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A New Self-Restrained Solidification Crack Susceptibility Test for Electron-Beam Welding of Aluminum Alloys†

— Taper-Shaped Hot Cracking Test —

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KEY WORDS: (Solidification Crack Susceptibility) (Cracking Test) (Electron-Beam Welding) (Aluminum Alloy)

As electron-beam welding (EBW) is usually done with high energy density and high welding speed, the feature of the welded joint shows narrow width of weld bead and HAZ in addition to deep penetration. Accordingly the susceptibility to solidification cracking in weld bead of EBW is lower than that with coventional arc welding in general. Therefore the solidification cracking does not usually reappear in the weld bead when the crack susceptible test is done with EBW using ordinary self-reatrained cracking test specimens such as Houldcroft-type test and so on. Then the ordinary self-restrained cracking test has not been usually used for EBW so far.

Whereas, in order to investigate simply the solidification crack susceptibility of EBW weld metal for aluminum alloys, the authors have tried to develop a new self-restrained cracking test specimen taking into consideration the principle of initiation and propagation of solidification cracking in Houldcroft-type test specimen which was reported in the previous reports.[1)]

As a result, the authors shortly reported here as a conclusive example for the shape and dimension of the cracking test specimen obtained.

The materials used were 6 mm thick commercial aluminum alloy plates of 6061-T5 (0.57 %Si, 0.16 %Fe, 0.18 %Cu, 0.04 %Mn, 0.89 %Mg, 0.01 %Zn, 0.03 %Cr, 0.02 %Ti), 2017-T6 (0.27 %Si, 0.27 %Fe, 4.09 %Cu, 0.48 %Mn, 0.48 %Mg, 0.02 %Zn, 0.01 %Cr, 0.01 %Ti) and 5052-0 (0.09 %Si, 0.28 %Fe, 0.02 %Cu, 0.02 %Mn, 2.50 %Mg, 0.01 %Zn, 0.20 %Cr, 0.01 %Ti).

The First experiment is to decide the specimen width at the edge of test specimen from which the solidification crack occurs at the start part of weld bead by EBW. As illustrated with a sketch in **Fig. 1**, the full-penetrated bead with EBW was made parallel to the plate edge, on the distance of (1/2) **Ws** apart from one side of the plate (100 mm in width ×200 mm in length ×6 mm in thickness).

Then (1/2) **Ws** was varied from 5 to 100 mm in this experiment. The most important thing is that a full-penetration welding was completed from the start of weld bead. Sciaky EBW machine of 60 kV max. in accelarating voltage was used through this experiment and all welding were done without any fixtures on the carrage with an V-grooved ditch. In Fig. 1 the relations between (1/2) **Ws** of specimen width and crack length on the specimen for 6061, 2017 and 5052

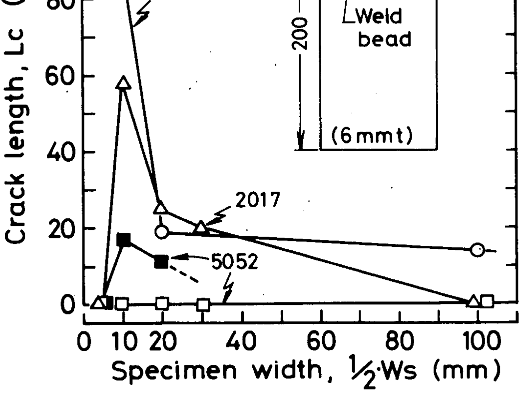

Fig. 1 Investigation of specimen width, (1/2) Ws, required to cause crack initiation and to keep crack propagation.

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alloys. The focal point of electron-beam shown with a_b value is upside of the plate surface, which is not the minimum bead width, and welding speed is 100 cm/min. As shown in Fig. 1, the recommended specimen width for (1/2) **Ws** which surely initiated the solidification crack in the weld bead and definitely showed the difference in crack length against type of alloy was about 10 mm. This means that the specimen width **Ws** at weld start of the self-restrained cracking test specimen is considered to be the best at about 20 mm. The meaning of **Ws** is as follows in principle; the solidification crack occurs at the start of full-penetrated weld bead when the tearing force (or tearing deformation) immediately after molten puddle, which is caused by the lack of uniformity of the temperature distribution vertical to welding direction, exceeds the restraint force whose value is estimated by the specimen width at the specimen edge. Therefore, for lower heat input welding as EBW the specimen width required to cause cracking is to be narrower than that of arc welding in principle.

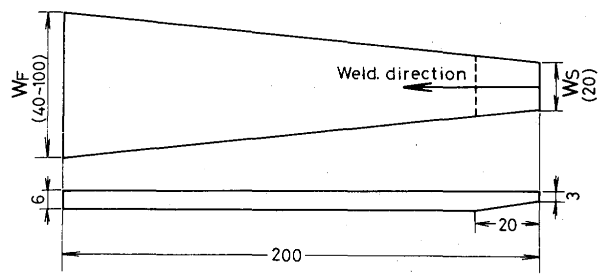

Fig. 2 Specimen shape and dimension of self-restrained cracking test for EBW in this experiment (W_F was fixed at 60 mm after this experiment).

Secondary the shape and dimension of the self-restrained cracking test specimen was experimentally decided for higher welding speed as 100 cm/min as shown in **Fig. 2** taking into consideration the result of the previous report[1]. The specimen width at the start of welding (**Ws**) is 20 mm and as welding proceeds the width is increased as shown in Fig. 2. The meaning of this shape is as follows; the propagation of the solidification crack initiated at the weld start is gradually restrained with an increase of the restraint force due to increase of specimen width, as welding proceeds, and then is finally stopped on way to weld end even in very high speed welding[1]. From the restriction of welding vacuum chamber size in this experiment the specimen length was selected for 200 mm. Moreover, in order to complete the full-penetrated bead at the start of welding the thickness of specimen is reduced to 3 mm as shown in Fig. 2.

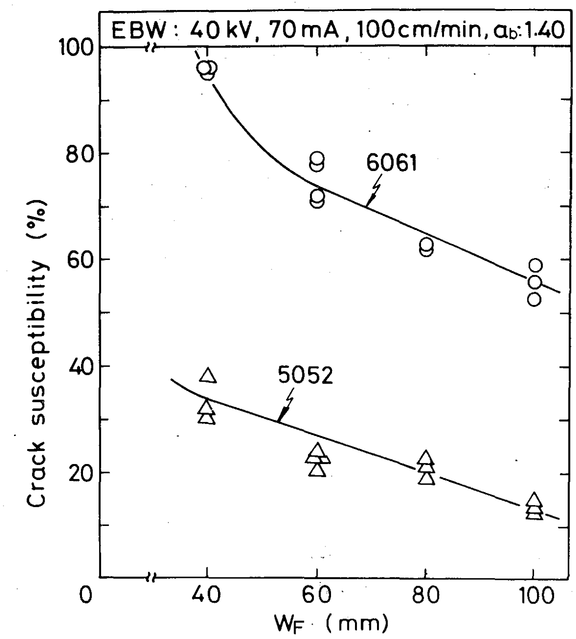

Fig. 3 Effect of width W_F on crack susceptibility of weld bead for 6061 and 5052 6 mm thick alloys with a welding condition of 40kV-70mA-100 cm/min-1.40 a_b.

Then the effect of the specimen width at the end of specimen (end of welding) W_F on the crack susceptibility was investigated for 6061 and 5052 alloys. The result is shown in **Fig. 3**. On vertical axis the crack susceptibility is represented by the ratio of crack length on the surface to whole bead length of 200 mm. The scattering of the data was seen small enough. On 40 mm of W_F the cracking is almost completed over whole weld bead for 6061 alloy. Therefore the authors recommended the dimension of W_F to 60 mm for specimen length of 200 mm. However, if a large size of welding vacuum chamber is available, the authors have felt to recommend longer specimen length than 200 mm, for example 300 mm or more, in order to make much clear the difference in the crack susceptibility against type of alloy.

An example of overall specimen tested and cros-sectional macrostructure cracked are shown in **Fig. 4** (**a**) and (**b**), respectively.

Moreover **Figure 5** shows the result of investigation on the necessity of the fins for the test specimen which are usually provided in Houldcroft-type specimen. (A), (B) and (C) in Fig. 5 show respectively the specimen shape without fin, with short fins and with long fins for larger specimen in size. The results tested were shown for 6061 and 5052 alloys. The difference in crack susceptibility was seen only in (A) of 6061 but not so clear in this experiment for 100 cm/min of welding speed. Of course in lower welding

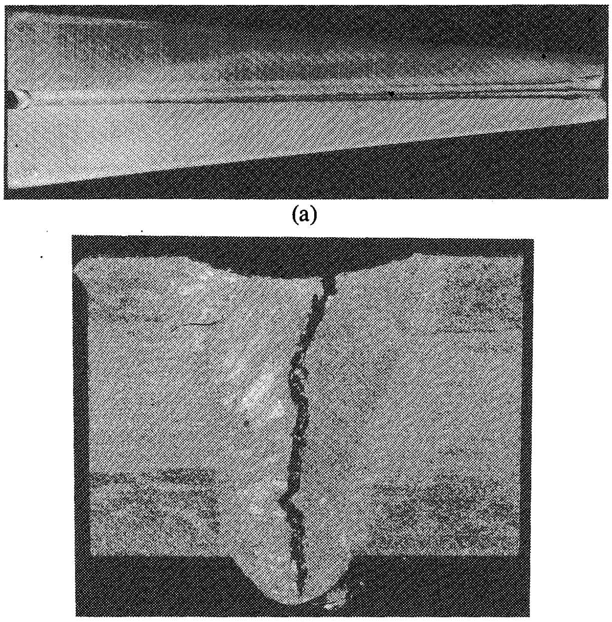

Fig. 4(a) Overall cracking test specimen (W_F=60 mm) after test.
(b) Crossectional macrostructure of solidification cracking.

speed the difference will be much clear, but for this experiment as 100 cm/min the fins will be unnecessary as a result.

The following conclusions were drawn for the shape and dimension of self-restrained solidification cracking test of EBW for aluminum alloys;

(1) The longitudinal weld bead cracking test for EBW is possible under a suitable selection of the shape and dimension of self-restrained test specimen.

(2) The test specimen shape recommended here was a trapezoid as shown in Fig. 2. The optimum specimen width in the short side from which test welding starts and in the long side at which test welding ends were respectively recommended to be 20 mm and 60 mm for aluminum alloys in case of 200 mm in specimen length. The specimen length will be better to be extended to 300 mm or more if the limit of space in vacuum chamber is admitted.

(3) The addition of the fins in both sides of specimen which are usually provided in Houldcroft-type specimen is not so important for comparison of the crack susceptibility of high welding speed weld bead as 100 cm/min for aluminum alloys.

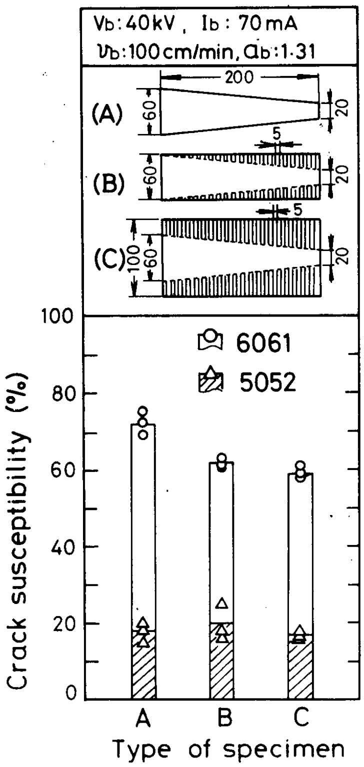

Fig. 5 Effect of addition of fins to the test specimen on solidification crack susceptibility.

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Reference

1) F. Matsuda, K. Nakata, S. Harada: Trans. JWRI, Vol. 9 (1980), No. 2, 83–93.