

Corrosion fatigue strength of stainless steels is controlled by tangled interaction among environmental, mechanical and metallurgical factors. In order to estimate corrosion fatigue strength it is indispensable to understand the role of an each influencing factor. The aim of this paper is to present briefly surveyed results on metallurgical factors on corrosion fatigue strength of stainless steels such as austenitic, martensitic and duplex stainless steels mainly based upon author's experimental results. The targeted dominant metallurgical factors focussed upon are chemical compositions, heat treatment, manufacturing process and microstructures.
The emphasis is placed upon effect of Molybdenum content on corrosion fatigue strength of austenitic stainless steels in 3%NaCl aqueous solution, tempering temperature on corrosion fatigue strength of 13% Chromium stainless steel in 3%NaCl aqueous solution and volume percent ferrite on corrosion fatigue strength of duplex stainless steel in potassium alum aqueous solution. The surface and fracture surface observation by optical and scanning electron microscopy revealed that corrosion pit formed at corrosion fatigue crack initiation area. In light of relatively smaller effect of corrosive environment on corrosion fatigue crack propagation rate it can be surmised that corrosion fatigue strength of stainless steels is governed by crack initiation process. It can be concluded that corrosion fatigue strength of stainless steels is strongly influenced by metallurgical factors such as chemical compositions, heat treatment, manufacturing process and microstructures.
The information obtained in this survey directly lead to prevention of corrosion fatigue failure in stainless steels made components, selection of stainless steels in corrosive environments and development of corrosion resistant stainless steels.

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Keywords: Corrosion fatigue, Stainless steels, Molybdenum content, Tempering temperature, Volume percent ferrite

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1. Introduction

Stainless steels are widely used as structural materials in various kinds of machine and plant. A lot of information on environmental degradation such as corrosion resistance and stress corrosion cracking under various kinds of environment has been accumulated so far. However information on corrosion fatigue strength of stainless steels seems not to be enough. Especially long term corrosion fatigue strength to estimate design stress of components under corrosive environments and corrosion fatigue crack initiation behavior to understand corrosion fatigue crack initiation mechanism are still unsolved problems.
It has been well recognized that corrosion fatigue strength of structural materials is controlled by tangled interaction among environmental, mechanical and metallurgical factors. Therefore it is indispensable to understand the role of each factor influencing on corrosion fatigue strength of stainless steels. In this paper it is focused upon the metallurgical factors to control corrosion fatigue strength of stainless steels. Dominant metallurgical factors to control corrosion fatigue strength of stainless steels are manufacturing processes, chemical compositions, heat treatment, microstructure and weld metal. In this paper it is reported on the briefly surveyed results on effect of chemical compositions, heat treatment, microstructure and manufacturing processes on corrosion fatigue strength of stainless steels on the basis of mainly author's experimental results.

2. Effect of chemical compositions on corrosion fatigue strength of stainless steels

Very few papers on long term corrosion fatigue strength of stainless steels can be found. Plate bending corrosion fatigue tests were conducted for SUS304 and SUS316 in 3% NaCl aqueous solution up to over than 231 days (Hirakawa and Kitaura,1981). Plane plate specimens with 6mm thick were used and the frequency was 0.5 Hz. Reduction of corrosion fatigue strength up to 10^6 cycles was 6% at most for both SUS304 and SUS316.The reduction rate in SUS304 gradually increased after $2x10^6$ cycles and reached to 30% at 10^7 cycles. The sudden reduction of corrosion fatigue strength of SUS304 at $7x10^6$ cycles was attributed to corrosion pit initiation at the specimen surface. On the contrary the reduction rate in SUS316 was 6% up to $2x10^6$ cycles and 0% even at 10^7 cycles. The smaller reduction rate of SUS316L than that of SUS304 in 0.9wt% sodium chloride aqueous solution was also reported (Otsuka et al.,2010).The reason of the smaller reduction rate of SUS316 and SUS316L strongly depends on about 2% Molybdenum content in chemical compositions of these stainless steels. Molybdenum effect on corrosion fatigue strength of austenitic stainless steels can also be recognized for various kinds of austenitic stainless steels in 3% NaCl aqueous solution (Ebara et al.,2011, 2012).Chemical compositions and mechanical properties of tested austenitic stainless steels are shown in Table1 and Table2 (Ebara,2015), respectively. The dumbbell type specimens with minimum diameter of 3mm were used. The ultrasonic corrosion fatigue tests were very carefully conducted in 3% NaCl aqueous solution. Frequency was 20kHz and R(the ratio of minimum to maximum stress in the loading cycle) was −1. Because of the low thermal conductivity in austenitic stainless steels ultrasonic fatigue tests were very carefully conducted to prevent heating of the specimens during corrosion fatigue testing. The compressed air was blown into the center of dumbbell type specimens and the solution was circulated with a speed of 3l/min. Intermittent testing with frequency of 110ms duty and 1100ms pause was also applied.Fig.1 shows S-N diagrams of SUS 304 and SUS316 in air and in 3%NaCl aqueous solution. Corrosion fatigue strength of SUS304 at 10^9 cycles in 3% NaCl aqueous solution is 245MPa and is 15.5% lower than that in air. The reduction of corrosion fatigue strength of SUS316 at 10^9 cycles in 3% NaCl aqueous solution is 12% and the reduction rate is

Table1. Chemical compositions of austenitic stainless steels (mass %). (Ebara 2015)

Material	C	Si	Mn	P	S	Ni	Cr	Mo	Nb	N
SUS304	0.005	0.44	0.87	0.025	0.005	8.15	18.15			
SUS304N2	0.004	0.81	0.082	0.029	0.001	7.55	19.45		0.09	0.2
SUS316	0.06	0.43	0.84	0.027	0.001	10.07	16.26	2.1		
NSSC250(Heat)	0.015	0.37	0.45	0.022	0.001	17.72	25.16	2.43		0.28
NSSC250(TMCP)	0.011	0.42	0.44	0.025	0.001	17.87	24.87	2.4		0.27
YUS270	0.08	0.46	0.46	0.02	0.01	18.9	19.9	6.16		