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Comparison of Weld Crack Susceptibility of Recent Aluminum Alloys†

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Abstract

The solidification crack susceptibility of weld bead and crater have been evaluated by means of the Lap fillet type cracking test and the Weld crater cracking test, respectively, during GMA welding as the base metal of 7N01 and 7003 Al-Zn-Mg alloys with various commercial and tentative welding filler wires in comparison with the base metals of 5083 and 6351 alloys. The main conclusions obtained were as follows; (1) In general the weld metal less than about 2%Mg content was the most susceptible to cracking in weld bead and the weld metal more than about 3.5%Mg content was less susceptible to cracking but in higher welding speed than 500mm/min the weld metals of about 4.5%Mg content again became susceptible to some degree. (2) Increase in magnesium content in welding filler wire and/or addition of B with Ti in filler wire decreased the susceptibility for cracking in weld crater of 7N01 base metal. (3) The Weld crater cracking test used in this experiment could be recommended as a crater cracking test method, but the Lap fillet cracking test could not be recommended for optimum bead cracking test method.

KEY WORDS: (Weld Cracking Test) (Hot Cracking) (GMA Welding) (Al-Zn-Mg Alloy) (Al-Mg-Mn Alloy) (Al-Mg-Si Alloy) (Solid Filler Wire)

1. Introduction

Recently some high strength aluminum alloys have been widely utilized for vehicle and container industries in Japan, including the use of 7N01 (A1-4.5%Zn-1.2%Mg) and 7003 (A1-5.5%Zn-0.7%Mg) alloys for the vehicles of new high speed train. For welding of these alloys one of the most regrettable problems is also weld cracking during welding. Therefore, in order to soluve the cracking problem, some modifications of welding electrodes have been continuously investigated in this field and some of them have resulted in success.

There are few report in the recent years for the comparison of weld crack susceptibility of high strength aluminum alloys, though the collective report was published from Japan in 1976[1]. In the previous report the crack susceptibility for 5083 was mainly treated that the most suitable cracking test was Lap fillet type for these aluminum alloys.

Therefore, taking the focus to the cracking of advanced alloys, the authors have treated the investigation for weld crack susceptibility of some aluminum high strength alloys as 7N01 and 7003 which were welded in GMA welding using commercial and tentative welding filler wire of 5554, 5356, 5356TiB, Al-6MgTiB and Al-7Mg in comparison with 5083 and 6351 welded with 5183TiB wire.

The cracking tests used were Lap fillet type and Weld crater cracking tests in variation of welding speed.

As an additional remark, this work was done under the international co-operative research program in Nonferrous group of IIW Commission IX.

2. Experimental Procedure

2.1 Materials used

Materials used are mainly commercial 7N01-T5 (A1-4.5%Zn-1.2%Mg) and 7003-T5 (Al-5.5%Zn-0.7%Mg), and partly 6351-T5 and 5083-0 as base metal in 30mm thickness and partly 12mm thickness, and commercially used 5554, 5356 and 5183TiB, and tentative 5356TiB, Al-6MgTiB and Al-7Mg as welding filler wire of 1.6mm in diameter.

Chemical compositions of base metal and filler wire are collectively shown in **Table 1**.

Addition of B with Ti is treated in 5183TiB, 5356TiB and Al-6MgTiB filler wires.

2.2 Weld cracking test and welding conditions

2.2.1 Lap fillet cracking test

The shape and size of this test specimen is shown in **Fig. 1**, which was originated in the previous report[1].

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Table 1 Chemical compositions of materials used

Material		Chemical composition (wt%)									
		Si	Fe	Cu	Mn	Mg	Cr	Zn	Zr	Ti	B
Base metal	7N01-T5	0.06	0.18	0.07	0.47	1.11	0.21	4.36	0.16	0.02	-
	7003-T5	0.08	0.21	0.05	0.15	0.68	0.29	5.32	0.15	0.02	-
	6351-T5	0.94	0.29	0.04	0.55	0.88	0.02	0.02	-	0.02	-
	5083-0	0.13	0.19	0.01	0.68	4.47	0.12	0.02	-	0.01	0.0012
Welding filler wire	5554	0.10	0.16	0.01	0.70	2.67	0.10	0.01	-	0.09	-
	5356	0.05	0.14	0.01	0.09	4.82	0.10	-	-	0.09	-
	Al-7Mg	0.08	0.17	-	0.12	7.22	0.11	0.01	-	0.07	-
	5356TiB*	0.07	0.18	-	0.68	5.09	0.08	-	-	0.08	0.0020
	5183TiB*	0.10	0.19	0.01	0.60	4.87	0.08	0.02	-	0.07	0.0018
	Al-6MgTiB*	0.03	0.16	-	0.12	6.34	0.09	-	-	0.07	0.0035

Diameter of Welding filler wire:1.6mm
* B with Ti treated wire

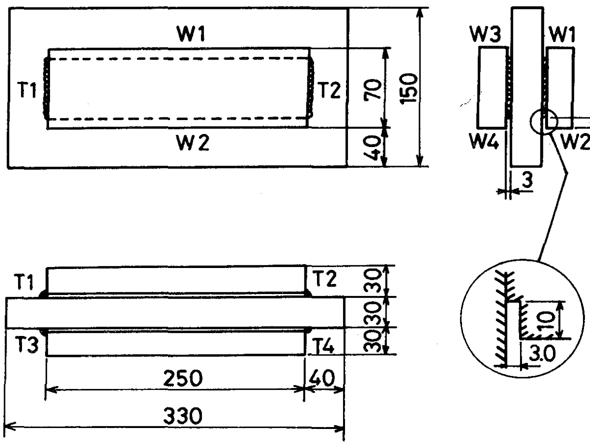


Fig. 1 Shape and size of the Lap fillet cracking test

Basically as shown in Fig. 1 four test weld beads are evaluated for weld crack susceptibility under four restraint weld beads. In advance of test welding the restraint beads are welded in T1 to T4 seams by GMA welding with 270A-400mm/min using 1.6mm diameter 5356 filler wire.

Test weld beads are done on four grooved fillet seams of W1 to W4 with the same welding condition preset. After each run of test welding, test specimen was cooled to room temperature. Then the crack susceptibility of the weld bead is evaluated as the ratio of total-length of cracks observed on one welded bead surface to a full length of each weld bead excluding crater.

Welding condition of test welding in this cracking test was selected in two welding current levels of 280A-28V and 300A-29V with welding speeds 300, 400, 500 and 600mm/min. In case of welding with more than 600mm/min bead appearance became abnormal with intermittent bead or unconnected weld bead with base metal on its one side especially in the base metals of 7N01 and 7003. For industrial purpose, fillet welding of thicker aluminum alloy more than 20mm is practically done with welding speed of 300 to 400mm/min in the above welding current levels in general.

2.2.2 Weld crater cracking test

The shape and size of this test specimen is shown in **Fig. 2**, which was originated in the previous report[2]. Three short weld beads of about 70 mm in length were discontinuously made on a vee-grooved specimen as base metal of 7N01 in 12 mm thickness. The crater cracking susceptibility was evaluated by the ratio of the total-length of cracks observed on the surface of a weld crater to maximum length of each weld crater longitudinally. Mean value of these ratios for three weld craters was adopted as the crater cracking index in this experiment.

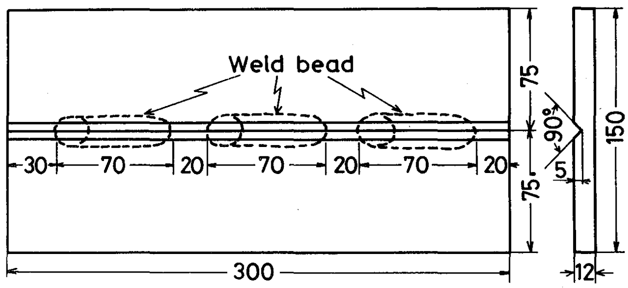


Fig. 2 Shape and size of the Weld crater cracking test

The welding conditions are 230A and 270A of welding currents and 200, 400 and 600 mm/min of welding speeds for each welding current.

2.3 Structural and metallurgical investigations

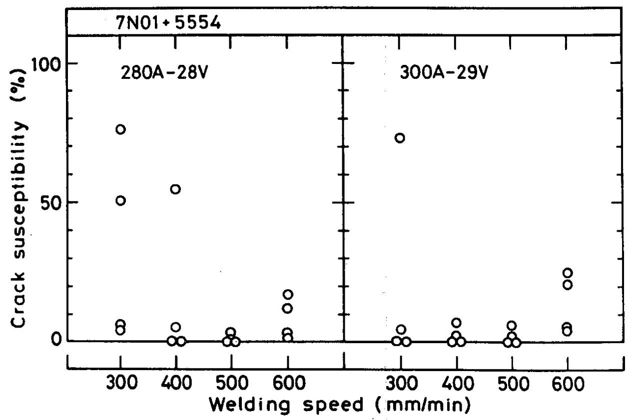
After the evaluation of crack susceptibilities, all the test specimens were cut in center of bead and crater to cross-sectional investigation.

Crack shape and location and grain refining were investigated after Burker's etched. Moreover magnesium and zinc contents were analysed by emission spectrochemical analysis for the weld metals of 5554, 5356 and 7 Mg filler wires in Lap fillet specimens.

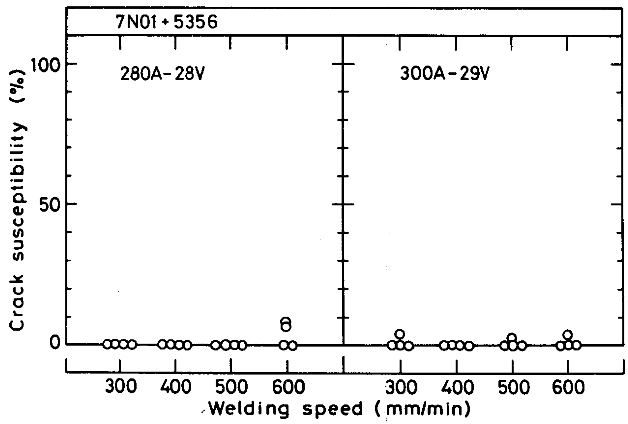
3. Test Results

3.1 Crack susceptibility of weld bead

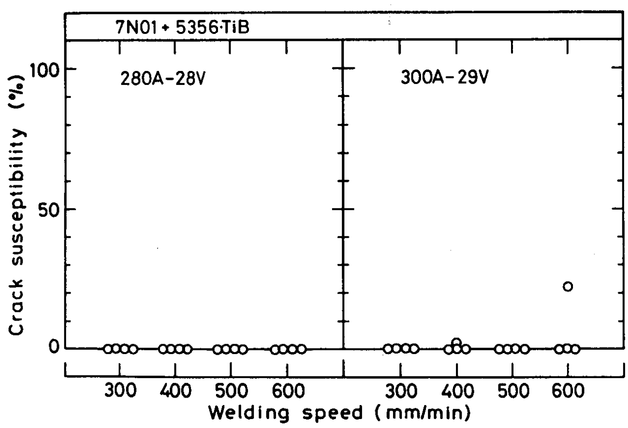
The cracking results for each test weld are shown for eight welding conditions in **Fig. 3 (a)** to **(e)** for 7N01, in **Fig. 4 (a)** to **(e)** for 7003, in **Fig. 5** for 6351 and in **Fig. 6** for 5083 base metal.



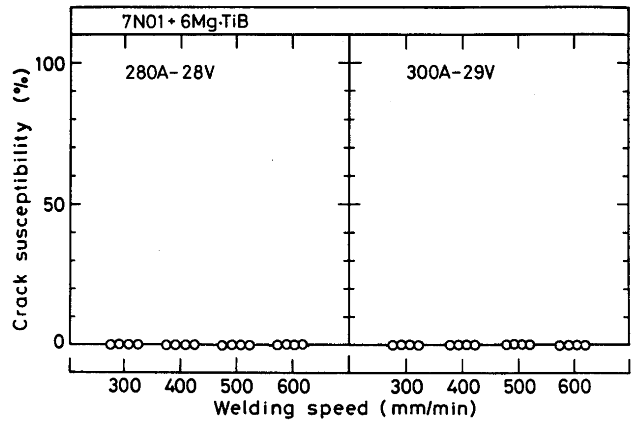
(a) 7N01 + 5554



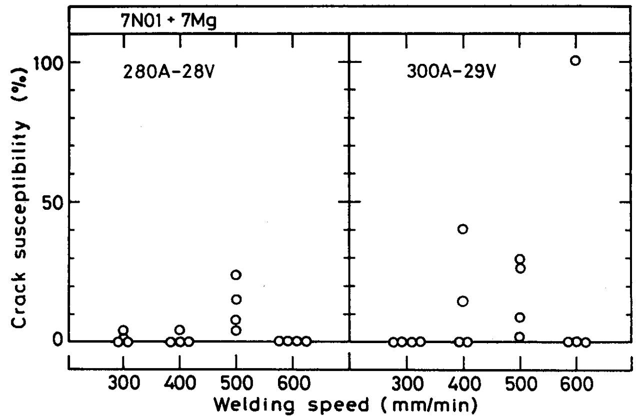
(b) 7N01 + 5356



(c) 7N01 + 5356TiB



(d) 7N01 + 6MgTiB

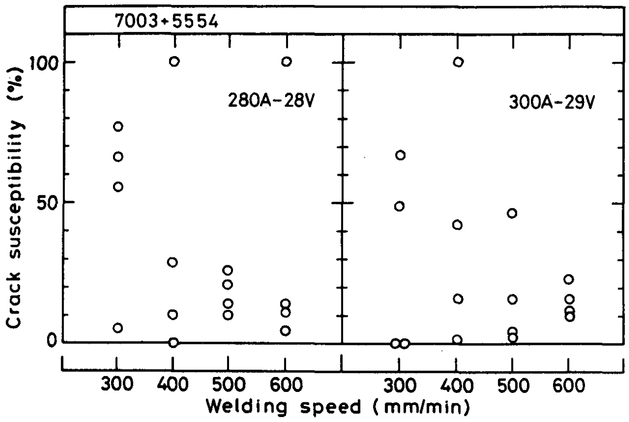


(e) 7N01 + 7Mg

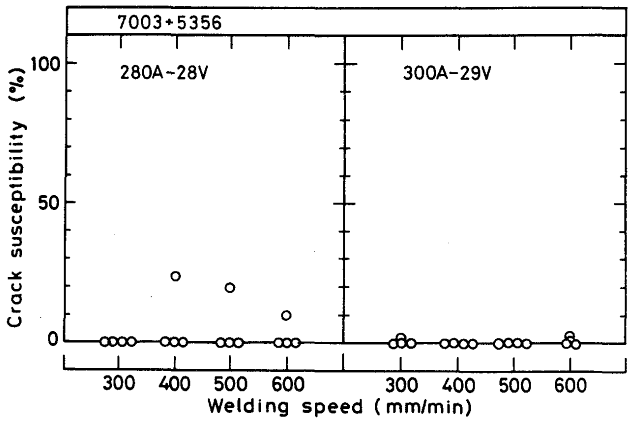
Fig. 3 Crack susceptibility in weld bead as 7N01 base metal for various welding filler wires in variation of welding speed and current.

In the weld beads for 7N01 and 7003 base metals by 5554 filler wire a considerable cracking is observed through whole welding speeds. In the weld beads by 7Mg wire a little scattering in cracking is also observed in higher welding speeds. Moreover the crack susceptibility in the weld beads of 5183TiB on 6351 base metal and 5183TiB on 5083 base metal is low enough.

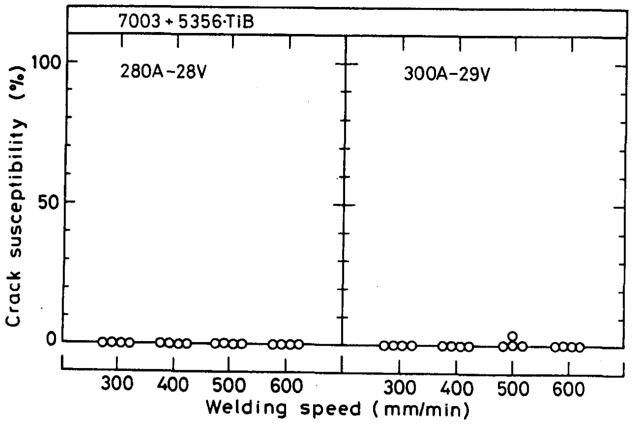
Now crack susceptibility on the average of four weld beads in the same test specimen was shown in **Fig. 7** for 7N01 and **Fig. 8** for 7003 base metals. The weld metals for 7003 are slightly crack susceptible than those of 7N01 in general. It is due to higher zinc and lower magnesium contents of weld metal. They are shown in **Fig. 9 (a)** and **(b)** for 7N01 and **Fig. 10 (a)** and **(b)** for 7003. There are little changes in magnesium and zinc contents with welding speed and welding current. There are considerable difference in magnesium content of the weld metals with 5554, 5356 and 7Mg filler wires but little difference in zinc content.



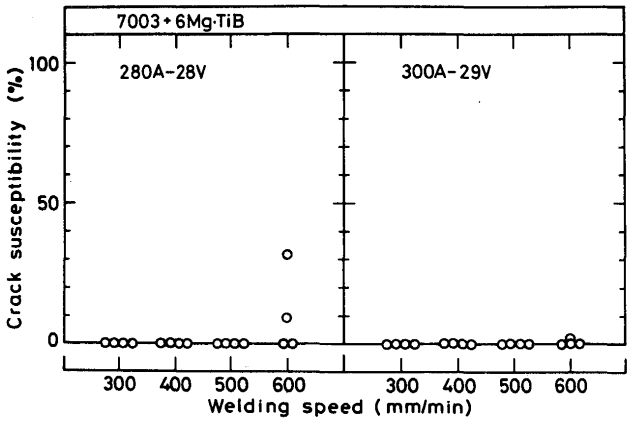
(a) 7003 + 5554



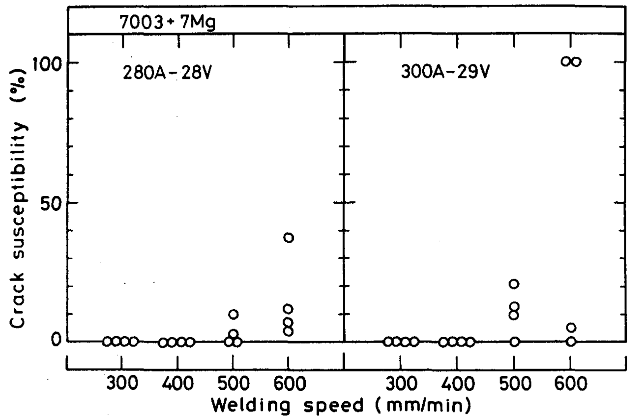
(b) 7003 + 5356



(c) 7003 + 5356TiB



(d) 7003 + 6MgTiB



(e) 7003 + 7Mg

Fig. 4 Crack susceptibility in weld bead as 7003 base metal for various welding filler wires in variation of welding speed and current.

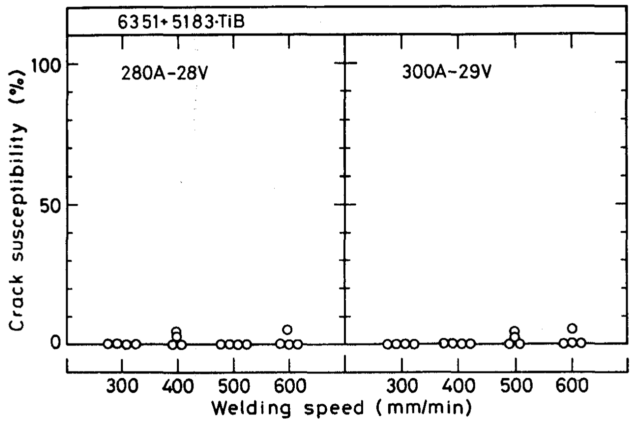


Fig. 5 Crack susceptibility in weld bead as 6351 base metal with 5183TiB filler wire in variation of welding speed and current

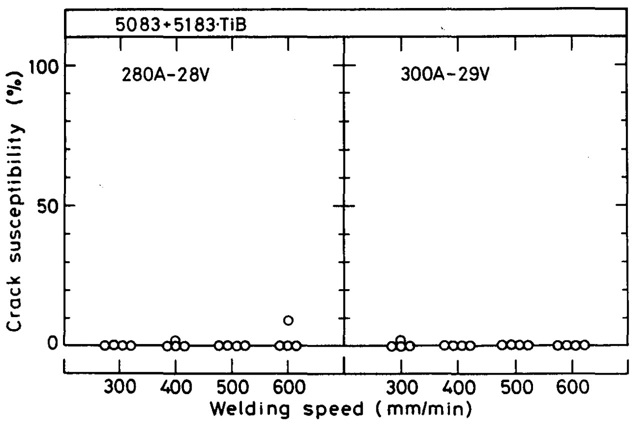


Fig. 6 Crack susceptibility in weld bead as 5083 base metal with 5183TiB filler wire in variation of welding speed and current

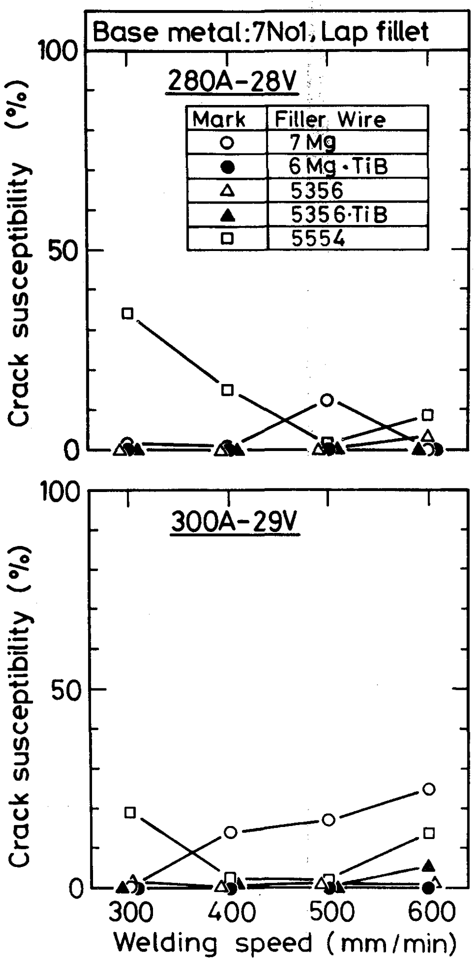


Fig. 7 Crack susceptibility on the average of four weld beads in the same test specimen as 7N01 base metal

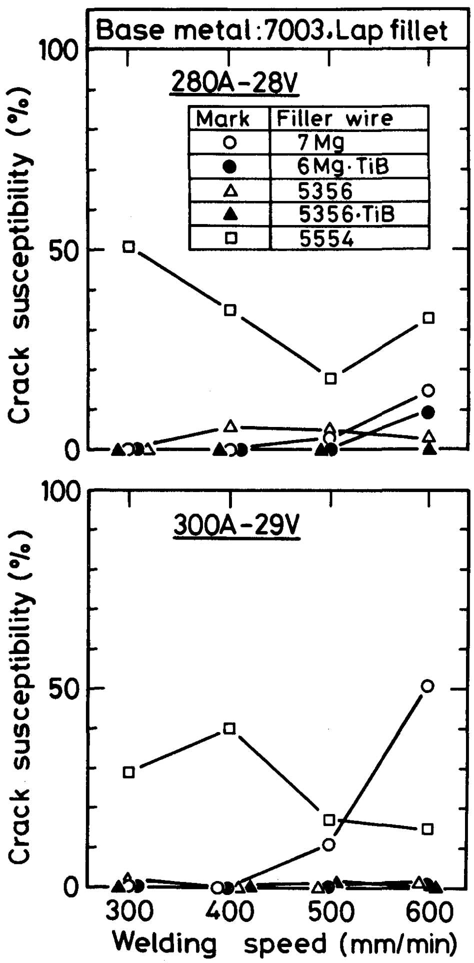
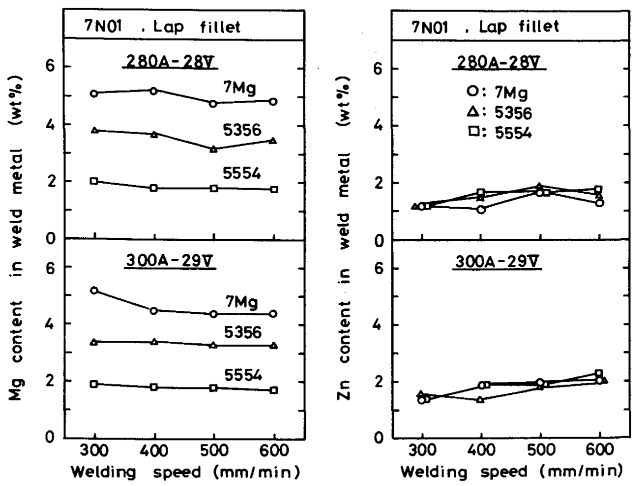
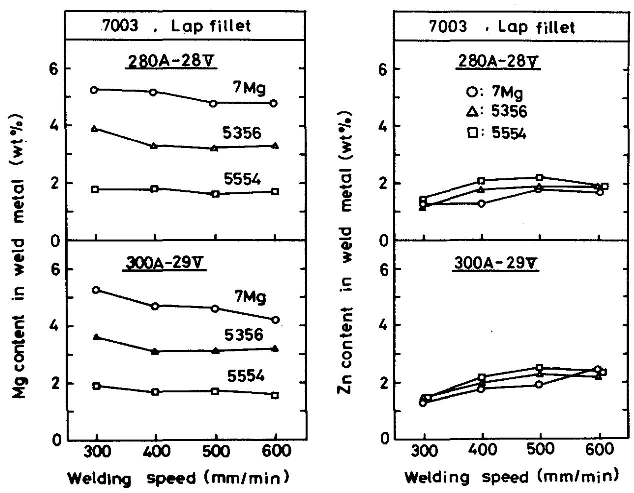


Fig. 8 Crack susceptibility on the average of four weld beads in the same test specimen as 7003 base metal



(a) Mg content (b) Zn content

Fig. 9 Mg and Zn contents in weld metal of 7N01 base metal with 5554, 5356 and 7Mg filler wires.



(a) Mg content (b) Zn content

Fig. 10 Mg and Zn contents in weld metal of 7003 base metal with 5554, 5356 and 7Mg filler wires.

From Fig. 7 and 8 the crack susceptibilities of 5356, 5356TiB and 6MgTiB wire were the lowest in all weld beads, that of 5554 whose magnesium was 1 to 2% in weld metal was the most crack susceptible and that of 7Mg was an intermediate. In the weld metal of higher magnesium content crack sometimes occurred in the weld bead of high welding speed.

Figure 11 shows the relation between crack susceptibility and magnesium content in weld metal for 7N01 and 7003 base metals with different welding speed. From Fig. 11, it is suggested that the weld metal less than about 2% Mg content shows the most susceptible to cracking

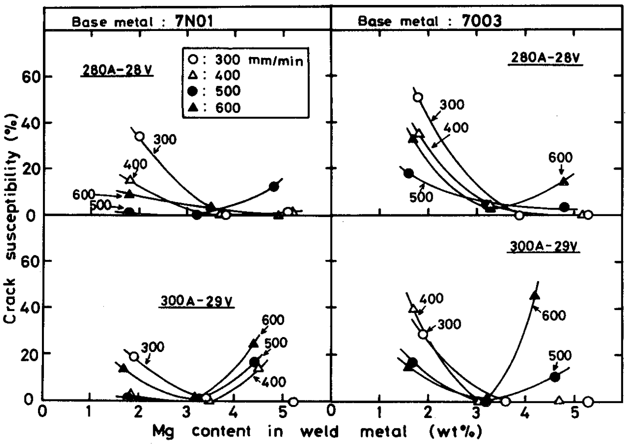
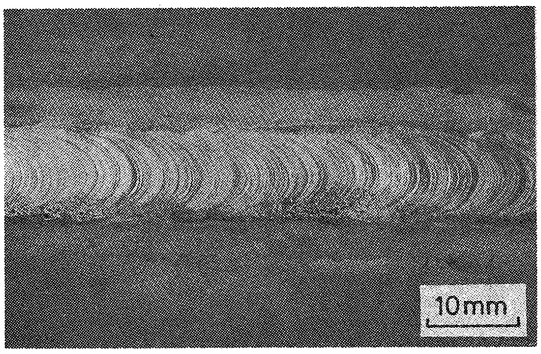
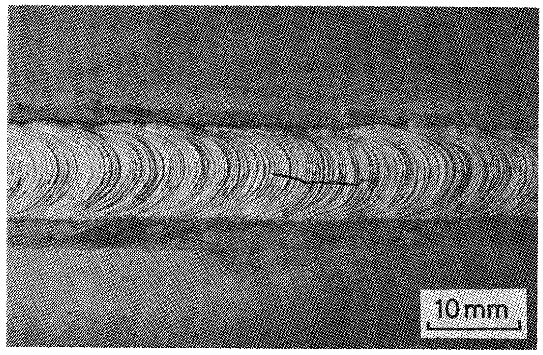


Fig. 11 Relation between crack susceptibility and Mg content in weld metal for 7N01 and 7003 base metals with different welding speed and current.



(a) 5554 filler wire



(b) 7Mg filler wire

Fig. 12 Appearance of cracking on surface of weld bead as 7N01 base metal.

and that in practical welding speed of 300 and 400 mm/min the weld metal more than about 3.5% Mg content shows less crack susceptible but in higher welding speed more than 500 mm/min the weld metal which contains about 3.5% Mg content shows minimum in crack susceptibility. This was different from the results[2-4] evaluated with ring-cast cracking test.

Typical appearances of cracking on surface are shown in **Fig. 12 (a)** and **(b)** in the weld bead with 5554 and 7Mg filler wires, respectively, as the base metal of 7N01. In general, with 5554 wire many slender cracks as shown in (a) are observed, but with 7Mg wire a few bold cracks as shown in (b) are observed in bead center.

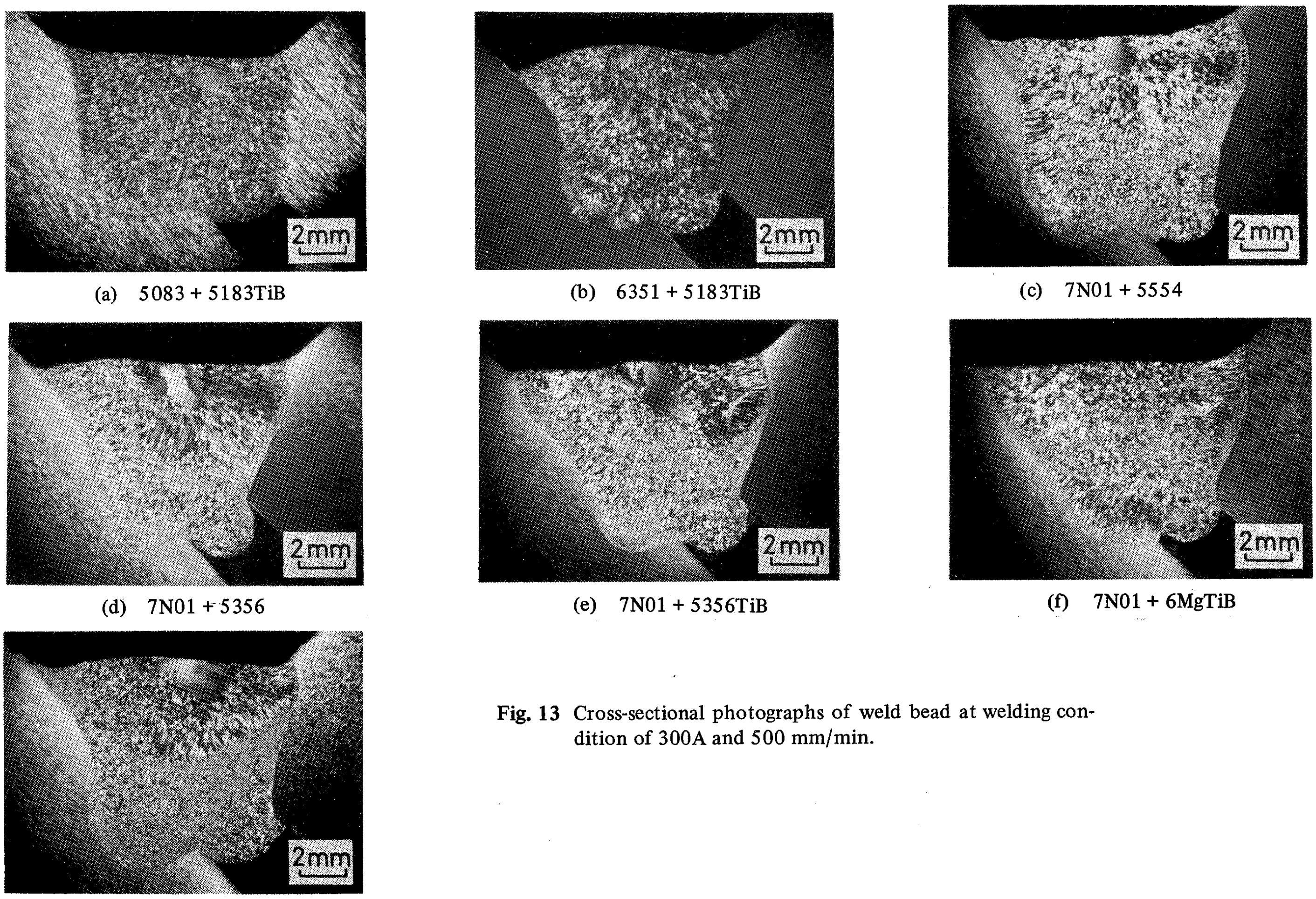
Cross-sectional photographs of weld bead are shown in **Fig. 13 (a)** to **(g)** for each specimen with same welding condition of 300A and 500 mm/min. From Fig. 13 (a) and (b) the macrostructures are much refined in whole weld beads of 5083 and 6351 base metals with 5183TiB wire.

This is due to the effect of B addition with Ti. In the case of 7N01 base metal as shown in (c) to (g), macrostructures consist of very fine grains in the bottom in the weld bead and relatively large columnar grains with feathery grains near bead surface. Among them the grain structures with 5554 and 5356 wires are comparably larger than the others, though difference in them is a lettle. It seems that the crack was propagated independent of these grain structures through weld bead.

3.2 Crack susceptibility of weld crater

Weld crater cracking susceptibilities of 7N01 base metal are shown in **Fig. 14** as crater-cracking index for the difference of filler wires at different welding currents and welding speeds in comparison with that of 5083 base metal with 5183TiB filler wire.

As a result the crack susceptibility could be arranged as the next order for each welding condition, that is, 5554 > 5356 > 5356TiB > 6MgTiB > 7Mg $\geqq$ (5083 base metal with 5183TiB wire). These results well agreed with those previously reported[2].



(a) 5083 + 5183TiB

(b) 6351 + 5183TiB

(c) 7N01 + 5554

(d) 7N01 + 5356

(e) 7N01 + 5356TiB

(f) 7N01 + 6MgTiB

(g) 7N01 + 7Mg

Fig. 13 Cross-sectional photographs of weld bead at welding condition of 300A and 500 mm/min.

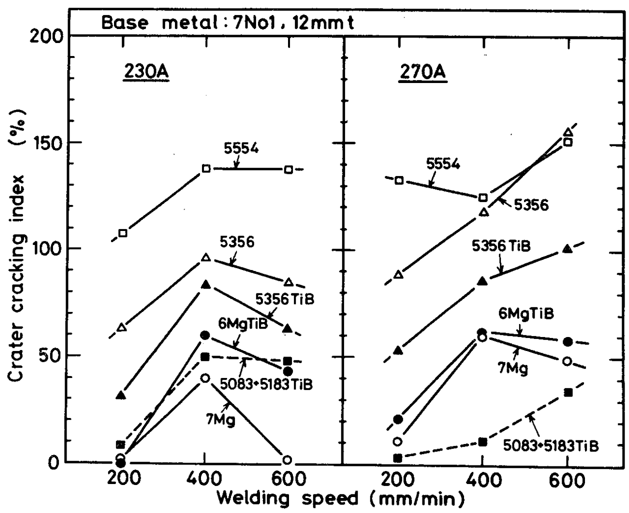


Fig. 14 Crack susceptibility in weld crater as base metal of 7N01 with different filler wires and welding conditions

In general an increase in welding speed and/or welding current increased the crack susceptibility in weld crater.

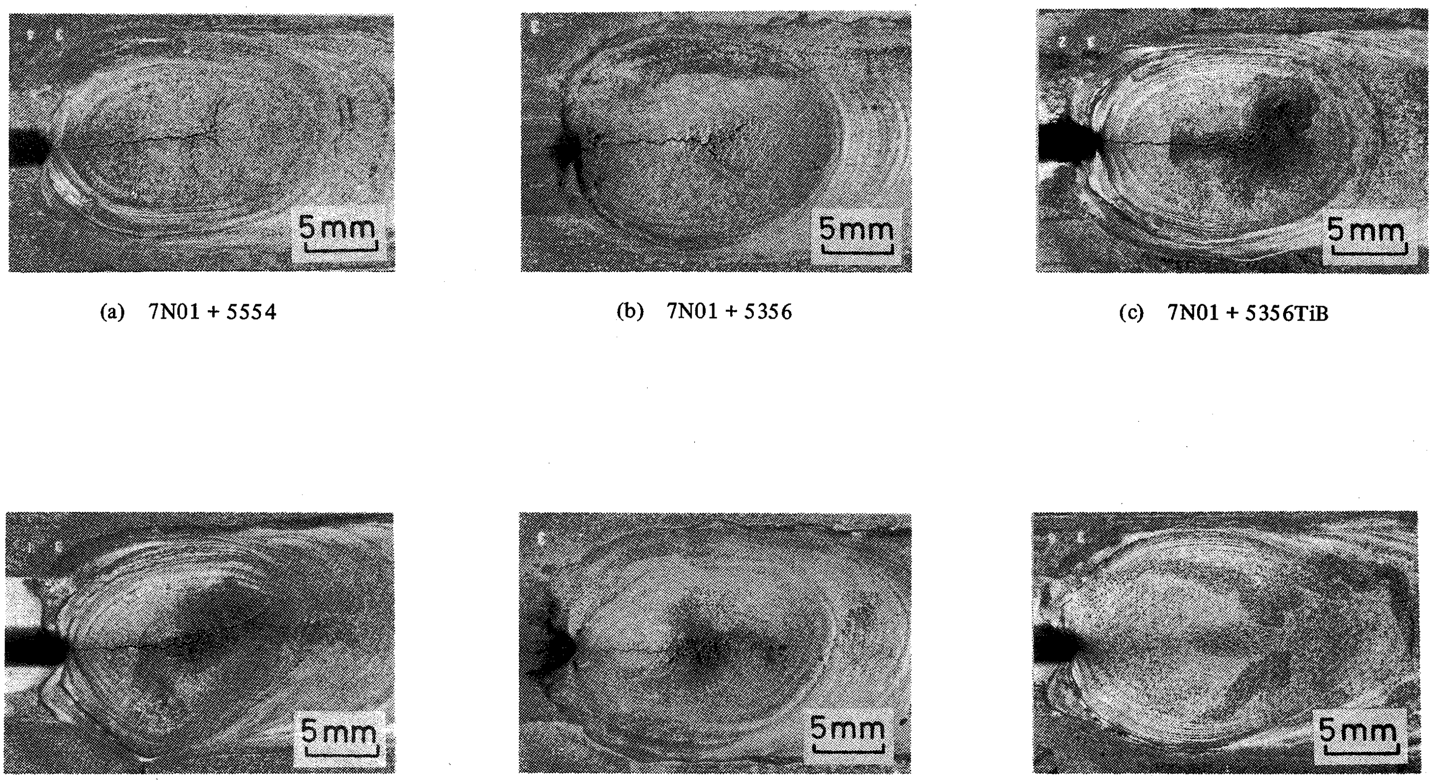
In addition to this, slight decrease in crack susceptibility at welding speed of 600 mm/min suggested that crater cracking was also affected with shape of weld crater.

Figure 15 shows typical appearance of weld craters showing crater cracking. Y-shaped crack was usually seen in high crack susceptible weld crater with 5554 and 5356 filler wires, but in less crack susceptible weld craters than them it didn't appear.

Nextly **Figure 16** shows cross-sectional macrophotographs of the center of weld crater. They are almost the same as those observed in Lap fillet test specimen. Grain structures with 5554 and 5356 wires are comparably larger than others.

4. Discussion on Cracking Test

In this paper two types of cracking test, that is, Lap fillet and Weld crater cracking tests were attempted to evaluate the solidification cracking susceptibility of welds with GMA welding. Features of these cracking tests which became clear through this experiment are as follow;



(a) 7N01 + 5554 (b) 7N01 + 5356 (c) 7N01 + 5356TiB

(d) 7N01 + 6MgTiB (e) 7N01 + 7Mg (f) 5083 + 5183TiB

Fig. 15 Appearance of cracking in weld crater at the welding condition of 270A and 400 mm/min.

For Lap fillet test, (1) It is a costly test for laboratry, because large amount of thick material such as 30 mm in thickness is required for test specimen and in addition, precise machining is also required to make a slit in groove. (2) Welding condition for test is recommended to be lower welding speed than 500 mm/min and higher welding current than about 280A, otherwise abnormal weld bead is likely to occur especially in the base metals of 7N01 and 7003. (3) In addition, in the above recommended welding conditions there was little difference in cracking in weld bead for different base metal and filler wire except for very high crack susceptible weld bead.

For crater cracking test, (1) The shape of this test specimen is very simple and its amount of base metal required is much less than that for Lap fillet test. (2) As a welding parameter, wide condition range can be selected. (3) Moreover, this cracking test is very sensitive to cracking for the difference in base metal and also in filler wire and in addition scattering in data is relatively low. (4) However, crack susceptibility was farely affected with the shape of crater. Therefore it is necessary that the same dimension of groove, the same welding method such as torch position and angle inclined and the same welding conditions are required to minimum the scattering in data.

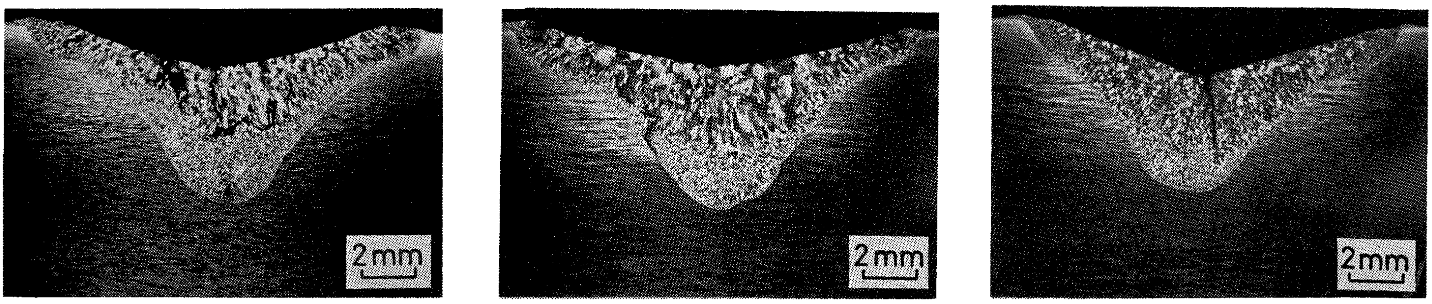
As a result the authors think at the present that the weld crater cracking test used in this experiment can be recommended as a crater cracking test method, but the Lap fillet cracking test cannot be recommended for optimum bead cracking test.

5. Conclusions

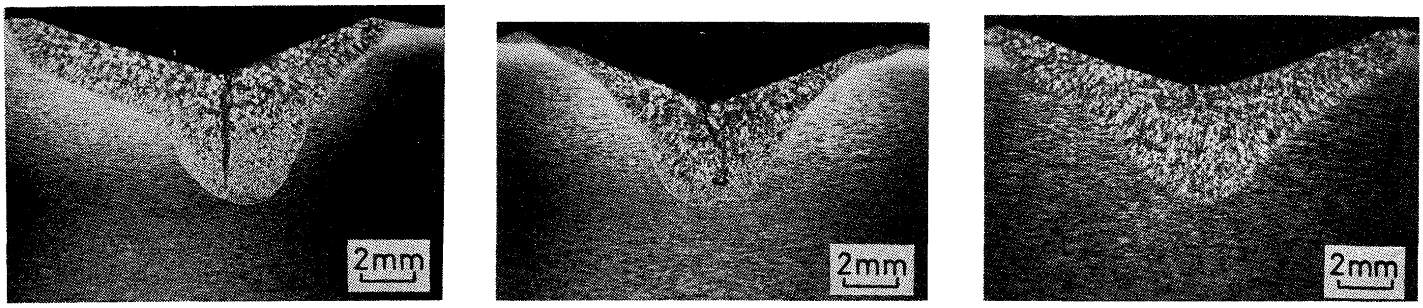
The solidification crack susceptibilities of weld bead and crater have been evaluated by means of Lap fillet type cracking test and Weld crater cracking test, respectively, as the base metal of 7N01 and 7003 Al-Zn-Mg high strength alloys with various commercial and tentative welding wires in comparison with the base metal of 5083 and 6351 alloys.

The main conclusions obtained are as follows; As a results of Lap fillet cracking test;

(1) The crack susceptibility in the weld bead was arranged as the next order for 7N01 and 7003 base metals, that is, 5554 wire > 7Mg wire > 5356, 5356TiB and 6MgTiB wires ($\gtreqqless$ 5083 and 6351 base metals with 5183TiB wire).



(a) 7N01 + 5554 (b) 7N01 + 5356 (c) 7N01 + 5356TiB



(d) 7N01 + 6MgTiB (e) 7N01 + 7Mg (f) 5083 + 5183TiB

Fig. 16 Cross-sectional photographs of weld crater at welding condition of 270A and 400 mm/min.

(2) The weld beads of 7003 are slightly crack susceptible than those of 7N01.

(3) In general the weld metal less than about 2%Mg content was the most susceptible to cracking and the weld metal more than about 3.5%Mg content was less susceptible to cracking but in higher welding speed than 500 mm/min the weld metals of about 4.5% content again became susceptible to some degree.

(4) Lap fillet cracking test was costly for laboratry and on the other hand, its discrimination for difference in weld cracking of material was relatively low.

As a result of Weld crater cracking test for 7N01 base metal;

(5) The crack susceptibility in weld crater was arranged as the next order, that is, 5554 wire > 5356 wire > 5356TiB wire > 6MgTiB wire > 7Mg wire ($\geqq$ 5083 base metal with 5183TiB wire).

(6) The increase in welding speed and welding current increased the crack susceptibility in weld crater in general.

(7) The Weld crater cracking test is an useful cracking test at the viewpoints of discrimination of crack susceptibility, simplicity and economy of test specimen.

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