International Journal of Modern Physics B
Vol. 20, Nos. 25, 26 & 27 (2006) 4141–4146

World Scientific
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FATIGUE CHARACTERISTICS OF SM490A WELDED JOINTS

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We compared the fatigue characteristics of weld metal with those of base metal heat-treated and non heat-treated. Also, we examined the influence of bead on fatigue life. From the experimental results of this study, it has been seen that the fatigue characteristics of welded specimens grinded the toe of bead are slightly better than those of welded specimens not grinded. Fatigue life is affected more by the stress concentration due to the profile change in the weld toe rather than by the residual stress, and heat-treatment had almost no influence on the fatigue characteristics.

Keywords: Fatigue characteristics; welded joints; stress concentration factor; weld bead profile.

1. Introduction

As a method of joining, welding has been widely used in manufacturing of mechanical structures such as automobiles, railway vehicles, bridges and ships, due to its high workability and the simplicity of the structures. However, heating and subsequent cooling of welding deform the welded material. In addition, the welding residual stress could lead to the crack initiation. Thus, the safety must be considered in designing welded structures.[1] In designing welded joints of structures such as automobiles and railway vehicles, which are subjected to the repeated loadings, the environment in which the structures are used and the fatigue characteristic of the welded joint must be considered as top priority. In addition, railway vehicles move with increasingly high speeds, the safety of welded joints must be ensured. For this reason, railway vehicles industry are required to submit data about the fatigue characteristic of structural materials in the fatigue design standard and to design vehicles which can endure the stress of a load repeated 2x 10^6 cycles.

However, these design standards are based on the fatigue characteristic of wholesome materials and suggest a number of general design standard curves that do not consider the shape and weld points of the specimens and, as a result, the actual status of the vehicle may not be reflected in the vehicle evaluations. To solve this problem, specimens representing a part of an actual structure should be prepared to investigate the fatigue characteristics of structural materials. Moreover, the fatigue behavior of a structure should be studied rigorously for quantitative design and safeguard of existing structures.

In this study, we examines the effect of heat treatment and weld toe profile on the fatigue life for the base metal and welding material of SM490A which is widely used as a structural material.

2. Test Material and Method

2.1. *Material and test conditions*

SM490A welded joints were tested by 3 pass GMAW (Gas Metal Arc Welding) method in this study. Table 1 shows the chemical compositions of SM490A steel, and Table 2 shows the welding and heat treatment conditions.

Table 1. Chemical compositions of SM490A (wt pct)

C	Si	Mn	P	S	Fe
~0.20	~0.55	~1.60	~0.035	~0.035	Bal.

Table 3 Description of the specimens

Specimen	Grinding	Heat treatment	Specimen symbol
As welded	No	No	WNN
	Yes	No	WGN
	No	Yes	WNH
	Yes	Yes	WGH
Cut-offed bead	Yes	Yes	CGH

Table 2. Welding and heat treatment nditions

	Specification			
Welding method	GMAW (Gas Metal Arc Welding)			
Welding conditions	Semi-auto ROBOT			
		1 Pass	2 Pass	3 Pass
	Current (A)	150	190	180
	Voltage (V)	103	105	105
	Speed (cm/min)	29	18	18
Wire size	Diameter 1.2 mm			
Form	1F			
Welded material	Filler metal spec. : A5.18 Classification : AWS ER 70S-6			
Shielding gas	CO_2 or Ar(85%)+CO_2(15%) Flow rate : 15-20 *l*/min			
Direction	Backhand			
Heat treatment conditions	Holding temperature : 590±20°C Holding time : 1 Hour Heating and Cooling rate : 120°C/h Maximum temperature : 200 °C			

2.2. *Specimen preparation and test equipment*

Specimens for both tensile and fatigue test were fabricated from a 10mm-thick plate according to the ASTM E8 and E466, respectively.[2, 3] Figures 1 and 2 show the configuration of the test specimens used in this study. Table 3 provides information about the specimens.

To evaluate the influence of weld toe profile on fatigue strength, two types of butt-welded joints, that is, as-welded and grinded so as to have uniform radius of curvature in weld toe, were prepared. as shown in figure 2 (a) and (b).

In this study the universal testing machine with capacity a maximum dynamic load of 25ton was used for both tensile and fatigue tests. Figure 3 shows the electro-hydraulic material testing system.

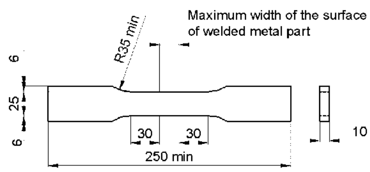

Fig. 1 Tensile test specimen

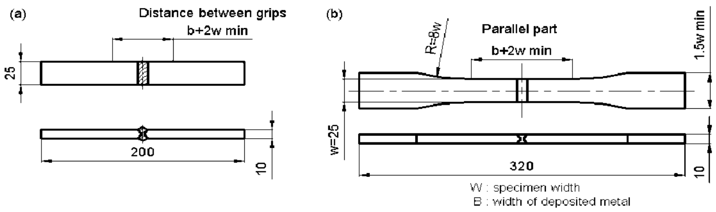

Fig. 2 Fatigue test specimen, (a) without cut-offed bead, (b) with cut-offed bead

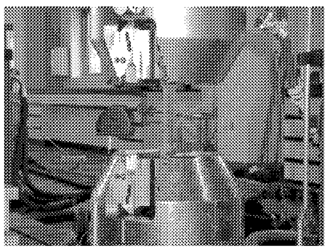

Fig. 3 Electro-hydraulic material testing system

Table 4 Tensile test results of SM490A Steel

Specimen	Base metal-1	Base metal-2	Base metal-3
Yield strength (MPa)	346	348	347
Ultimate strength (MPa)	515	522	519

3. Tensile and Fatigue Test

Tensile test was carried out according to ASTM E8 to obtain the mechanical properties of the SM490A welded joint. The test speed was 1mm/min, and a 25mm-long strain gauge was used to measure strain. Table 4 shows the yield strengths and ultimate strengths obtained from the tensile tests.

Fatigue tests were carried out according to E466. Fatigue loading was applied in tension by load control at an R-ratio equal to 0.1 and frequency of 20Hz. The testing was stopped when the specimen was broken into two separate pieces.

4. Test Results and Discussion

4.1. *Result of fatigue test according to bead profile*

Figures 4 and 5 show the fatigue test results for the base metals, WNN, WGN, WNH and WGH, before and after heat treatment, respectively. As shown in Fig. 4, without heat-treatment, the fatigue life of welded-joints are much shorter than that of the base metal. Residual stresses were developed in the welded joints due to the local heating and subsequent cooling during the welding process, and these residual stresses significantly decrease the fracture strength and the fatigue strength of welded joints.[4]

In general, the fatigue strength of a welded joint is lower than that of the base metal because a weld metal has a cylindrical crystal structure and a microstructural constituent near the fusion line has rough crystal structures. In addition, the intrinsic welding defects at the weld toe such as inclusions and undercuts may also contribute to the decrease in the fatigue strength of welded joints.[5] Fig. 4 also shows the comparison of the test results between welded specimens with and without grinding. The fatigue life of WGN was generally similar to that of WNN. However, if the scatter in the test results of WGN is less than that in the test results of WNN, WGN seems somewhat superior. The distribution region of the fatigue strength of WGN increased more than that of WNN. This increase may be due to the relaxation in stress concentration by the geometry change at the weld toe. Accordingly, the effect of bead profile on fatigue life must be examined.[6,7]

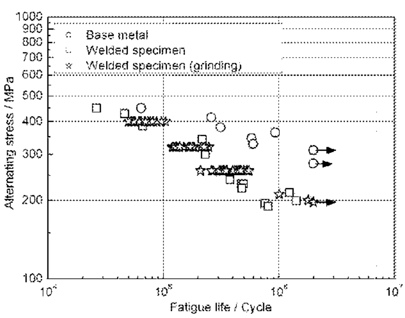

Fig. 4 Comparison between base metal and welded specimen before heat treatment

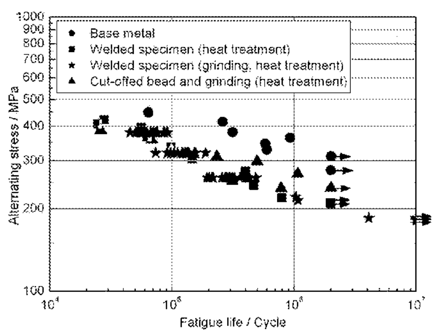

Fig. 5 Comparison between base metal and welded specimen after heat treatment

Figure 5 shows the comparison of the test results between the base metal and welded specimens after heat treatment. COB shows the highest fatigue limit than the other welded joints. It can be seen that grinding has little effect on the fatigue strength regardless of whether the specimen is heat treated or not.

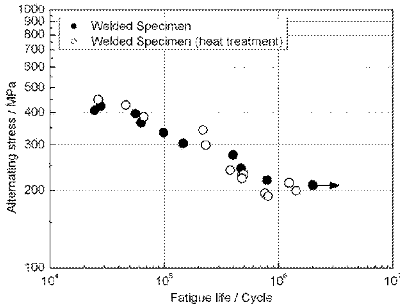

Fig. 6 Comparison of test results according to heat treatment for welded specimens

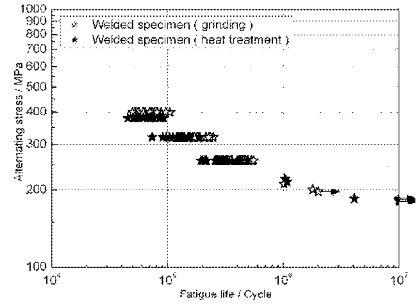

Fig. 7 Comparison of test results according to heat treatment for welded specimens

4.2. *Result of fatigue test according to heat treatment*

Figure 6 shows no significant difference between WNN and WNH in the fatigue strength. WNH showed a somewhat long life than WNN in the long life region. In case of the before and after heat treatment from Figure 7, no significant difference between WGN and WGH was observed similar to the case in Fig. 6.

In general, post weld heat treatment(PWHT) or mechanical stress relieving treatment(MSRT) is applied after welding for uniform distribution of texture and hardness in the weld structure and to minimize the lowering of fatigue strength and deformation caused by residual stress. Some recent researches, however, reported that fatigue life of weld structure was not affected significantly even in long-term use without PWHT.[8] These reports suggest that such no remarkable difference in fatigue strengths was due to the relaxation of the residual stress according to the applied loading during the fatigue test.

5. Influence Analysis of Weld Bead Profile

To evaluate the effect of stress concentration factor on the fatigue strength, bead shapes for the specimens were measured before the fatigue test by using a stylus type measuring instrument. (CV-4000 S4, Mitutoyo) To consider the geometrical influence only, we used Equation (1) to calculate the stress concentration factor.[9] Symbols in Equation (1) are as in Figure 8. Table 5 shows the result of Kt and bead profile data.

$$K_t = 1 + \left[\frac{1-\exp(-0.9\sqrt{T/h}\cdot(\pi-\theta))}{1-\exp(-0.9\sqrt{T/h}\cdot\pi/2} \right] \cdot \left(\frac{1}{2.8T/t-2} \cdot \frac{h}{\rho} \right)^{0.65} \tag{1}$$

The results of fatigue test showed that the location of crack initiation identifies the maximum point of the stress concentration factor. The smaller the weld toe radii, the bigger the frank angle and the taller the bead height, these conditions lead to a bigger stress concentration factor. Figure 9 shows the fracture surface of a specimen, cracks occurred where the stress concentration factor was the highest. Some other recent researches reported that stress concentration factor has a significant effect on fatigue life.

This suggest that stress concentration factor according to the bead profile of a welded joint has a significant effect on fatigue life.

Table 5 Results of K_t and bead profile data

Specimen number	Fracture position	Toe radius ρ(mm)	Angle θ(°)	Height h(mm)	K_t
WNH-1	4	0.64	47.00	1.86	2.35
WNH-2	8	1.67	38.88	1.78	1.71
WNH-3	5	0.18	40.59	1.72	3.95
WNH-4	8	0.38	38.27	1.92	2.89
WNH-5	4	0.34	44.28	1.95	3.06
WNH-6	8	0.22	59.89	2.16	3.76
WNH-7	4	1.29	57.84	1.87	1.85
WNH-8	8	0.16	39.73	1.85	4.24
WNH-9	6	0.25	50.83	2.78	3.73
WNH-10	3	0.38	37.77	1.50	2.77

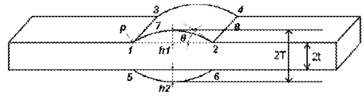

Fig. 8 Schematic of the specimen

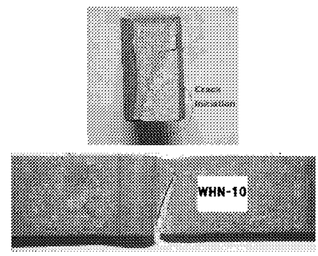

Fig. 9 Fracture surface of a welded specimen

6. Conclusions

In this study, fatigue tests were carried out to investigate the influence of heat-treatment and bead profile on the fatigue strength of the SM490A metal and welded joint specimens. From the results of this study, the conclusions are as follows

(1) No remarkable difference was observed in the fatigue characteristics of welded joints according to whether or not heat treatment was applied, and the bead profile affected fatigue life.

(2) The position of crack initiation was coincident with the position of the highest stress concentration factor.

Acknowledgments

This work was supported by the Brain Korea 21 Project.

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