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A Study on the Fatigue Strength of Welded Joints of Duplex Stainless-Clad Steel Plates for Application in Chemical Tankers

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Fatigue tests of butt welded-joints and non-load-carrying full-penetration cruciform welded joints that are composed of newly developed and commercialized duplex stainless SUS329J3L(UNS S32205)-clad steel plates were carried out to determine their potential for application in the cargo-tank structures of chemical tankers. The fatigue strength of these welded joints was evaluated by comparing them with welded joints that are composed of conventional austenitic stainless SUS316L(UNS S31603)-clad steel plate. The cargo-tank construction of chemical tankers using SUS329J3L-clad steel plate was superior to that of conventional tankers, which confirms the suitable fatigue strength of the SUS316L-clad steel plate.

***Key words*:** Fatigue Strength, Butt-Welded Joint, Non-Load-Carrying Full-Penetration Cruciform Welded Joint, Duplex Stainless-Clad Steel Plate, Chemical Tanker

1. INTRODUCTION

In 2016, duplex stainless SUS329J3L(UNS S32205) -clad steel plate, which is composed of stainless-clad steel plate with SUS329J3L steel plate, was developed and commercialized in Japan. In cargo-tank construction,[1), 2)] a combination of SUS329J3L-clad steel plate and SUS329J3L steel plate is expected to conserve nickel resources and to reduce the ship's mass compared with conventional cargo-tank construction that uses a combination of austenitic stainless SUS316L(UNS S31603) -clad steel plate and austenitic stainless SUS316LN(UNS S31653) steel plates.

We carried out fatigue tests on butt-welded joints[3)] and non-load-carrying full-penetration cruciform welded joints using SUS329J3L-clad steel plates and SUS329J3L steel plates. The fatigue strengths were evaluated and compared with those of the same welded joints in which conventional SUS316L-clad steel plate and SUS316LN steel plate was used.

2. TEST STEEL PLATE, WELDING PARAMETERS AND TEST FATIGUE SPECIMEN

The typical chemical composition and mechanical properties of the tested steel plates are shown in Tables 1 and 2.

Representative welding conditions using FCAW (flux cored arc welding) for the butt-welded joints with tested stainless-clad steel plates are shown in Tables 3 and 4 for non-load-carrying full-penetration cruciform welded joints with SUS329J3L-clad steel plate and SUS329J3L steel plate.

Figures 1 and 2 provide examples of the specimens that were used in the fatigue tests.

Table 1 Chemical composition of test steel plates

(wt%)

Test Steel Plate		Thick. (mm)	C	Mn	Cr	Ni	Mo
SUS329J3L	①	16	0.008	1.80	22.50	5.80	3.10
	②	16	0.013	1.81	22.55	5.75	3.10
SUS316LN		17.5	0.019	0.60	18.22	10.60	2.83
SUS329J3L-Clad*		16 (3+13)	0.013	0.97	22.55	5.42	3.10
SUS316L-Clad*	③	15 (3+12)	0.008	0.77	16.94	12.11	2.84
	④	16 (3+13)	0.008	0.78	17.14	12.17	2.75

* SUS329J3L, SUS316L Steel Plate (3mm)

Table 2 Mechanical properties of test steel plates

Test Steel Plate		Thick. (mm)	0.2% Proof Stress (N/mm^2)	Tensile Strength (N/mm^2)	Elongation (%)
SUS329J3L	①	16	615	772	38
	②	16	594	771	35
SUS316LN		17.5	399	679	48
SUS329J3L-Clad*		16 (3+13)	433	554	23
SUS316L-Clad*	③	15 (3+12)	−	476	35
	④	16 (3+13)	290	480	27

* Full-Thickness Tensile Test (15,16mm)

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Table 3 Welding parameters of butt welded joints (FCAW)

Test Steel Plate	Build-up Sequence		Welding Current (A)	Arc Voltage (V)	Travel Speed (cm/min)	Heat Input (kJ/cm)
SUS329J3L-Clad Steel Plate + SUS329J3L-Clad Steel Plate		4, 5 Stainless	200	32 ～33	16.8 ～17.8	22.2 ～22.9
		1～3 Mild Steel	200 ～280	24 ～32	17.5 ～28.3	15.4 ～19.0
SUS316L-Clad Steel Plate + SUS316L-Clad Steel Plate		4, 5 Stainless	200 ～220	34	13.9 ～26.0	19.4 ～23.6
		1～3 Mild Steel	200 ～300	25 ～34	19.0 ～21.0	19.4 ～23.7

Plate Thickness : 16 mm, Gas Flow Rate : 18 ℓ/min,
Interpass Temperature ≦ 150 ℃

Table 4 Welding parameters of full-penetration cruciform welded joints (FCAW)

Test Steel Plate	Build-up Sequence	Welding Current (A)	Arc Voltage (V)	Travel Speed (cm/min)	Heat Input (kJ/cm)
SUS329J3L-Clad Steel Plate + SUS329J3L Steel Plate		180 ～200	30 ～32	17.0 ～28.2	13.6 ～22.6
		200	32	15.7 ～28.3	13.6 ～24.5

Plate Thickness : 16 mm, Gas Flow Rate : 18 ℓ/min,
Interpass Temperature ≦ 150 ℃

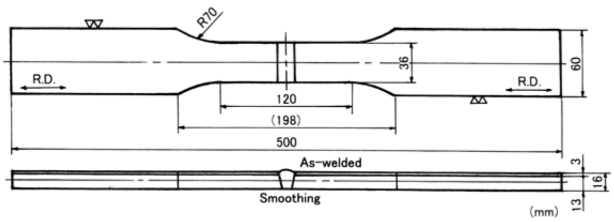

Fig. 1 Shape of fatigue test specimen (butt-welded joint of clad steel plate)

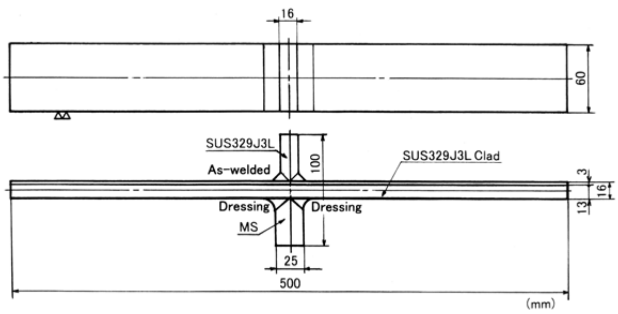

Fig. 2 Shape of fatigue test specimen (non-load-carrying full-penetration cruciform welded joint)

3. FATIGUE TEST RESULTS AND DISCUSSION

Figures 3 to 7 show the fatigue test results.

Figure 3 shows the fatigue test results for the butt-welded joints (weld toe treatment : as-welded) of the newly developed and commercialized SUS329J3L-clad steel plates and those of the well butt-welded joints (as-welded) of the SUS316L-clad steel plates (④).

Figure 4 shows the fatigue test results of the butt-welded joints (as-welded, dressing by grinding) of the SUS329J3L steel plates (①).

Figure 5 shows the fatigue test results of the well-proven butt-welded joints of the SUS316LN steel plates (dressing by grinding).

Figure 6 shows the fatigue test results of the non-load-carrying full-penetration cruciform welded joints (as-welded, dressing by grinding) with SUS329J3L-clad steel plate and SUS329J3L steel plate (②).

Figure 7 shows the fatigue test results of the non-load-carrying full-penetration cruciform welded joints (as-welded, dressing by grinding, dressing by TIG (tungsten inert gas) arc) with well-proven SUS316L-clad steel plate (③) and SUS329J3L steel plate (①).

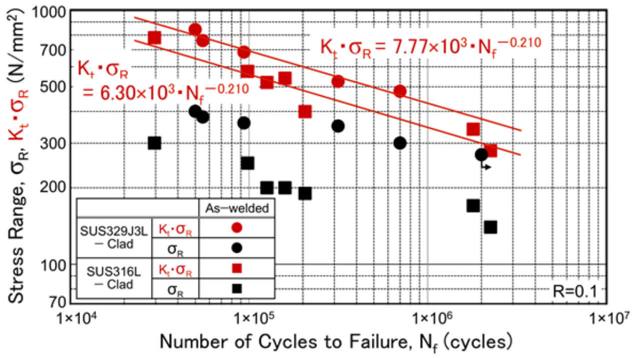

Fig. 3 Results of fatigue test (butt-welded joint of SUS329J3L-clad steel plate and SUS316L-clad steel plate)

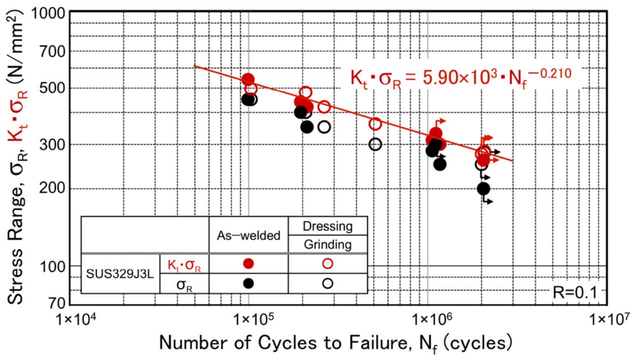

Fig. 4 Results of fatigue test (butt-welded joint of SUS329J3L steel plate)

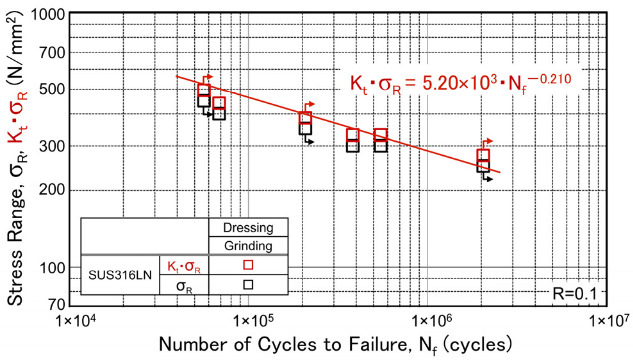

Fig. 5 Results of fatigue test (butt-welded joint of SUS316LN steel plate)

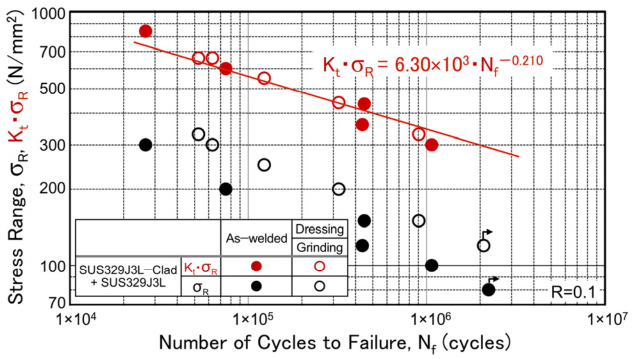

Fig. 6 Results of fatigue test (non-load-carrying full-penetration cruciform welded joint of SUS329J3L-clad steel plate and SUS329J3L steel plate)

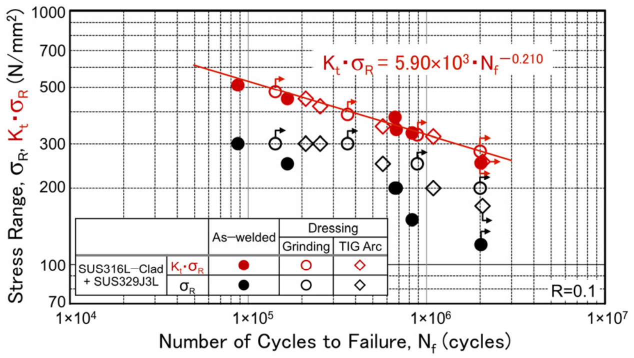

Fig. 7 Results of fatigue test (non-load-carrying full-penetration cruciform welded joint of SUS316L-clad steel plate and SUS329J3L steel plate)

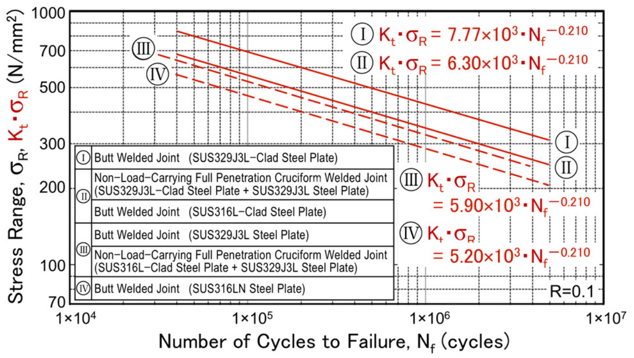

Fig. 8 Fatigue strength of butt-welded joint and non-load-carrying full-penetration cruciform welded joint

Figures 3 to 7 show the relationships between the stress range σ_R and the number of cycles to failure N_f, and those between $K_t \cdot \sigma_R$ and N_f. K_t is the stress-concentration factor at the fatigue crack-initiation point in the weld toe of each tested specimen. K_t was calculated by taking the mold of the weld toe at the fatigue crack-initiation point with silicon, then by measuring the toe radius and the flank angle from the cross section at the point. By using the stress-concentration factor K_t at the toe of the welded joint, the ratio of fatigue strength (notch factor K_f) between the tested welded joint and its flushed welded joint, which represents the reduction in fatigue strength of the tested welded joints compared with its flushed welded joint (K_t = 1.0), can be estimated. Based on the estimated notch factor K_f, we attempt to evaluate the degree of fatigue strength improvement of each tested welded joint with an ideal dressing treatment.

To estimate K_f, it is presumed that for a K_t of 3.0 or below, $K_f = K_t$ and for K_t above 3.0, K_f = 3.0. With an ideal dressing treatment, based on the estimated K_f, stress range σ_R is corrected as $K_t \cdot \sigma_R$. Therefore, from the relationships between $K_t \cdot \sigma_R$ and N_f, the fatigue strength of all tested welded joints can be evaluated by comparison[3].

Figure 8 shows the fatigue test results of the relationships between $K_t \cdot \sigma_R$ and N_f in Figures 3 to 7. A comparison of these fatigue test results in Fig. 8 yields the following:

(1) The butt-welded joint of the SUS329J3L-clad steel plates has a ~1.2 times higher fatigue strength than that of the SUS316L-clad steel plates and a ~1.5 times higher fatigue strength than that of the SUS316LN steel plates.

(2) The-butt welded joint of the SUS329J3L steel plates shows a ~1.1 times higher fatigue strength than that of the SUS316LN steel plates.

(3) The non-load-carrying full-penetration cruciform welded joint with SUS329J3L-clad steel plate and SUS329J3L steel plate shows a ~1.1 times higher fatigue strength than that with the SUS316L-clad steel plate and SUS329J3L steel plate.

4. CONCLUSIONS

We suggest that the cargo-tank construction of chemical tankers using a combination of newly developed and commercialized duplex stainless SUS329J3L(UNS S32205)-clad steel plate and SUS329J3L steel plate has a superior fatigue strength compared with that when using a conventional combination of austenitic stainless SUS316L (UNS S31603)-clad steel plate and austenitic stainless SUS316LN(UNS S31653) steel plate.

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