Development of Restraint-relaxation U-form Hot Cracking Device †

Yue-Chang ZHANG*, Hiroji NAKAGAWA**, and Fukuhisa MATSUDA***

KEY WORDS: (Hot Cracking) (Solidification) (Controlled Expansion Alloys) (Stainless Steels)

The demands of thin sheets of austenitic stainless steel, iron, nickel and Co-base high alloys increase gradually for special condition with the development of high technology. One of the problems of welding these alloys is weld hot cracking. As well known, the Varestraint test is excellent for hot cracking, but is not useful to thin sheet material. Moreover, the deformation rate in the Varestraint test is too high in some cases[1,2], and thus is not necessarily suitable for ductility-dip cracking test of Fe-36%Ni alloy[2]. On the other hand, as well known, the Houldcroft hot cracking test is useful well for the solidification cracking of thin sheet material, but not for the liquation-crack and the ductility-dip crack in HAZ and weld metal reheated. Therefore, it is required to develop a cracking test suitable for the different types of hot cracking in thin sheet.

In this report, the authors have invented a new hot cracking device suitable for thin sheet material, named "Restraint-relaxation U-form hot cracking device". This device has the capability to deform specimen and to measure deformation rate. According to the testing results obtained, the U-form hot cracking device has been judged suitable well to the different types of hot cracking test in the thin sheet material.

Figure 1 shows the principle of the "Restraint-relaxation U-form hot cracking device", which consists of one restraint plate and two restraint beams taking the form of letter U nearly. Testing procedure is: (a) At first, the two restraint beams are deformed by compressive force F_i

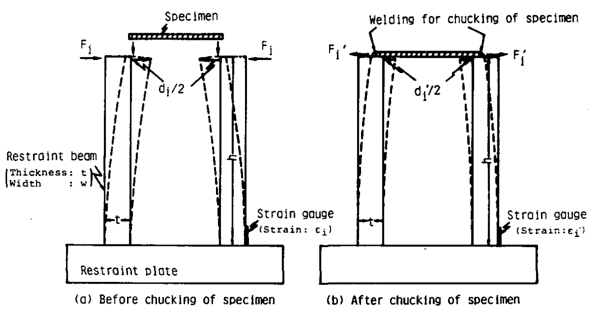


Fig. 1 Principle of Restraint-relaxation U-form hot cracking device.

with C-clamp, for example, to produce initial deflection d_i at the top of the beams. Then, a specimen is fixed on the top of the beams, by welding, for example. (b) After that, the force F_i is unloaded. As the result, the deflection d_i', and tesile force F_i' act to the specimen. Then, test welding is done on the specimen. Since the strength of specimen is lowered due to the heating by the test welding, tensile plastic deformation begins to be produced by the tensile force F_i'. The tensile force and deflection gradually reduce together with the deformation of specimen. That is to say, the restraint condition of the specimen is gradually relaxed during the test welding, similarly to most actual welding fabrication. This is the derivation of "Restraint-relaxation U-form hot cracking device". Hereafter, however, this name is generally abbreviated as "U-form hot cracking device". One of the advantages of this device is that deformation rate can be easily measured during the test welding by strain gauges stuck near the root of the beam, because the longitudinal strain on any position of the beam has a simple correlation with the deflection at the top of the beams according to the beam theory. The gradient of time-strain curve during the test welding gives the deformation rate through the calibration from the strain to the deflection.

The actual configuration of the U-form hot cracking device used and its general appearance are shown in **Fig. 2** and **Fig. 3**(a), respectively. This is capable of biaxial loading and is made of 80 kgf/mm^2 class high strength steel because of its high yield strain. The relationship between the deflection d of the beam and the strain ϵ at the position of strain gauge is given by next equation according to the beam theory:

$$\epsilon = (3/4)\,(h't/h^3)\,d \qquad (1)$$

where, t is the thickness of the restraint beam, and h' is the distance from the top of the restraint beam to the strain gauge. In Fig. 2, t = 20 mm, and h' = 125 mm, and thus Eq.(1) can be represented as:

$$\epsilon = 5.1 \times 10^{-4}\,d \qquad (1')$$

† Received on Apr. 21, 1986
* Foreign Researcher (Shanghai Jiao Tong Univ.)
** Research Instructor
*** Professor

Transactions of JWRI is published by Welding Research Institute of Osaka University, Ibaraki, Osaka 567, Japan

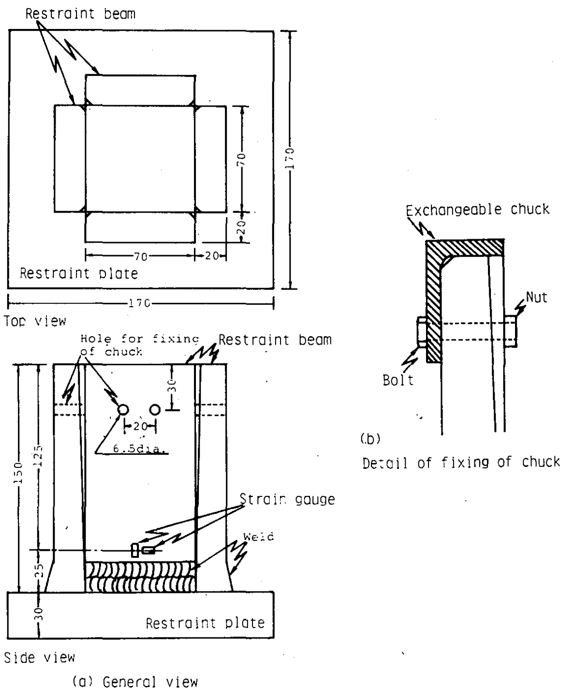


Fig. 2 Configuration of U-form hot cracking device used.

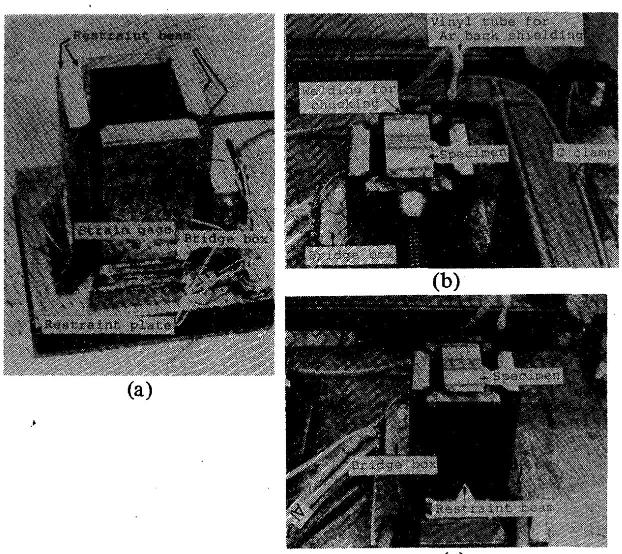


Fig. 3 Setting manner of specimen on U-form hot cracking device.
(a) general appearance of the device
(b) chucking of specimen on the device
(c) situation just before test welding

Actual relation between d and ϵ is compared with Eq. (1′) in **Fig. 4**, and it is seen that both agree well with each other. The reason why the actual strain is somewhat larger than the theoretical value is maybe due to the effect of reinforcement at the root of the beams. The right ordinate in Fig. 4 gives the load calculated by the next theoretical equation:

$$F = (E/8)\,(wt^3/h^3)d \qquad (2)$$

$$= 3.4d \quad \text{(kN)} \qquad (2')$$

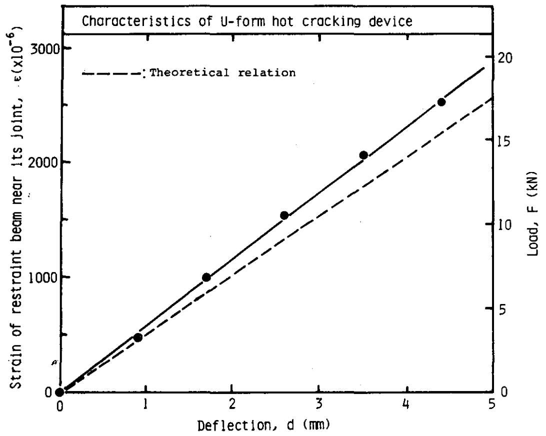


Fig. 4 Relation between deflection and strain in restraint beam in U-form hot cracking device.

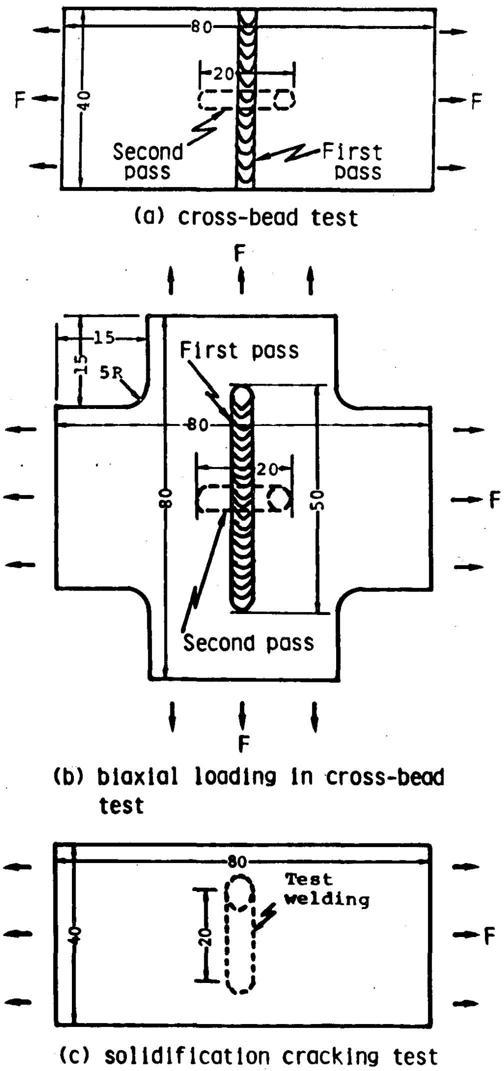


Fig. 5 Configuration of specimen used for U-form hot cracking test.

where, w is the width of the restraint beam and E is Young's modulus. It is understood that the capacity of this device is about 20 kN.

The other characteristic of this device is that different restraint condition can be easily attained by varying h, t, w and E, namely material in Eqs. (1) and (2).

It is desirable to fix the specimen on the device tightly, for example, by welding. If the specimen is fixed by welding, however, it is impossible to use the device repeatedly. Therefore, the specimen was welded to L-shaped steel fixed on the device by bolts and nuts as shown in Fig. 2(c). Figure 3(b) shows the setting manner of the specimen on the device by C-clamp and welding, and Fig. 3(c) shows the situation just before the test welding.

Types of hot cracking studied in this paper are reheat hot cracking as ductility-dip cracking in weld metal of Fe-36%Ni alloy Invar[2,3], commercially pure Ni and Inconel alloy 600, liquation cracking in weld metal of Inconel alloy 600 and AISI 310S, and solidification cracking of AISI 310S, 304 and 316L. Their specimen configurations are shown in **Fig. 5** together with tensile direction (F). The specimen in Fig. 5(a) where the tensile direction was perpendicular to the first pass bead made in advance was used to reheat hot cracking and the liquation cracking. The specimen in Fig. 5(b) was used to check the effect of biaxial loading on the reheat hot cracking. The specimen in Fig. 5(c) where the tensile direction was perpendicular to the test welding was used to the solidification cracking.

Figure 6 shows an example of the behavior of strain ϵ and thus deflection d during test welding. Both ϵ and d gradually decrease during the test welding, and the slope of d gives the deformation rated $\dot{d}$.

Figure 7 shows the macroscopic behavior of reheat hot cracking in the weld metal of Fe-36%Ni alloy Invar in relation to initial deflection d_i, and this behavior agrees with the result obtained by the dynamic observation technique with tensile hot cracking machine[3].

The effect of weld heat input on the total length of reheat hot cracking in the weld metal of Invar is shown in **Fig. 8**(a) in relation to d_i, and in Fig. 8(b) in relation to mean deformation rate $\dot{d}$ when GTA torch passed the middle of the length of test welding. Both expressions mean that an increase in weld heat input of either first pass or second pass promotes the total crack length, but

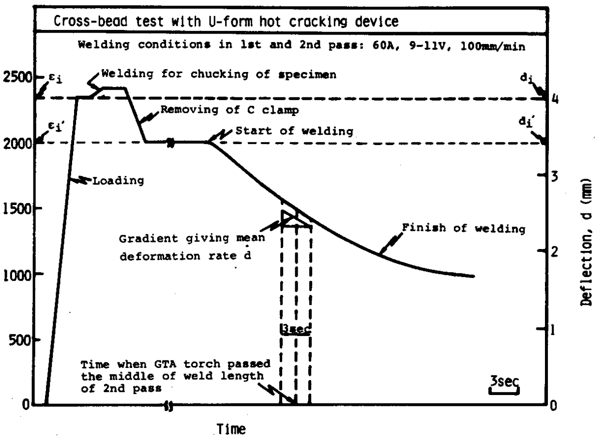


Fig. 6 An example of behavior of strain and deflection during test welding.

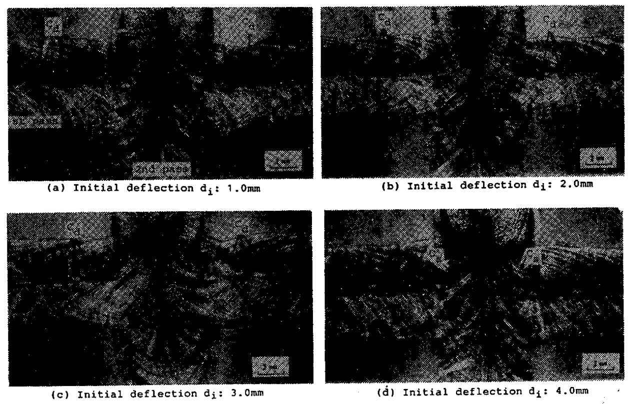
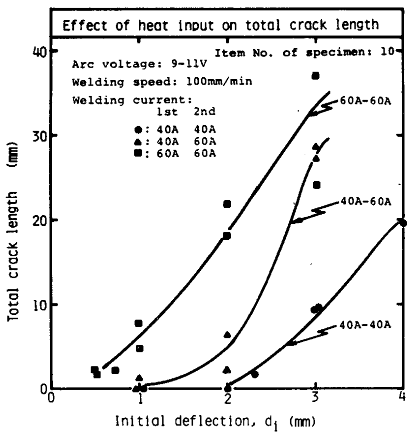
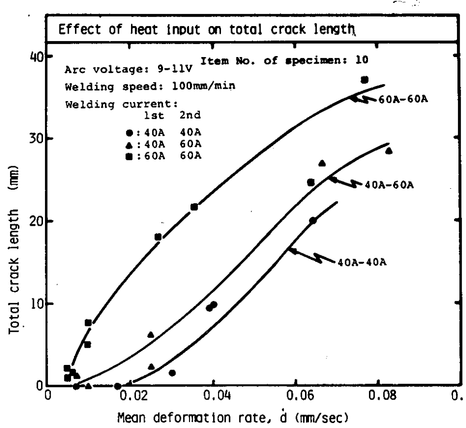


Fig. 7 Macroscopic behavior of reheat hot cracking in weld matel of Invar in cross-bead cracking test under different initial deflections with U-form hot cracking device.



(a) Effect of heat input on total length of reheat cracks vs. initial deflection in cross-bead cracking test with U-form hot cracking device



(b) Effect of heat input on total length of reheat hot cracks vs. mean deformation rate in cross-bead cracking test with U-form hot cracking device

Fig. 8 Effect of heat input on total length of reheat hot crack in weld metal of Invar.

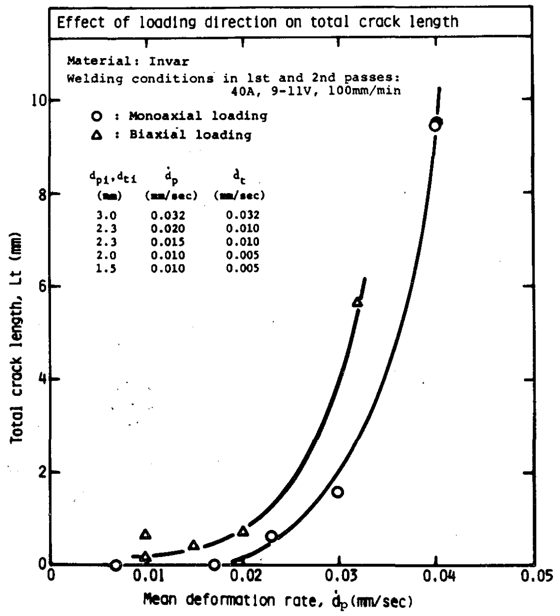


Fig. 9 Effect of biaxial loading on total length of reheat hot crack in weld metal of Invar.

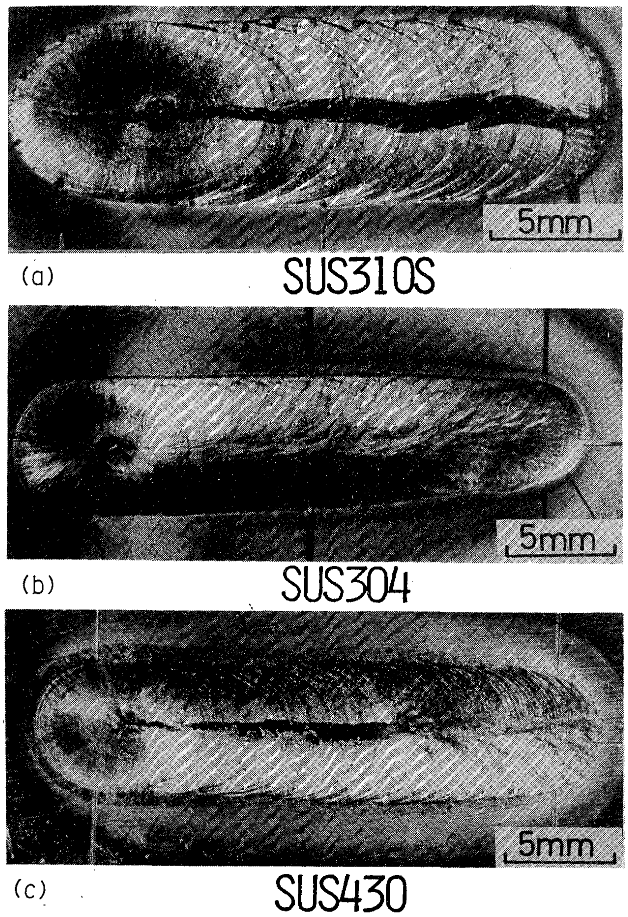


Fig. 10 Macrostructure of weld bead in austenitic stainless steels after solidification cracking test.

Fig. 8(b) suggests clearly that the effect of the first pass is stronger than that of the second pass. In this sense, it is valuable to be able to evaluate the deformation

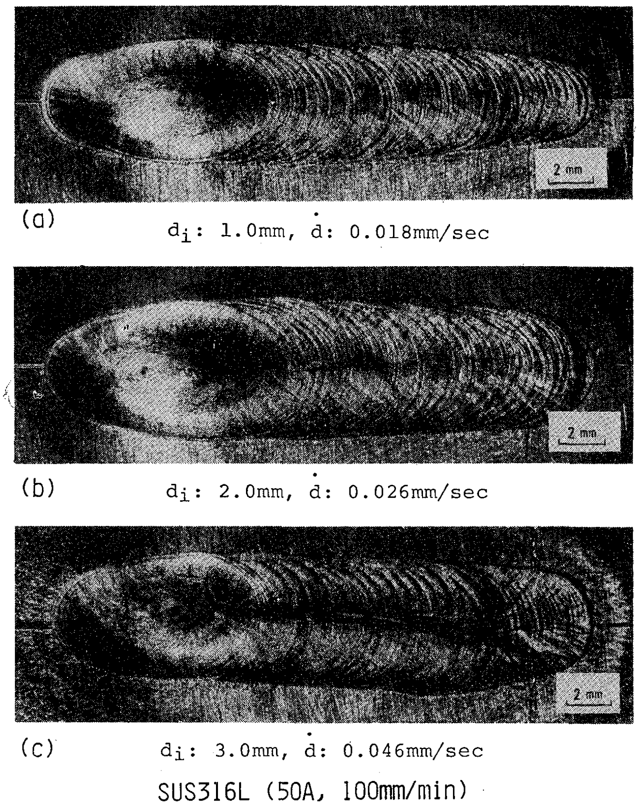


Fig. 11 Effect of initial deflection d_i on cracking behavior of AISI 316L in solidification cracking test.

rate.

Effect of biaxial loading is compared with monoaxial loading in **Fig. 9**. This means that the biaxial loading promotes the reheat hot cracking in the weld metal of Fe-36%Ni alloy.

The U-form hot cracking device was useful to the study of the liquation crack. For example, testing results using the specimen shown in Fig. 5(a) showed that the weld metal of AISI 310S and Inconel alloy 600 was susceptible to the liquation crack.

Furthermore, the applicability of the U-form hot cracking device to the solidification cracking was examined. **Figure 10** compares the macrostructure after the testing under the same initial deflection d_i between AISI 304 and 430 insusceptible to the cracking and 310S susceptible to the cracking. It is understood that the difference in the susceptibility is well reflected on the macrostructure. On the other hand, **Fig. 11** compares the macrostructure of AISI 316L after the testing under different initial deflection, and means that the decrease in the initial deflection and thus in the deformation rate delays the initiation of solidification cracking. Therefore, this device is also suitable to examine the solidification crack susceptibility under different restraint condition.

According to the above mentioned, it is understood that the "U-form hot cracking device" is suitable well to the different types of hot cracking in thin sheets of various materials.

The authors would like to thank Mr. K. Maki, student of Osaka Institute of Technology, for his cowork in the experiments.

References

1) Y. Arata, et al.: Trans. JWRI, 6 (1977), p. 91.
2) Y-C Zhang: Dr. thesis, Osaka Univ., 1986.
3) Y-C Zhang, et al.: Trans. JWRI, 14 (1985), p. 107.