Title	The LB-TRC Test for Cold Crack Susceptibility of Weld Metal for High Strength Steels(Materials, Metallurgy, Weldability)
Author(s)	Matsuda, Fukuhisa; Nakagawa, Hiroji; Shinozaki, Kenji
Citation	Transactions of JWRI. 1979, 8(1), p. 113-119
Version Type	VoR
URL	https://doi.org/10.18910/5244
rights	
Note	

The LB-TRC Test for Cold Crack Susceptibility of Weld Metal for High Strength Steels†

Fukuhisa MATSUDA*, Hiroji NAKAGAWA** and Kenji SHINOZAKI***

Abstract

This investigation is made to establish a new testing method for hydrogen-induced cracking of weld metal of high strength steel. The principle of this testing method which is named the LB-TRC (Longitudinal Bead-TRC) test is that two test specimens are butted together to provide a slit across which a test bead is laid and then a constant load is applied parallel to the weld line after welding. Then, a transverse crack occurs at the slit after a period depending on hydrogen content, stress level and type of material. Therefore, the testing machine doesn't require a large capacity in load and in size. Then, the relations between the fracture stress and the fracture time were measured in different level of hydrogen in welding electrode for HT-60 and HT-80 high strength steels. Consequently, it was shown that the lower critical stress and the fracture mode in the LB-TRC tested specimen were approximately equal to those obtained in the original TRC test, and that the LB-TRC test was useful to evaluate cold cracking susceptibility of weld metal.

KEY WORDS: (Cold Cracking) (Weldability Tests) (Weld Metal) (Covered Electrodes) (High Strength)

1. Introduction

Recently, in compliance with the demand lighter and stronger structure, many high strength steels have been developed. Concurrently the developments of high strength weld metal have been investigated. However, in general, the cold cracking is easy to occur in the heat-affected zone of high strength steel welds because of hydrogen absorbed during welding. The susceptibility for cold cracking is increased with an increase in strength of steel. Therefore, the crack susceptibility of welded zone for high strength steel has so far been evaluated by y-groove Tekken, the TRC and the RRC tests and so on. In these test, however the crack is easy to initiate and propagate in heat-affected zone$^{1)}$, so that these tests are suitable for evaluation of susceptibility to cracking of these high strength steels. However, increasing of strength of weld metal there is every indication that the cracking occurs within the weld metal of welded joint. It was reported$^{2)}$ by the authors that the weld metal cracking was easy to occur in HY-130 steel and generally known$^{3),4)}$ that a transverse cold cracking in weld metal occurred in multipassed weld bead of HT-80 and Cr-Mo steels. In this situation the developement of insusceptible weld metals against hydrogen-induced cracking is need. Therefore the simple and convenient testing method is required in order to investigate the characteristics for hydrogen-induced cracking of weld metal for high strength steels.

The GBOP test$^{5), 6)}$ was developed in order to assess weld metal cracking, whereas fracture stress can not be obtained by this test due to self restraint type. Accordingly in this work, the new test which is named the LB-TRC (Longitudinal Bead-Tensile Restraint Cracking) test is developed by the authors by modifying the original TRC test$^{7)}$ and the GBOP test for the purpose of investigation of susceptibility for weld metal cold cracking of higher strength steel. Then the LB-TRC test was applied for the HT-60 and HT-80 weld metals in comparison with the original TRC test. Consequently it is concluded that the LB-TRC test is available to evaluate the susceptibility of weld metal cold cracking. Moreover, comparing with the original TRC test, the other features of the LB-TRC test are smaller in specimen size, which is economical for testing the costly steels, and lower in testing load, which is small in machine size and also easy to operate.

---

† Received on March 31, 1979

* Professor

** Research Instructor

*** Graduate Student

2. Principle of the LB-TRC Test

2.1 Principle and Apparatus

The LB-TRC test essentially consists of two plates butted together to provide a slit across which the test bead is laid as shown in **Fig. 1**, and then after welding a constant load is applied parallel to the weld line. **Photograph 1** shows this test apparatus with specimen being tested.

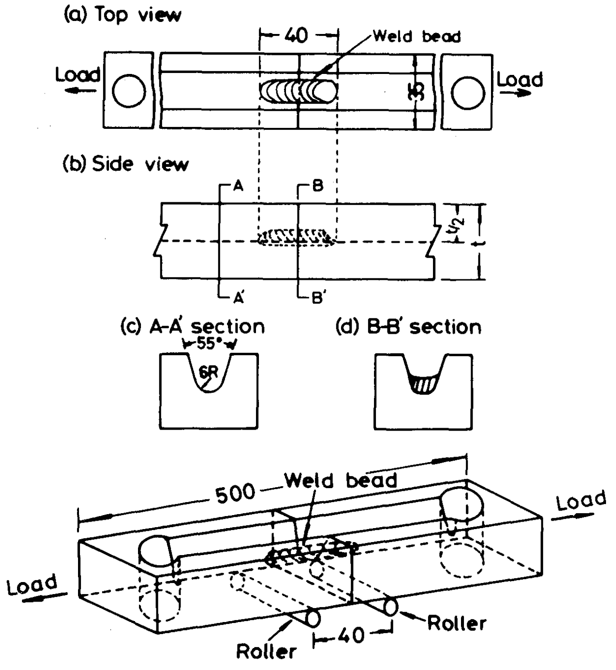


Fig. 1 LB-TRC test specimen and testing method

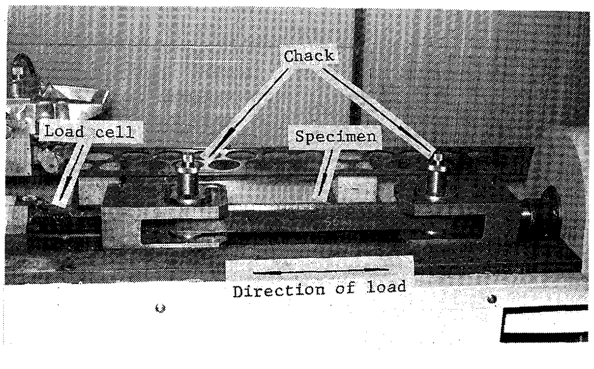


Photo. 1 Apparatus for the LB-TRC test

U-groove is machined to the middle of thickness of plate and the supporting rollers with the space of 40mm are put under the specimens in order to prevent the bend of the joint which occurs and eccentric stress during testing. The two groove faces are polished by emery paper of 220 and cleaned by acetone, then two plates are lightly butted together without gap before welding. The bead can be tested by various welding processes, for example SMA, GTA, GMA and SAW, etc. The cooling rate can be varied with the change of preheating of the specimen and of bead length. Then predetermined load is applied with a screw method using an electric motor at predetermined temperature or time after the completion of welding, and is maintained constant until the specimen is fractured.

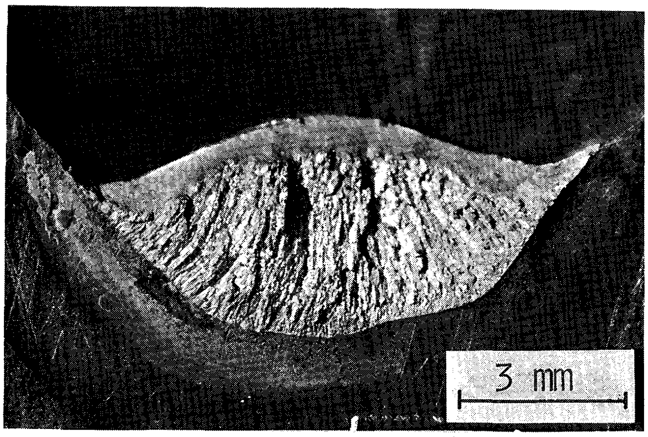
In this study, SMA welding with bead length of 40mm was mainly made in the heat input of 17kJ/cm, when the cooling rate from 800 to 500°C was about 4 to 5sec which was nearly equal to that in the case where a long weld bead was laid on sufficiently large plate of the same thickness. The load was applied at about 150°C of weld metal after the completion of welding without preheating.

Specimen is 250mm in length at first, but the bead is cut off after the test and then is again prepared for the next test. This is repeated until the length is not shorter than 150mm. Applied stress is decided by a dividing the load by the area of transverse cross section of weld metal at the butt joint which was measured by an optical scope of 10 magnification after fractured.

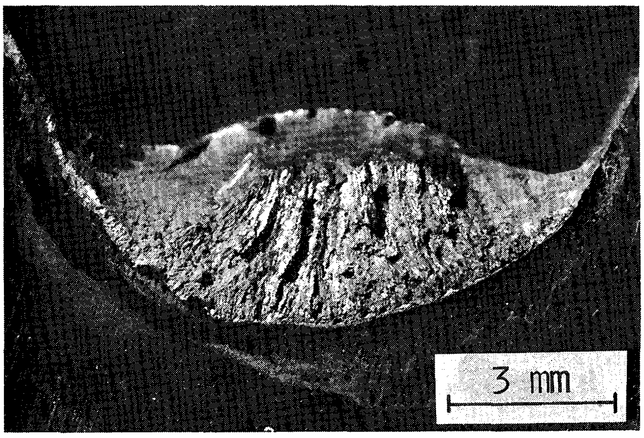
2.2 Crack and Fracture Mode

Photograph 2 shows the change in fractured surface with an increase of applied stress in HT-80 with the LB-TRC test in which SMA welding is done utilizing 170A, 25V, and 150mm/min at room temperature. Chemical composition and mechanical properties of HT-80 steel are shown in Tables 1 and 2 of 3.1. Macroscopic fractured surface in 30kg/mm^2 applied stress in Photo. 2(a) has mainly a directional and brilliant appearance containing shear lip mode in a limitted region along the bead surface. In photo. 2(b) of 53kg/mm^2 applied stress, a directional region and a fibrous region spread from the root edge parallel to the groove face as a fan-like shape, and shear lip region is larger than that in Photo. 2(a). The directional and brilliant region occupied in the majority and the fibrous region in part in a fan-like shape region. Fractured surface of 70kg/mm^2 in Photo. 2(c) has mainly a fibrous region and a shear lip in the bead surface region. The directional region is microscopically composed of intergranular fracture mode along columnar crystals and quasi-cleavage fracture mode, which correspond nearly to IG$_C$ region in the previous report$^{2)}$. The fibrous region is composed of dimple fracture mode and the shear lip region is composed of shear dimple fracture mode, which correspond to D region in the previous report$^{2)}$.

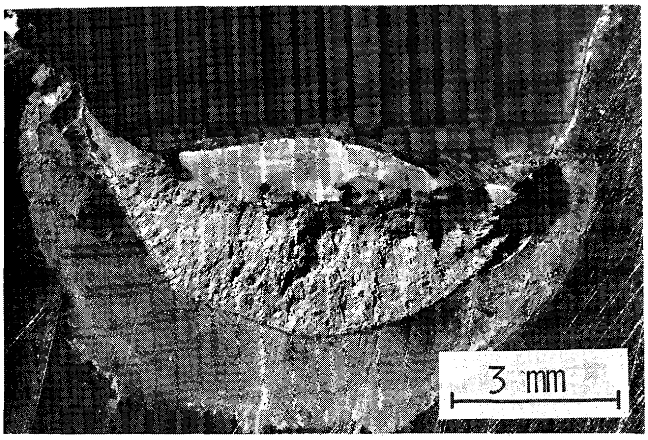
For the sake of reference, the original TRC test was tried with U-groove and without the root gap, where a weld bead of 35mm in length was laid for full specimen width and a constant load was applied perpendicular to the weld line in HT-80. Light fractograph of the TRC tested specimen is shown in **Photo. 3**. Fractured surface which has a directional and brilliant appearance spreads from the root edge in the lower side. This fracture mode in Photo. 3 microscopically and macroscopically resembles well to that in Photo. 2(a) by the LB-TRC test at the same stress level. Moreover, area fraction of IG_c region in the TRC test is approximately equal to that in the LB-TRC test.



(a) Applied stress (σ): 30kg/mm^2
Fracture time (t_F): 19 min



(b) σ = 53kg/mm^2, t_F = 4 min



(c) σ = 70kg/mm^2, t_F = 3 min

Photo. 2 Variation of fractured surface of HT-80 + D8016 (A) with increase in applied stress in the LB-TRC test without preheating

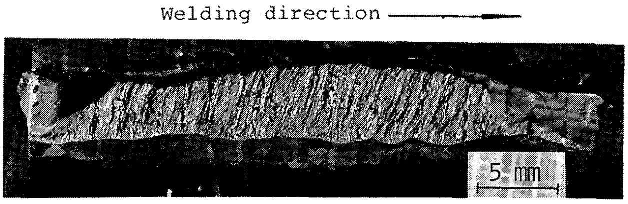
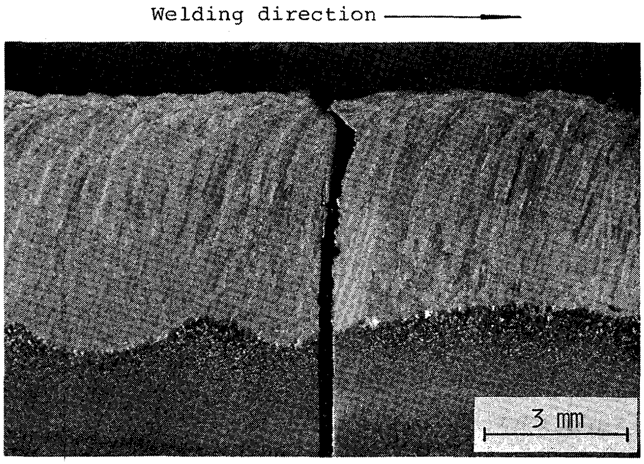


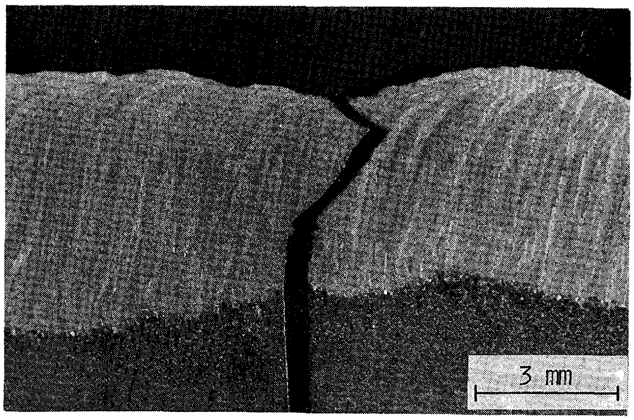
Photo. 3 Light fractograph of the original TRC test with U-groove without the root gap and preheating in HT-80 + D8016 (A)
σ = 31kg/mm^2, t_F = 61 min

The IG_c region increases with an increase of fracture time by decreasing of applied stress as shown in Photo. 2. It seems that the IG_c is affected by hydrogen embrittlement. On the contrary, D region increases with an increase of applied stress, that is, decrease of fracture time. This tendency of change in fractured surface with fracture time and applied stress is similar to those in the original TRC test. Macrostructure of longitudinal cross section along the center of HT-80 weld metal in the LB-TRC test is shown in **Photos. 4(a) and (b)**. At lower applied stress in Photo. 4(a) the crack initiates from the root of the joint, and propagates vertically along the growing direction of columnar crystal in weld metal and finally fractures in shear mode at the top portion. At higher applied stress in (b) the crack propagates vertically in the first and turn into shear mode. **Photographs 5(a) and (b)** show the macroscopic feature of the root crack in the transverse cross section at applied stress of 31kg/mm^2 and of 44kg/mm^2 in the original TRC test with U-groove. At lower applied stress in Photo. 5(a), the crack initiates from the root and propagates vertically along the columnar crystal. At higher applied stress in (b), the crack propagates vertically and turn into shear mode.

Judging from the above, as for the crack occured in weld metal, the characteristics of fracture mode and fractured surface in the LB-TRC test are essentially equal to those in the original TRC test with U-groove and without root gap whose fracture occurs within weld metal.

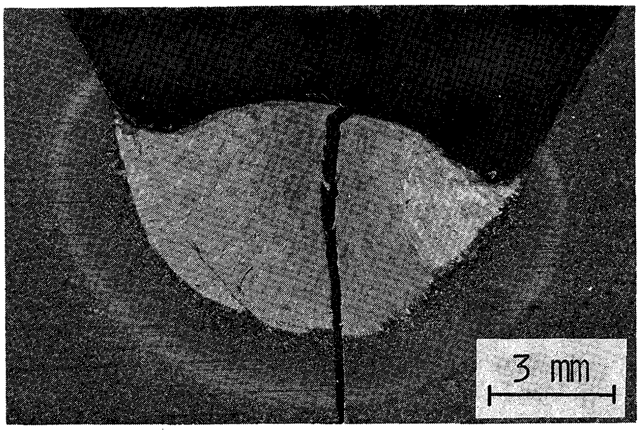


(a) $\sigma = 19\text{kg/mm}^2$, $t_F = 35$ min, without preheating

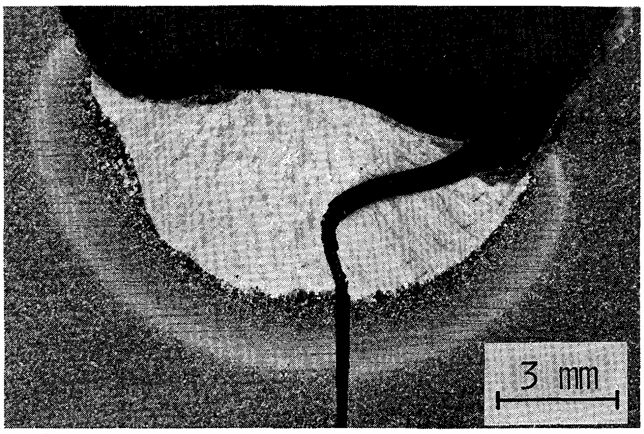


(b) $\sigma = 91\text{kg/mm}^2$, $t_F = 0$ min, preheating temperature: 150°C

Photo. 4 Macrophotograph of longitudinal cross section in the LB-TRC test in HT-80 + D8016 (A)



(a) $\sigma = 31\text{kg/mm}^2$, $t_F = 61$ min



(b) $\sigma = 44\text{kg/mm}^2$, $t_F = 6$ min

Photo. 5 Macrophotograph of transverse cross section in the TRC test with U-groove in HT-80 + D8016 (A) without preheating

2.3 Lower Critical Stress

There is compared in Fig. 2 the lower critical stress of the LB-TRC test and the original TRC test for HT-80 weld metal, where SMA welding was done without preheating. Fracture time was extended with a decreasing applied stress and fracture didn't occur at the stress less than the critical value depending on kind of material and hydrogen content. These results indicate the typical behavior of hydrogen-induced delayed cracking in both tests. The lower critical stress and fracture time of the LB-TRC test approximately equal to those of the TRC test. Judging from the results of the above and 2.2, the LB-TRC test is useful for evaluating of weld metal cracking. One of the

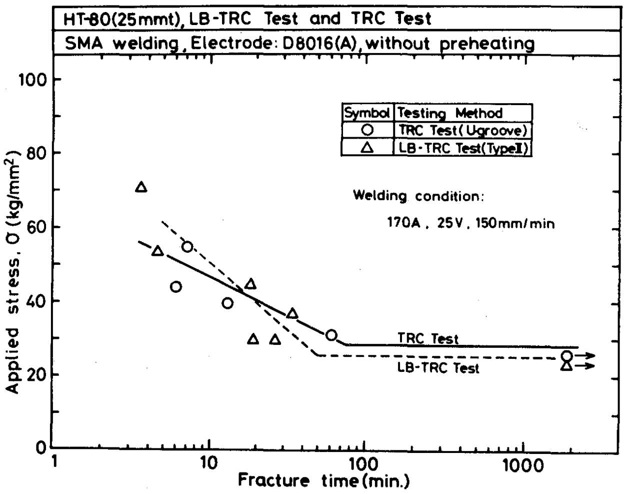


Fig. 2 Relation between applied stress and fracture time in HT-80 + D8016 (A) without preheating
(Compare the LB-TRC test and the original TRC test)

advantages of the LB-TRC test is that the test can be done easily with small capacity of machine. On the contrary in the original TRC test the loading capacity is proportionally increased with an increase of length of weld bead, therefore usually the TRC machine has larger capacity than the LB-TRC test.

The LB-TRC test is usually done without root gap, but the root gap of about 0.3mm arises occasionally because of error for edge preparation. There is compared in **Fig. 3** the lower critica[illegible] of HT-80 in the case of 0 and 0.3mm in root [illegible]th. In Fig. 3, the lower critical stress without r[illegible] approximately equal to that in 0.3mm gap widt[illegible]gh the times to failure in no root gap width are sca[illegible] in some extent. From these data, it is considered th[illegible]e root gap until 0.3mm does't have an influence upon the lower critical stress.

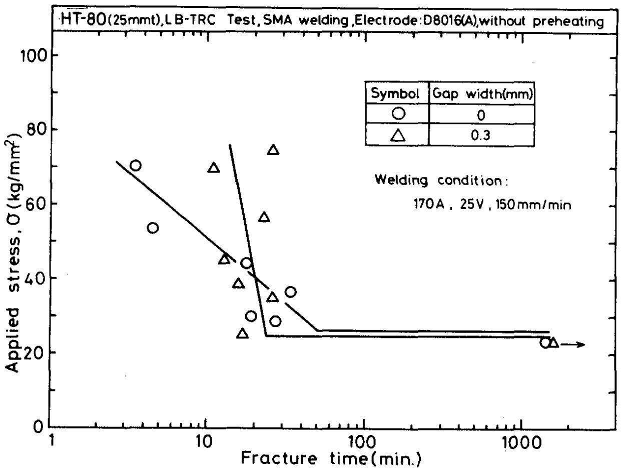


Fig. 3 Relation between applied stress and fracture time in HT-80 + D8016 (A) without preheating
(Effect of gap width for lower critical stress)

Moreover as mentioned before, specimen was used until the length was not shorter than 150mm, but the lower critical stress was not affected by the length within the range from 250 to 150mm.

3. Application of the LB-TRC Test

It is discussed here whether the LB-TRC test is able to well evaluate the effect of preheating, kind of material and electrode on the cold crack susceptibility.

3.1 Materials used and Experimental Condition

Table 1 contains the chemical compositions of base metals and welding electrodes used. **Table 2** summarizes

Table 1 Chemical compositions of base metals and deposited metals

Material		Thickness (mm)	Diameter (mm)	Composition (wt.%)									
				C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V
Base metal	HT60	35	–	0.13	0.34	1.33	0.019	0.008	–	0.02	0.02	0.21	0.04
	HT80	25	–	0.13	0.27	0.86	0.011	0.004	0.25	1.08	0.50	0.43	0.04
Welding rod	D5816	–	4.0	0.07	0.53	1.14	0.008	0.005	–	0.60	–	0.26	–
	D8016 (A)	–	4.0	0.06	0.63	1.36	0.010	0.005	–	1.73	0.24	0.44	–
	D8016 (B)	–	4.0	0.06	0.55	1.47	0.015	0.007	–	2.50	0.18	0.48	–
	D8016 (C)	–	4.0	0.08	0.68	1.40	0.009	0.007	–	1.68	0.29	0.36	–
	F (HT-80)	–	1.6	0.09	0.39	1.25	0.007	0.007	0.26	2.26	–	0.54	–

Table 2 Mechanical properties of base metals and deposited metals

Material		Yield strength (0.2% offset) (kg/mm²)	Tensile strength (kg/mm²)	Elongation (%)	Charpy V-notch energy absorption (kg-mm)		
					0°C	-5°C	-15°C
Base metal	HT60	59	67	26	–	21.1	–
	HT80	84	90	23	–	–	14.5
Welding rod	D5816	57	66	29	–	16.2	–
	D8016 (A)	70.3	82.8	24	–	13.0	–
	D8016 (B)	74.1	83.6	24	–	–	10.2
	D8016 (C)	75	85	22	10	–	–
	F (HT-80)	76	84	23	–	–	8.1

the mechanical properties of the both base metals and deposited metals. The LB-TRC test was done for weldable heat-treated high strength HT-60 and HT-80 base metal steels whose tensile strengths were 60 and 80 kg/mm^2 levels, respectively. The HT-60 was welded with JIS* D5816 (4mm diam.) low-hydrogen type covered electrode whose tensile strength of deposited metal was about 66 kg/mm^2. The HT-80 was welded with three kinds of JIS D8016 (4mm diam.) low-hydrogen type covered electrodes and F (HT-80)** (1.6mm diam.) bare wire electrode by GTA welding. The tensile strengths of deposited metals of D8016 and F (HT-80) were about 83 to 85 kg/mm^2 levels. Covered electrodes were dried for one hour at 350°C and maintained at 150°C. The LB-TRC test welds were deposited by SMA welding utilizing 170A, 25V and 150mm/min which corresponded to a heat input of 17kJ/cm and by GTA welding with constant wire feed system utilizing 300A, 17V and 120mm/min, which corresponded to a heat input of 25.5kJ/cm. Pure argon was used as shielding gas at a rate of 20 *l*/min. The welding condition in GTA welding was chosen in order to obtain the cooling time in weld metal from 800 to 150°C which was approximately equal to that in SMA welding. As occasion demanded, the specimen was wholly preheated by an electric furnace.

3.2 Effect of Preheating on Lower Critical Stress

Figure 4 shows the effect of preheating in HT-60 and HT-80 weld metals. SMA welding was done at room temperature and 75°C preheating for HT-60. The lower critical stress without preheating is about 59kg/mm^2 compared to 75kg/mm^2 at 75°C. The times to failure without preheating is shorter than that at 75°C. According to these data, the lower critical stress even without preheating in HT-60 weld metal is approximately equal to the nominal tensile strength of base metal and with 75°C preheating is satisfactorily exceeded the strengths of base and all deposited metals. Thus HT-60 weld metal has a less susceptibility to hydrogen-induced cracking. SMA welding was done at room temperature, 75 and 100°C preheating, and GTA welding at only room temperature for HT-80 steel. The lower critical stress without preheating is about 26kg/mm^2 compared to 38kg/mm^2 at 75°C and 96kg/mm^2 at 100°C which is exceeded the tensile strengths of base and all deposited metals. From these data, the lower critical stress and fracture time increase with increase of preheating temperature.

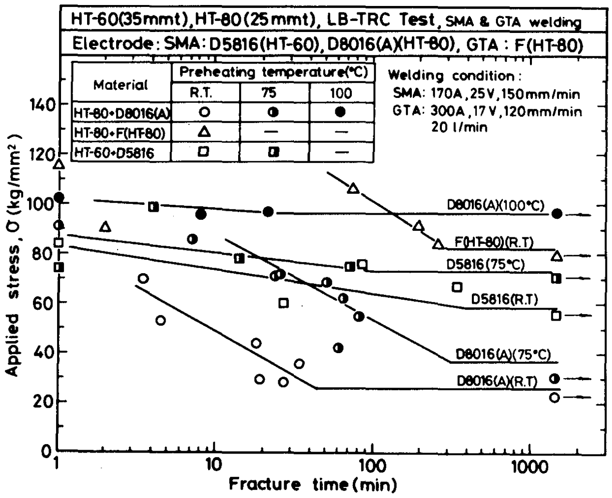


Fig. 4 Relation between applied stress and fracture time in HT-60 and HT-80 weld metal
(Effect of preheating for lower critical stress)

On the other hand, the lower critical stress with GTA welding without preheating is about 82kg/mm^2 compared to 23kg/mm^2 with SMA welding without preheating. The lower critical stress with GTA welding is higher than that with SMA welding and the time to failure with GTA welding is longer than that with SMA welding at the same stress level. From these data, the crack susceptibility of HT-80 weld metal to hydrogen-induced cracking is much higher than that of HT-60 weld metal with SMA welding without preheating. HT-80 with GTA welding has a very low crack susceptibility to hydrogen-induced cracking.

Judging from the above results, the LB-TRC test is one of the suitable testing methods in order to investigate the effect of preheating on lower critical stress and compare the cold crack susceptibility for different high strength weld metals.

3.3 Comparison of Electrodes at the Same Strength Level

There is compared in Fig. 5 the lower critical stress

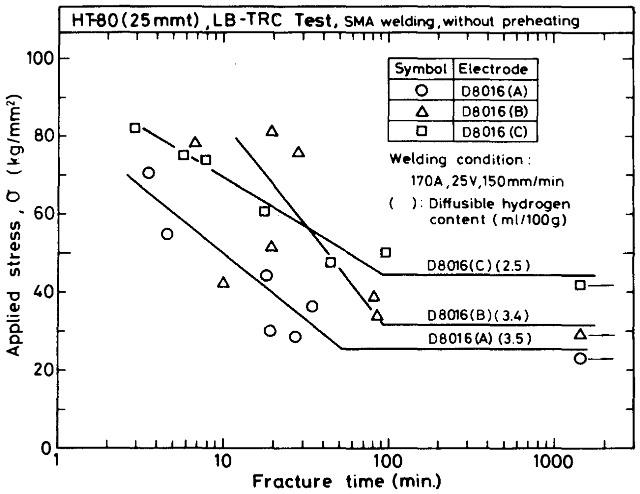


Fig. 5 Relation between applied stress and fracture time in HT-80 weld metal without preheating
(Effect of electrode for lower critical stress)

---

* Japan Industrial Standard

** F (HT-80) is the mark given for convenience in this study among three commercial low-hydrogen type electrodes of 80kg/mm^2 strength level which are made in different electrode maker. In Fig. 5, the values in parentheses show the diffusible hydrogen content measured by the modified JIS technique using mercury as a confining liquid. Diffusible hydrogen content for D8016 (C) is 2.5 m*l*/100g compared to 3.5 m*l*/100g for D8016 (A) and (B) weld metal, although the drying treatment is the same for all electrodes. The lower critical stresses for D8016 (A) and (B) are approximately equal to about 30 kg/mm^2, and D8016 (C) is about 45 kg/mm^2 and thus is superior to those of D8016 (A) and (B) weld metals. According to these data, the difference in the lower critical stress seems to be caused by the difference in diffusible hydrogen content. This indicates that the LB-TRC test is suitable to compare the cold crack susceptibility of weld metals obtained with different electrode.

4. Conclusion

In order to evaluate the cold crack susceptibility of weld metal in high strength steel easily and quickly, the new testing method, namely the LB-TRC test, was developed and the applications of this test were studied for the weld metals of HT-60 and HT-80. Main conclusions are summarized as follows;

(1) The crack in the LB-TRC test initiates at the root of the weld bead, mainly propagates along the columnar crystals in weld metal and finishes in shear type fracture at the bead surface The behavior of the crack propagation has shown in delayed type fashion. The characteristics of fractured surface and microscopic fracture mode and the lower critical stresses in the LB-TRC test approximately equal to those in the original TRC test.

(2) The cold crack susceptibility affected by preheating temperature, hydrogen content and combination of base metal and electrode can be well evaluated in the LB-TRC test.

(3) Judging from (1) and (2), the LB-TRC test is suitable to evaluate cold crack susceptibility of the weld metal for high strength steels. The obvious features of the LB-TRC test method are easy in operation due to small capacity of machine and saving the base metal which is much beneficial in case of test in expensive, unusual or tentative high strength steels.

The weld cracks will often occur within weld metal in cases of welding of higher strength steel than HT-80 in future, of multipasses welding of conventional steels due to much hydrogen content and so on. In these cases the LB-TRC test will be an useful device to select the suitable electrode and welding condition.

Acknowledgement

The authors would like to express our gratitude to Mr. Hiroshi Nakajima, formerly student of Osaka Institute of Technology, for his cooperation of testing.

References

1) H. Kihara, H. Suzuki M. Inagaki and H. Nakamura: J. Japan Weld. Soc. Vol. 31 (1962), pp. 53-66 (in Japanese)
2) H. Kihara, F. Matsuda et al,: Trans. JWRI, Vol. 6 (1977), No. 2, pp 59-73
3) E. C. Rollason and R. R. Roberts: JISI, Vol. 166 (1950), No. 10, pp. 105-112
4) P. C. Arnold: Weld. J., Vol 36 (1957), No. 8 pp. 373s-381s
5) B. A. Graville and M. Mcparlan: Brit. Weld. J., (1974), No. 2, pp. 62-63
6) B. A. Graville and M. Mcparlan: Weld. J., Vol. 41 (1976), No. 4, pp. 95s-102s
7) H. Suzuki, M. Inagaki and H. Nakamura: J. Japan Weld. Soc. Vol. 32 (1963), pp. 44-55 (in Japanese)