XXVI Konferencja Naukowo-Techniczna awarie budowlane 2013

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FATIGUE BEHAVIOUR OF MISALIGNED BUTT WELDED JOINTS IN THE BOTTOM FLANGE

ZACHOWANIE ZMĘCZENIOWE NIEWSPÓŁOSIOWYCH CZOŁOWYCH POŁĄCZEŃ SPAWANYCH W PASIE DOLNYM

Abstract In this study, we investigated the fatigue strength of butt welded joints with 10% or more misalignment of plate thickness through fatigue tests on 3 steel girder specimens. The specimens comprised an aligned butt welded joint, 18% and 36% misaligned butt welded joints against the 11 mm – thick plate in the bottom flange. We also verified the effect of the taper grinding and toe grinding against the misaligned butt welded joints. As a result, it was confirmed that the fatigue strength of the 18% or less misaligned butt welded joint satisfied JRA Class D, while that of the 36% misaligned butt welded joint may not satisfy JRA Class D. By taper grinding and toe grinding, the fatigue strength of the 36% misalignment butt welded joint was improved about one class.

Streszczenie Praca dotyczy badań zmęczeniowych spoin czołowych mających 10% i większą niewspółosiowość w stosunku do grubości pasa. Badania przeprowadzono na trzech dźwigarach stalowych. Każdy z dźwigarów posiadał w pasie dolnym o grubości 11 mm poprzeczną osiową spoinę czołową oraz czołowe spoiny o niewspółosiowości 18% i 36%. Badaniom poddano także wpływ efektu frezowania niewspółosiowych połączeń czołowych za pomocą frezu stożkowego i palcowego. Stwierdzono, że wytrzymałość zmęczeniowa spoin o 18% i mniejszej niewspółosiowości spełnia warunki klasy D Japońskiego Stowarzyszenia Drogowego (JRA), podczas gdy spoiny o niewspółosiowości 36% mogły nie spełniać warunków klasy D. Dzięki frezowaniu frezami stożkowym i palcowym, wytrzymałość spoin mających 36% niewspółosiowości wzrastała o jedną klasę.

1. Introduction

When butt welded joints are used to join the steel plates, a misalignment of the plate thickness may occur by the deformation of steel plates due to welding and assembly errors.

In Japan, when the plate thickness is 50 mm or less, specifications for highway and railway bridges specify that the misalignment of plate thickness butt welded joints should be 10% or less of the thinner plate thickness 1, 2.

In other countries, the misalignment of the butt welded joint is also allowed to be 10% or less of the thinner plate thickness 3,4. When the misalignment exceeds 10%, IIW recommends to modify the fatigue strength with the application of an additional stress raising factor 4.

However, the fatigue strength of butt welded joints with 10% or more misalignment of the plate thickness has not as yet been clarified.

In this study, we investigated the fatigue strength of butt welded joints with 10% or more misalignment of the plate thickness through fatigue tests of 3 steel girder specimens.

The specimens comprised an aligned butt welded joint, 18% and 36% misaligned butt welded joints against the 11 mm-thick plate in the bottom flange. We also verified the effect of the taper grinding and toe grinding against the misaligned butt welded joints.

2. Experimental method

2.1 Specimen

Figure 1 shows the configurations and dimensions of the specimens. We used 3 steel girder specimens (G1~G3). The material used was JIS SM490YA steel. Each of the specimens had 4 types of butt welded joints in the 11-mm-thick bottom flange, as follows (Fig. 2, Photo 1).

(1) aligned butt welded joint (M0)

(2) 18% misaligned butt welded joint (M2)

(3) 36% misaligned butt welded joint (M4)

(4) 36% misaligned butt welded joint with taper grinding (M4T)

We only grinded weld toes of M4 and M4T in the G3 specimen before the fatigue test (Photo 2). These joints are called M4G and M4TG.

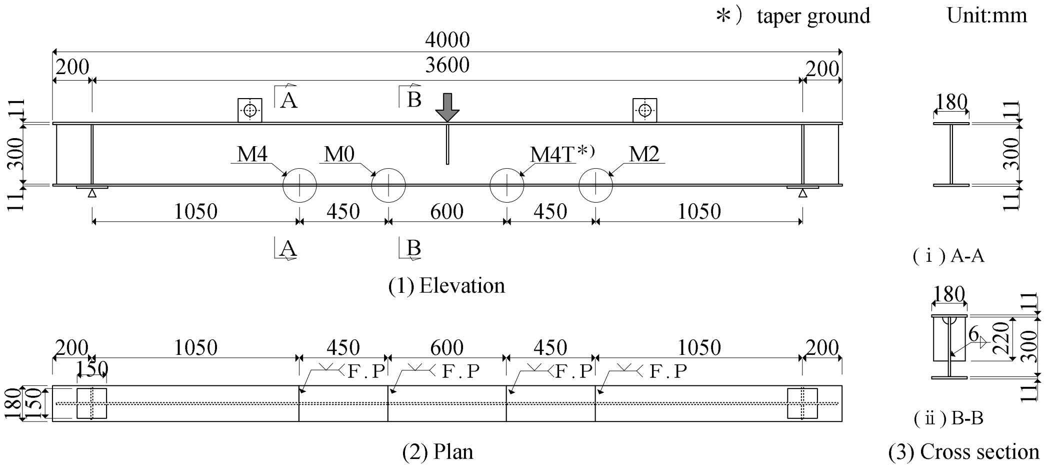
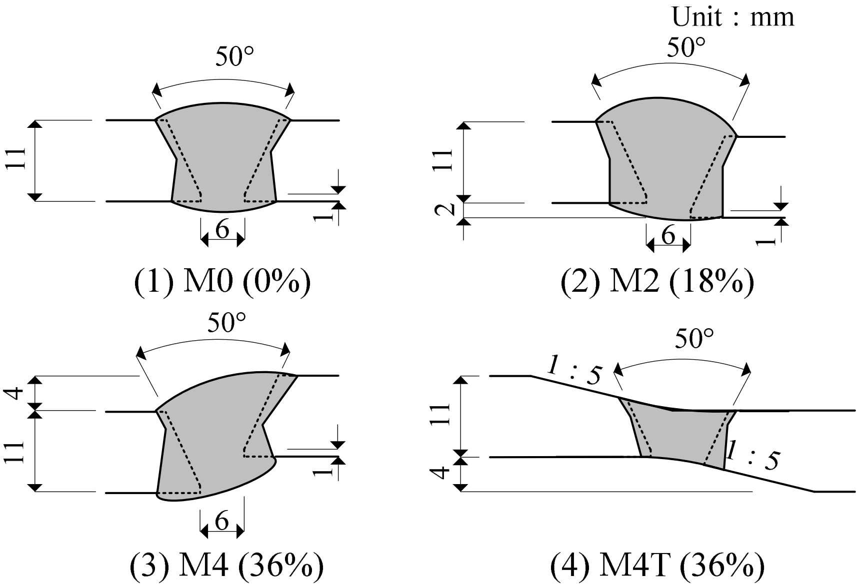


Fig. 1 Configurations and dimensions of the specimen



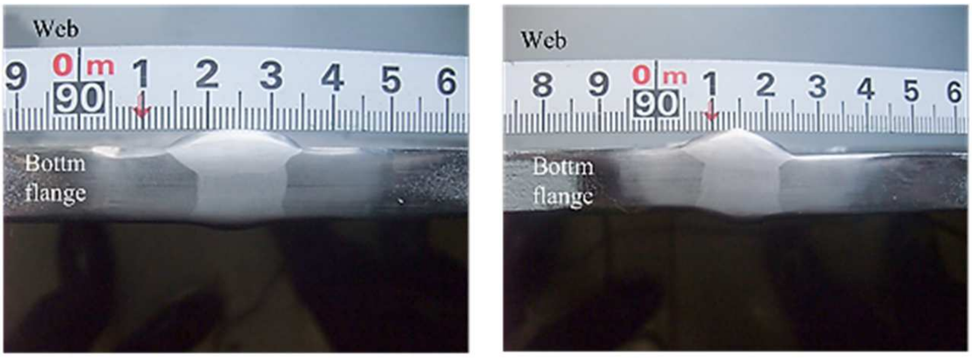
(1) M0 (0%)

(2) M2 (18%)

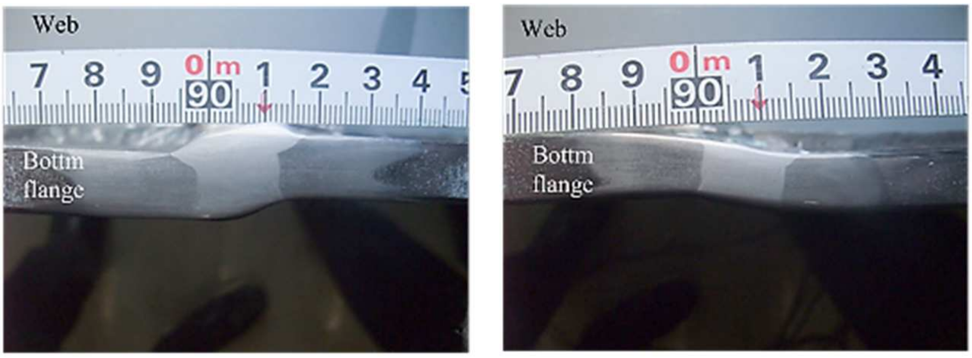
(3) M4 (36%)

(4) M4T (36%)

Fig. 2 Elevation details of butt welded joints

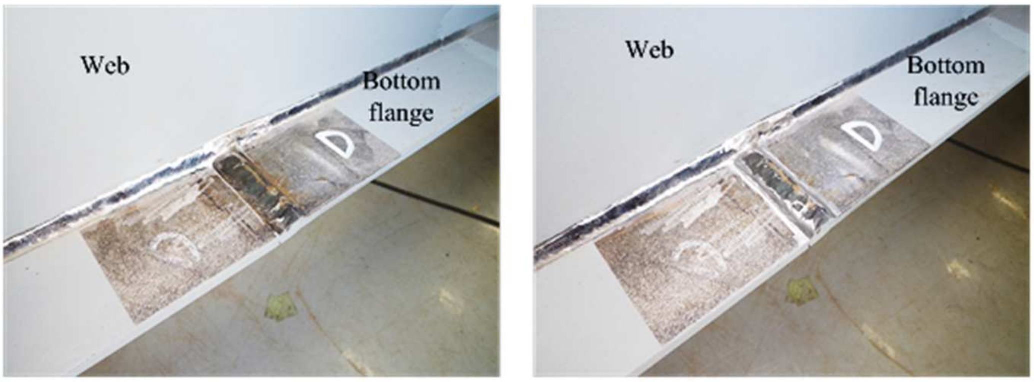


(1) M0（0%） (2) M2 (18%)

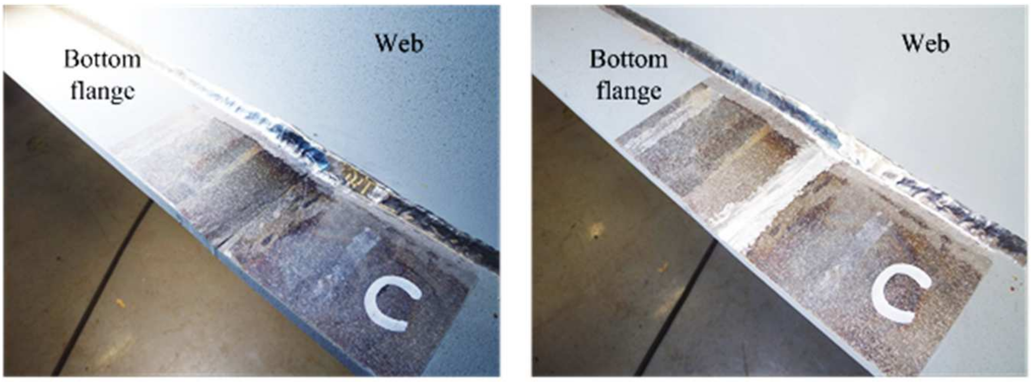


（3） M4（36%） （4） M4T（36%）

Photo 1 Butt welded joints



(1) M4G (before grinding) (2) M4G (after grinding）



(3)M4TG (before grinding) (4)M4TG (after grinding）

Photo 2 Weld toe grinding in the G3 specimen

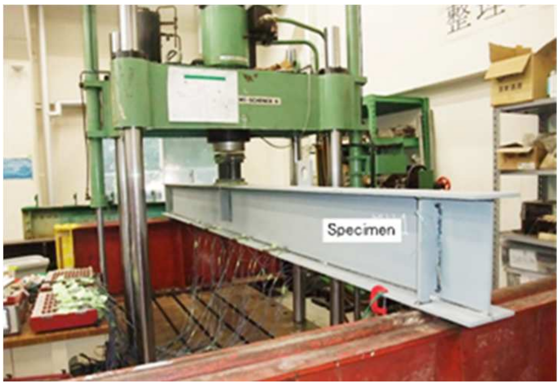


Photo 3 Fatigue test set up

2.2 Fatigue test method

We conducted fatigue tests in 3-point bending condition. Photo 3 shows the fatigue test set up. The maximum load was set to 180 kN, so that the maximum stress of the bottom flange would be the allowable stress. We then selected the loading range by changing the minimum load. The loading rate was 4 Hz.

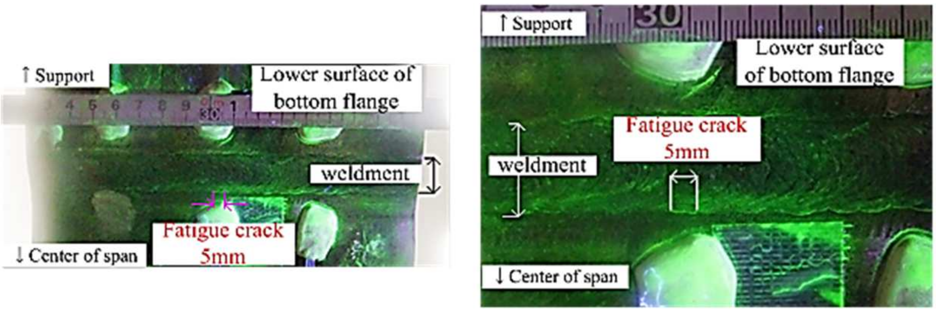
To detect the fatigue cracks, we conducted visual inspections, magnetic particle tests and penetrant tests.

3. Fatigue test results

3.1 Fatigue cracking behaviour

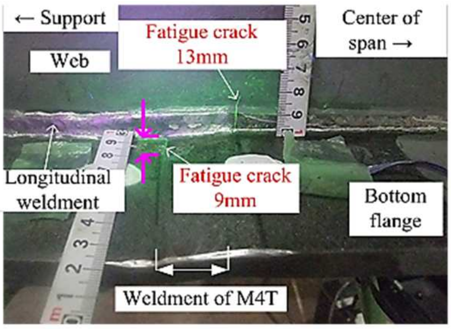
In the G1 specimen, fatigue cracks were detected at the longitudinal welded joint between the web and the bottom flange near the M0 and M4T joints after 5.0 Mcycles loading under ΔP = 100kN. No fatigue cracking was detected at butt welded joints.

In the G2 specimen, fatigue cracks were detected at the M4 and M4T joints after 1.8 Mcycles loading under ΔP = 130 kN (Photo 4, 5). Also, three fatigue cracks were detected at the longitudinal welded joint between the web and the bottom flange near the M4T (Photo 5) and M0 joints and in the section of the loading point. After reinforcing at those longitudinal welded joints with fatigue cracks (Photo 6), fatigue tests were continued. The fatigue test was finished the fatigue test when the fatigue crack of the M4 joint was propagated into the web. Photo 7 shows the fatigue cracking in the M4 joint. Photo 8 shows the fracture surface in the M4 joint. The fatigue crack was initiated at the weld toe on the lower surface of the bottom flange just under the web, and propagated to the web and the bottom flange. No fatigue cracks were detected at the M0 and M2 joints.

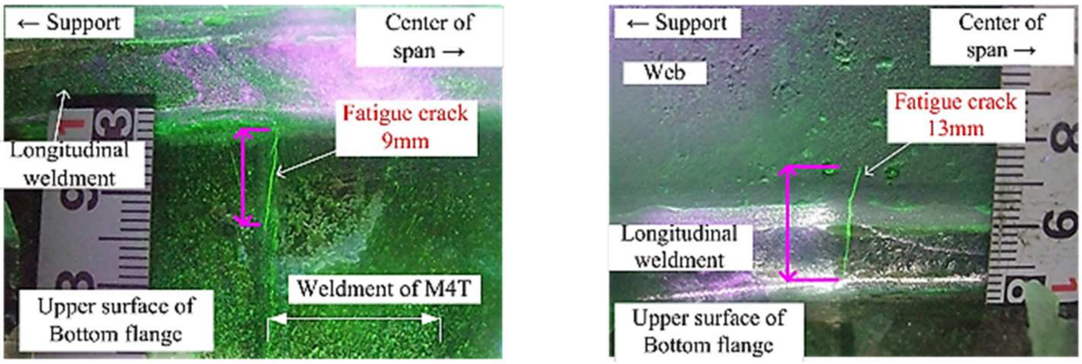


(1) Long shot (2) Closeup shot

Photo 4 Fatigue crack at M4 joint in G2 specimen after 1.8 Mcycles loading



(1) Long shot



(2) Closeup shot of crack at weld toe of M4T (3) Closeup shot of crack at longitudinal weldment

Photo 5 Fatigue cracks at M4T joint in G2 specimen after 1.8 Mcycles loading

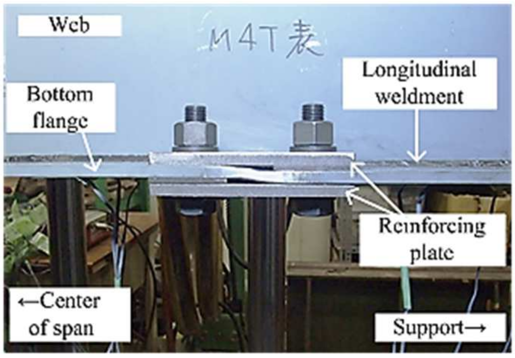


Photo 6 Reinforcing at M4T joint in G2 specimen after 1.8 Mcycles loading

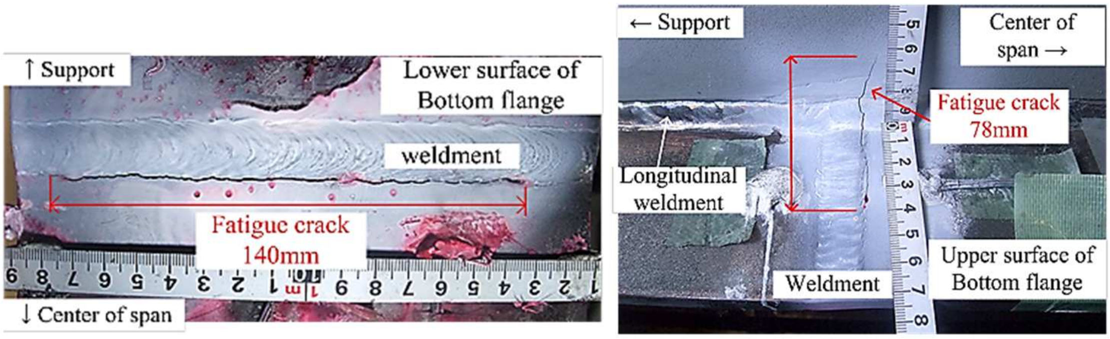


Photo 7 Fatigue crack at M4 joint in G2 specimen after 4.1 Mcycles loading

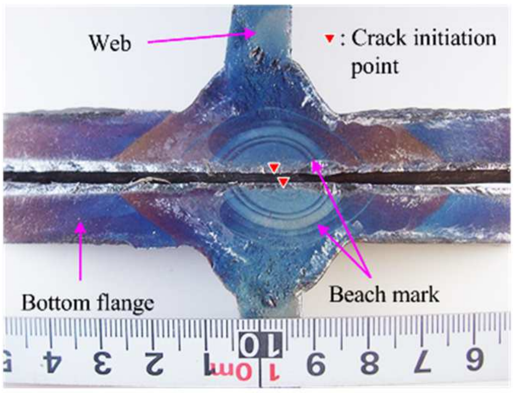


Photo 8 Fracture surface of fatigue crack at M4 joint in G2 specimen

In the G3 specimen, three fatigue cracks were detected at the longitudinal welded joint between the web and the bottom flange near the M4TG and M0 joints, and at the section of the loading point under ΔP = 140 kN. However, no fatigue cracking was detected at the butt welded joints.

3.2 Fatigue strength of welded joints

Table 1 shows fatigue test results. Figure 3 shows fatigue test results and fatigue design curves after JRA Fatigue Design Recommendations for Highway Bridges 5. The vertical axis represents the nominal stress range ($\Delta\sigma$), while the horizontal axis represents fatigue life N_d and N_f. N_d is fatigue crack detection life as the number of stress cycles until fatigue cracks are detected. N_f is fatigue life defined as the number of stress cycles until the fatigue crack propagates to the lower surface of the bottom flange.

Table 1. Fatigue test results

Specimen	P_{max} **[kN]**	P_{min} **[kN]**	ΔP **[kN]**	**Welded joint**	$\Delta\sigma$ **[MPa]**	**Fatigue life (Mcycles)**	
						N_d	N_f
G1	180	80	100	M0	96	> 5.0	> 5.0
				M2	65	> 5.0	> 5.0
				M4	66	> 5.0	> 5.0
				M4T	93	> 5.0	> 5.0
				flange-web	93	5.0	5.0
					96	5.0	5.0
G2	180	50	130	M0	126	> 4.0	> 4.1
				M2	87	> 4.0	> 4.1
				M4	87	1.8	4.1
				M4T	124	1.8	> 1.8
				flange-web	142	3.7	3.7
					126	4.0	4.0
					124	1.8	1.8
G3	180	40	140	M0	136	> 3.4	> 3.4
				M2	94	> 3.4	> 3.4
				M4	94	> 3.4	> 3.4
				M4TG	133	> 1.7	> 1.7
				flange-web	153	2.8	2.8
					136	2.1	2.1
					124	1.7	1.7

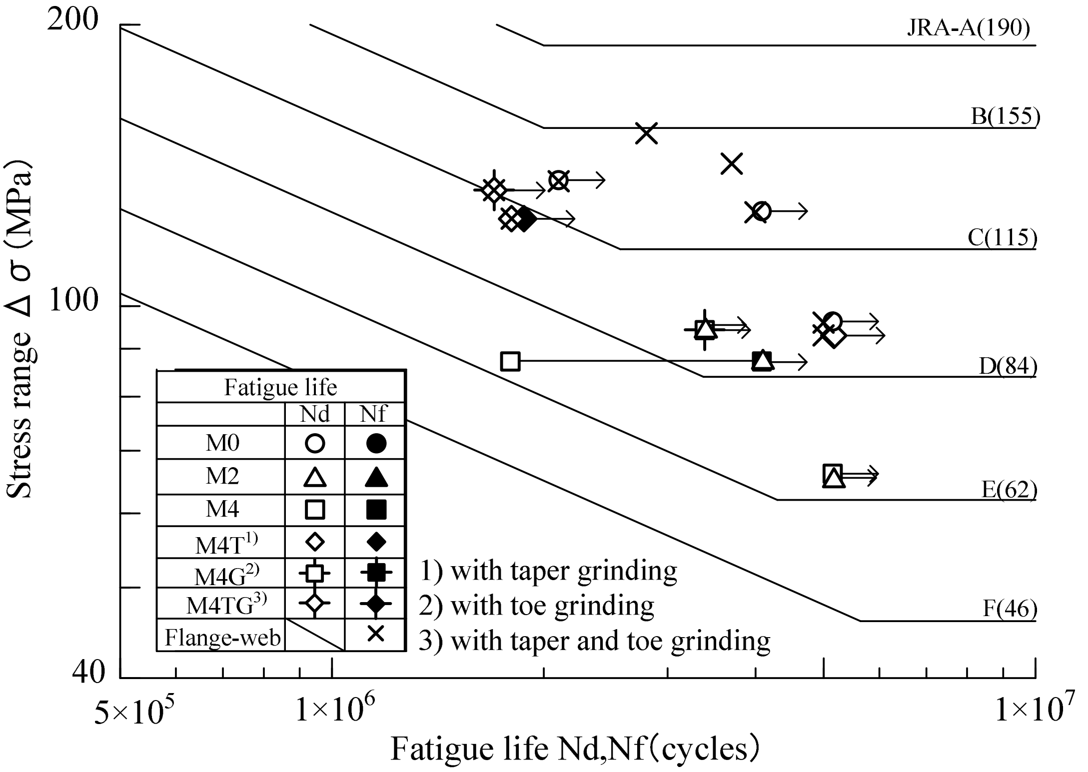


Fig. 3. Fatigue test results

3.2.1 Influences of misalignment

Because no fatigue cracking was detected at the M0 and M2 joint of 3 specimens, the fatigue strength of M0 satisfied Class C, and that of M2 satisfied Class D. At M4 joints, no fatigue cracking was detected under $\Delta\sigma$ = 66 MPa, however a fatigue crack occurred and N_f satisfied Class D under $\Delta\sigma$ = 87 MPa. Therefore, the fatigue strength of M4 was about Class E or D. The results show that the fatigue strength of the 18% misaligned butt welded joint (M2) satisfied Class D, as recommended for a butt welded joint without finishing by JRA. However, the fatigue strength of the butt welded joint may decrease from Class D to Class E with 36% misalignment.

3.2.2 Effect of taper grinding against misaligned butt welded joint

At M4T joints, no fatigue cracking was detected under $\Delta\sigma$ = 93 MPa. Fatigue cracking occurred under $\Delta\sigma$ = 124 MPa and N_f can be estimated as Class C. Therefore, the fatigue strength of M4T was about Class D or C, and it was confirmed that the fatigue strength of the 36% misaligned butt welded joint with the taper grinding was about 1-class higher than that of the joint without the taper grinding.

3.2.3 Effect of weld toe grinding against misaligned butt welded joint

Because no fatigue cracking was detected at the M4G joint under $\Delta\sigma$ = 94 MPa, the fatigue strength of M4G satisfied Class D. Also, because no fatigue cracking was detected at the M4TG joint under $\Delta\sigma$ = 133 MPa, the fatigue strength of M4TG satisfied Class C. It was therefore confirmed that both fatigue strength of these joints with weld toe grinding was about 1 class higher than those of joints without weld toe grinding.

3.2.4 Fatigue strength of the longitudinal welded joint between the web and the bottom flange

At longitudinal welded joints between the web and the bottom flange, 8 fatigue cracks occurred under $\Delta\sigma$ more than $\Delta\sigma_{ce}$ of Class D. Therefore the fatigue strength of the longitudinal welded joint satisfied Class D, as recommended by JRA. In comparison with butt welded joints, the fatigue life of the 18% or less misaligned butt welded joint was higher than that of the longitudinal welded joint. However, the fatigue life of the 36% misaligned butt welded joint was slightly lower than that of the longitudinal welded joint.

4. Conclusions

The principal results obtained through fatigue tests of 3 specimens with the 4 types of butt welded joints are as follows.

The fatigue strength of the 18% or less misaligned butt welded joint satisfied Class D, as recommended for a butt welded joint without finishing by JRA, while the fatigue strength of the butt welded joint may decrease from Class D to Class E with 36% misalignment.

The fatigue strength of the 36% misaligned butt welded joint was improved about 1 class and satisfied Class D through the taper grinding.

The fatigue strength of the 36% misaligned butt welded joint was improved about 1 class and satisfied Class D through the weld toe grinding.

References

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