# Effect of Additional Element on Weld Solidification Crack Susceptibility of Al-Zn-Mg Alloy (Report I)†

## – Results of Ring Casting Cracking Test –

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**Abstract**

*In order to select the favorable additional element to prevent the cracking occurred in GMA weld metal of 7N01 Al-4.5%Zn-1.2%Mg high strength aluminum alloy with 5356 Al-5%Mg filler wire, solidification crack susceptibility of synthesized-weld-metal Al-2%Zn-2 to 3%Mg alloy with and without 13 kinds of additional elements has been examined by means of the ring casting cracking test.*

*Among the additional elements of Ti+B, Ti, Zr, Fe, Mn, B, Si, Be, Ni, Cr, V, Misch metal and Cu with the added amount up to about 0.5%, Ti+B, Ti and Zr proved to be the most favorable element to reduce the cracking in casted metal and their effective amounts were decided to be 0.05, 0.14 and 0.24% respectively in this experiment. Moreover a close correlation between crack susceptibility and grain size in casted metal has been confirmed.*

KEY WORDS: (Solidification cracking) (Aluminum alloys) (Grain size)

## 1. Introduction

In the previous report[1] the effect of magnesium on solidification crack susceptibility of Al-Zn-Mg alloy was fundamentally investigated and it was made clear that high magnesium content in the alloy was beneficial to reduce the crack susceptibility of Al-Zn-Mg alloy. According to this result, a new filler wire of which magnesium content was 6 to 7% and more than that of commercially used 5356 (Al-5%Mg) filler wire was tentatively made and this filler wire showed the beneficial effect to prevent the weld cracking, especially weld crater cracking of 7N01 (Al-4.5%Zn-1.2%Mg alloy), though it was not so clear for reducing the susceptibility of weld bead cracking as reported in another additional investigation[2].

Therefore another new approach has been attempted to prevent the weld bead cracking of 7N01 alloy in this report by the addition of additional elements such as titanium (Ti), zirconium (Zr) and boron (B) to welding filler wire (electrode). These are well-known for favorable grain refiner for aluminum alloy and also the effects of these elements on solidification crack susceptibility have been investigated for Al-Mg[3-4] and Al-Zn-Mg[3-7] alloys so far. As regards to Al-Zn-Mg alloys, however, their effectiveness and also their optimum amounts required to reduce the crack susceptibility has not been made clear so far.

At the first investigation, the purpose of this report is to find out the most favorable element and to make clear its optimum content in welding filler wire in order to prevent the weld solidification cracking in GMA weld bead and crater of 7N01 alloy. For this purpose the synthesized-weld-metal alloy was made for the modeling of the GMA weld metal of 7N01 base metal with 5356 filler wire and then the effects of 13 kinds of additional elements were examined on the crack susceptibility of the synthesized-weld-metal alloy by means of the ring casting cracking test method.

Actual weld cracking test of 7N01 base metal using the tentative filler wire with some of favorable additional elements will be treated in the next report.

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## 2. Materials Used and Experimental Procedures

### 2.1 Materials used

The synthesized-weld-metal of 7N01 base metal with 5356 filler wire in GMA welding has been made on the assumption that the composition of 5356 filler wire is diluted by that of 7N01 base metal by the ratio of 50% which was ascertained from the previous experiment. The fundamental composition of the synthesized-weld-metal is Al-2%Zn-3%Mg as shown in **Table 1** in comparison with those of 7N01 base metal and 5356 filler wire.

Firstly, the synthesized-weld-metal Al-2%Zn-2%Mg alloy was used for the preliminary experiment to select the favorable additional element from 13 kinds of elements such as Ti+B, Ti, Zr, Fe, Mn, B, Si, Be, Ni, Cr, V, misch metal and Cu of which amounts were 0.5% except misch metal (0.3%) and Ti+B (0.06%) using their mother alloy with aluminum.

**Table 1** Chemical compositions of materials used

| Material | | Chemical composition (wt%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Zn | Mg | Fe | Si | Mn | Cr | Cu | Ti | Zr |
| Base metal | 7N01-T5 | 4.36 | 1.11 | 0.18 | 0.06 | 0.47 | 0.21 | 0.07 | 0.02 | 0.16 |
| Filler wire | 5356 | Tr | 4.82 | 0.14 | 0.05 | 0.09 | 0.10 | 0.01 | 0.09 | - |
| Weld metal | - | 2.18 | 2.97 | 0.16 | 0.06 | 0.28 | 0.16 | 0.05 | 0.06 | 0.08 |

### 2.2 Solidification cracking test

In order to select the favorable additional element and its amount required to reduce the crack susceptibility of the synthesized-weld-metal alloys, the ring casting cracking test was used under the test condition of 750°C at pouring temperature of the melts and 50°C of the preheating temperature of the ring mold of which inner diameter was 35 mm as shown in **Fig. 1**.

Total length of cracks observed on the surface of the ring-casted metal was used as the criteria to evaluate the cracking susceptibility in the casting. The number of the repetition of cracking test was 5 to 7 times for each testing alloy.

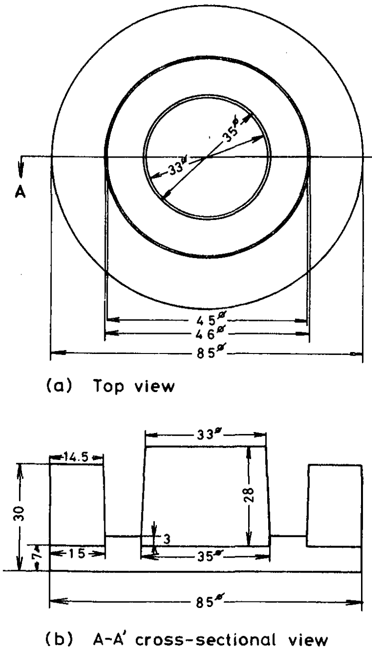


**Fig. 1** Shape and dimension of mold for ring casting cracking test

## 3. Experimental Results

### 3.1 Selection of favorable additional element to reduce solidification cracking

In order to select the favorable additional element to reduce the cracking susceptibility, the ring casting test was performed as the base alloy of Al-2%Zn-2%Mg ternary alloy without and with Ti+B, Ti, Zr, Fe, Mn, B, Si, Be, Ni, Cr, V, misch metal and Cu, independently, of which contents were about 0.5 % except for those of Ti+B of 0.06% and misch metal of 0.3%. To make clear the difference in cracking susceptibility of each alloy, higher susceptible base alloy of which Mg content was a little less than that of the synthesized-weld-metal as shown in Table 1 was used.

Cracking test results are shown in **Fig. 2.** Among 13 kinds of added elements, Ti+B, Ti and Zr showed the drastic decrease in crack length though the data were scattered in some degree in case of Zr addition. Fe, Mn, B, Si and Be also showed the beneficial effects to reduce

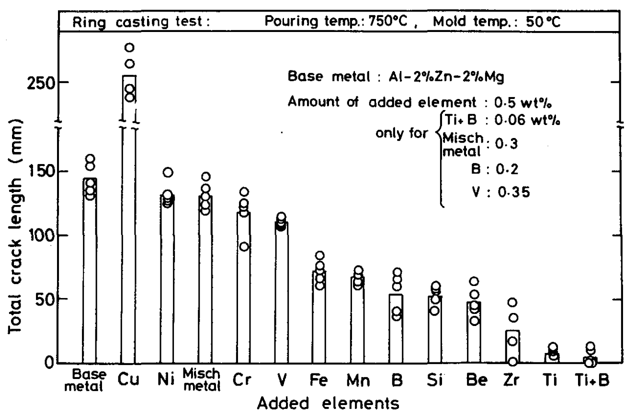


**Fig. 2** Effects of additional elements on total crack length of Al-2%Zn-2%Mg ternary alloys

the cracking. Ni, misch metal, Cr and V showed almost no effect. On the contrary, Cu showed detrimental effect to the crack susceptibility.

As a result in this experiment, it is confirmed that Ti+B, Ti and Zr are the most beneficial additional elements to reduce the crack susceptibility of Al-Zn-Mg alloy.

### 3.2 Decision of optimum amounts of Ti+B, Ti and Zr

*(1) Addition of individual element of Ti+B, Ti and Zr*

The favorable amounts of Ti+B, Ti and Zr added independently to the synthesized-weld-metal Al-2%Zn-3%Mg alloy have been examined.

Test results are shown in **Fig. 3** for each additional element though small amount of Zr (0.1%) was usually contained in base alloy in case of Ti+B and Ti additions.

The drastic decrease in crack length was observed at the content with more than 0.05, 0.14 and 0.24% for Ti+B, Ti and Zr, respectively. More additions showed the further decrease in crack length though the change in crack length was small.

Judging from their favorable amounts showing the obvious decrease in the cracking, it is considered that Ti+B is the most favorable element to reduce the crack susceptibility in casting among them. Ti followed after Ti+B and Zr was less effective in comparison with others.

**Figure 4** shows the typical macrostructures of base

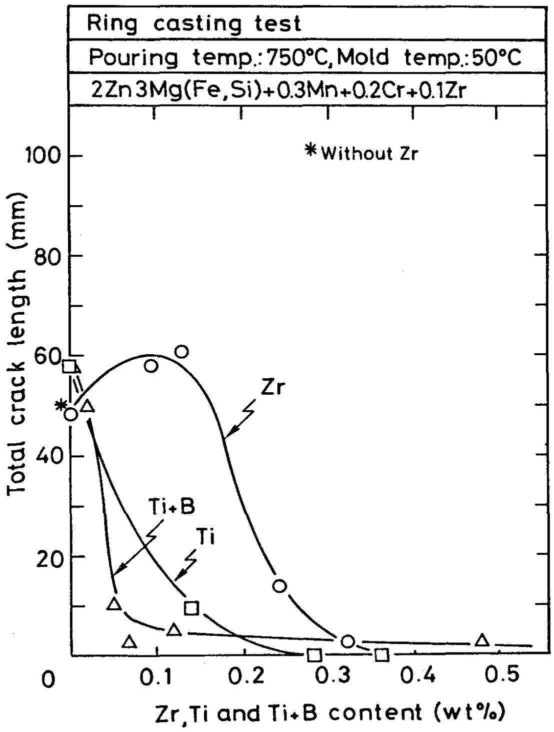


**Fig. 3** Effects of Ti+B, Ti and Zr additions on total crack length of Al-2%Zn-3%Mg synthesized-weld-metal alloy

alloy without and with 0.05%Ti+B, 0.14%Ti and 0.24%Zr respectively. The grain structure in base alloy shows large columnar fashion. However, by the addition of these grain refiners, they were suddenly changed to be very fine equiaxed grains as shown in Fig. 4 at the added amounts with more than 0.05, 0.14 and 0.24% for Ti+B, Ti and Zr respectively. Further more addition showed the decrease in grain size of equiaxed grains though its change was small. These effective amounts for the grain refinement coincided with those for the reduction in crack susceptibility as shown in Fig. 2.

*(2) Addition by combination of two elements*

The coexisting effect of Ti+B together with Zr and Ti was also examined to decrease the optimum amounts of these elements as small as possible without any loss in their beneficial effects to reduce the crack susceptibility because from the viewpoint of toughness of weld metal, these grain refining elements, especially Ti+B show the detrimental influence for toughness of aluminum alloy[8].

At first, the solid line in **Fig. 5** shows the effect of Zr addition on the crack susceptibility of the Zr free synthesized-weld-metal alloy in which 0.02%Ti+B was added in advance.

There was no cracking on the casted metal in case of Zr free base alloy by addition of only 0.02% of Ti+B. However, because of existence of small amount of Zr as about 0.1% in the alloy, this beneficial effect of Ti+B drastically disappeared. More addition of Zr than 0.25%, however, again decreased the crack length as the same way observed in case of Zr addition without Ti+B as shown by broken line in Fig. 5, though crack length was slightly longer even at the same Zr content. This indecates that beneficial effect of Zr became to be dominant with more Zr content than 0.25%, though this threshold content may depend on Ti+B content.

These results denote that the coexistence of Ti+B with Zr is not always effective to prevent the cracking because the beneficial effect of each element, especially of Ti+B is cancelled away.

This is due to the grain size effect as shown in **Fig. 6** where the macrostructures of ring-casting are shown for the alloys without Zr and with 0.03, 0.09 and 0.25%Zr containing 0.02%Ti+B, respectively.

Macrostructure without Zr shows very fine equiaxed grains by the grain refining effect of Ti+B, but it disappeared as the additions of Zr up to about 0.1% and the grains became much larger. However, fine equiaxed grains appeared with more then 0.25%Zr as shown in Fig. 6 (d) due to the effect of grain refining of Zr instead of Ti+B.

The reason why the grain refining effect of Ti+B is cancelled by the coexising with Zr has not been clear

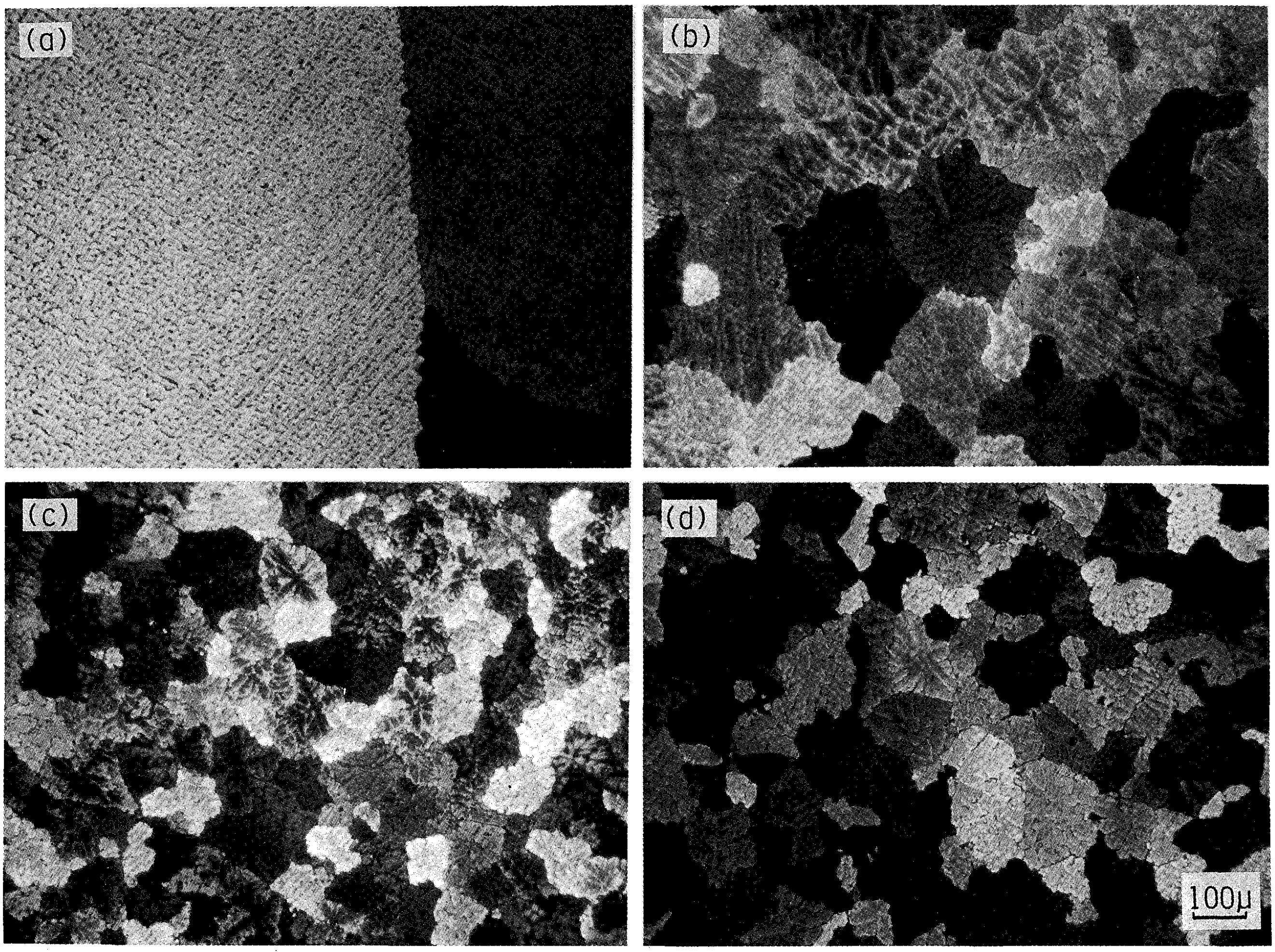


**Fig. 4** Typical macrostructures of ring casted metal of Al-2%Zn-3%Mg base metal; (a) without additional element, (b) with 0.05%Ti+B, (c) with 0.14%Ti and (d) with 0.24%Zr

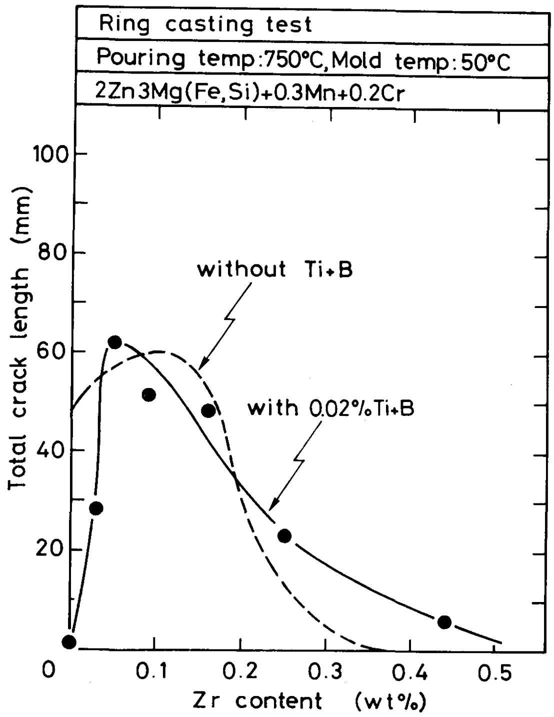


**Fig. 5** Effect of Zr addition on total crack length of ring casting of synthesized-weld-metal alloy with 0.02%Ti+B in comparison with those without Ti+B

so far. One reason was pointed out[9] that $TiAl_3$ compound which was considered to be one of the nuclei of equixed grains was changed to another less effective compound as nuclei by the reaction with Zr in the melted alloy.

Secondary, the effect of Ti addition onto the synthesized-weld-metal alloy with 0.02%Ti+B on the crack susceptibility has been investigated. Results are shown in **Fig. 7** in comparison with Ti+B free base alloy shown by broken line. Ti was added by using Al-5%Ti mother alloy. In Fig. 7, there was no remarkable favorable effect of addition of Ti+B of which content was low level such as 0.02% in order to reduce the crack length. However, abrupt decrease in crack length was observed at Ti addition with more than 0.05% in 0.02% Ti+B containing alloy.

This shows the promoting effect of Ti addition in addition to Ti+B to reduce the crack susceptibility in casting. This promoting effect of Ti is due to its grain refining effect as shown in **Fig. 8** in comparison with only 0.02% Ti+B containing alloy. Because of containing small

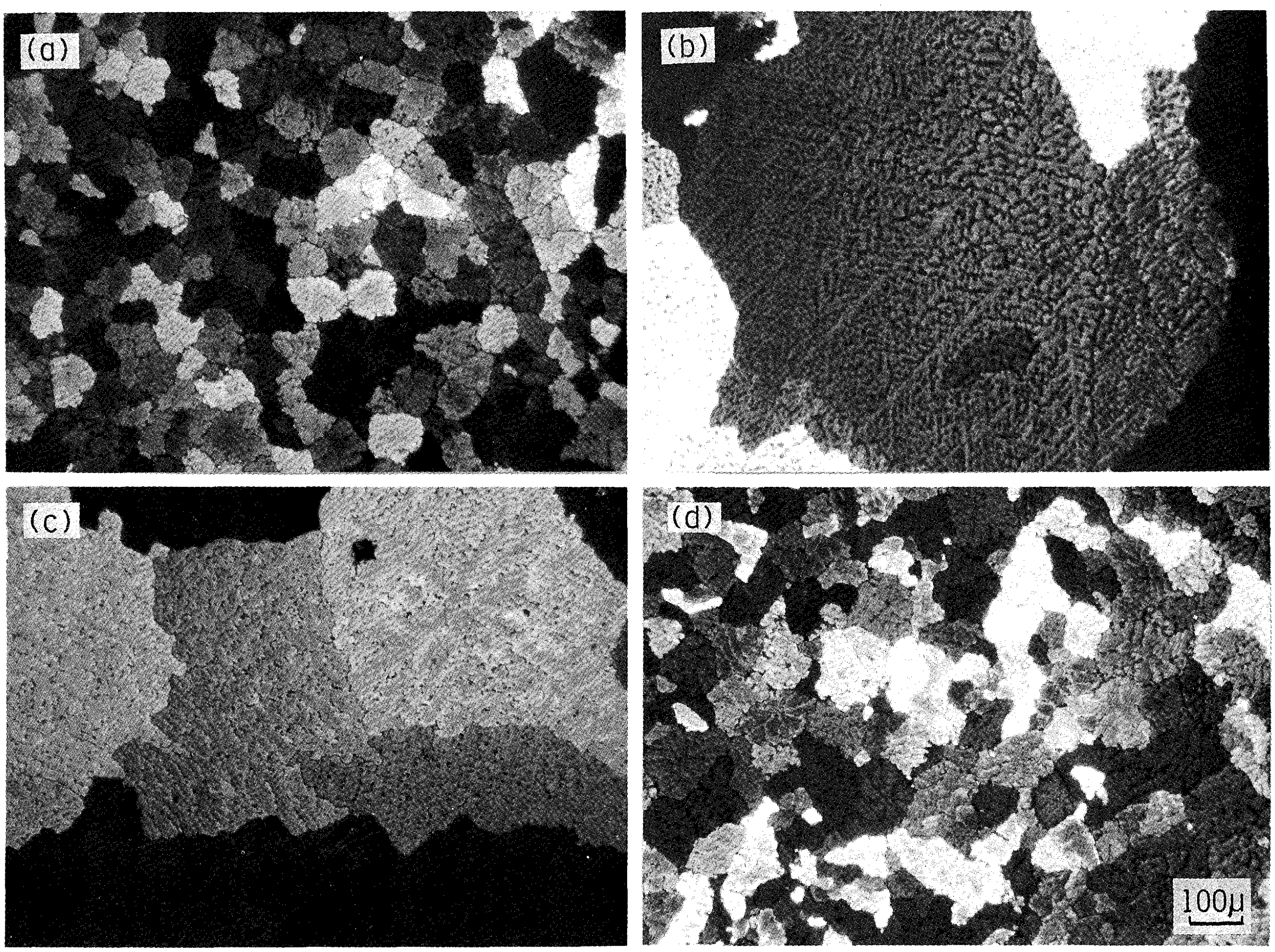


Fig. 6 Effect of Zr addition on macrostructure of synthesized-weld-metal alloy with 0.02%Ti+B

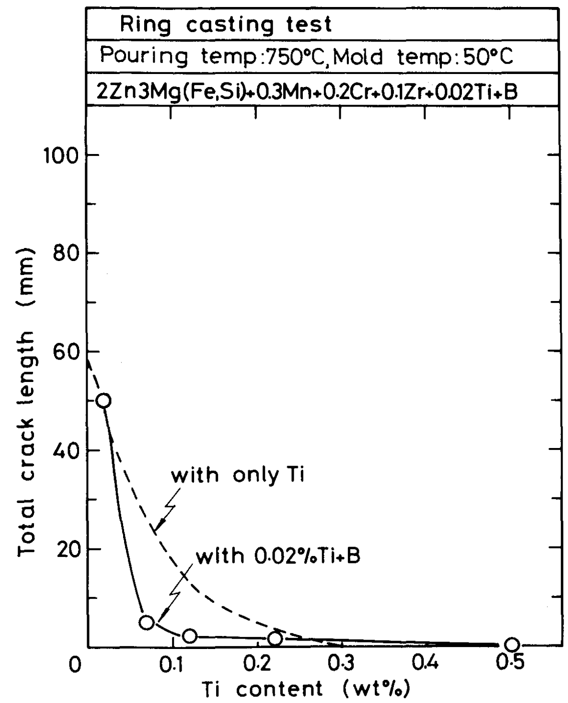


Fig. 7 Effect of Ti addition on total crack length of ring casting of synthesized-weld-metal alloy with 0.02%Ti+B

amount of Zr the macrostructure shows the large grains even containing 0.02% Ti+B. However only 0.05% addition of Ti on it changed them to be fine equiaxed grains.

## 4. Discussions

It is well known that grain size is one of the most dominant factors to control the solidification cracking in casting of aluminum alloys[10]. According to the macrostructural observation of ring-casted metal, test results in this investigation also suggest the close correlation between the crack susceptibility and grain size of the ring-casted metal of Al-Zn-Mg system alloys with and without Ti+B, Ti and Zr. To confirm this relationship more clearly the grain size measurement of all the ring-casted metal tested were performed by the line-intercept method on the microphotographs. **Figures 9** and **10** show the effects of mean grain size on the total crack length for Al-2%Zn-2%Mg and -3%Mg alloys, respectively. In Fig. 10 macrostructural change in grains were also illustrated.

In both cases, crack length was linearly increased as the

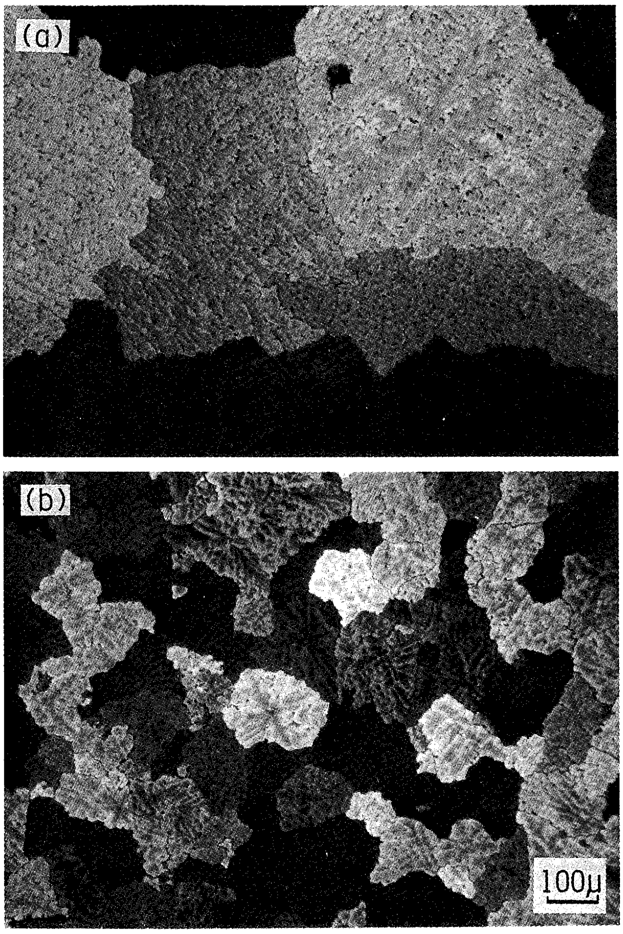


Fig. 8 Typical macrostructures of synthesized-weld-metal alloy with 0.02%Ti+B; (a) without additional Ti, (b) with 0.05%Ti in addition to 0.02%Ti+B

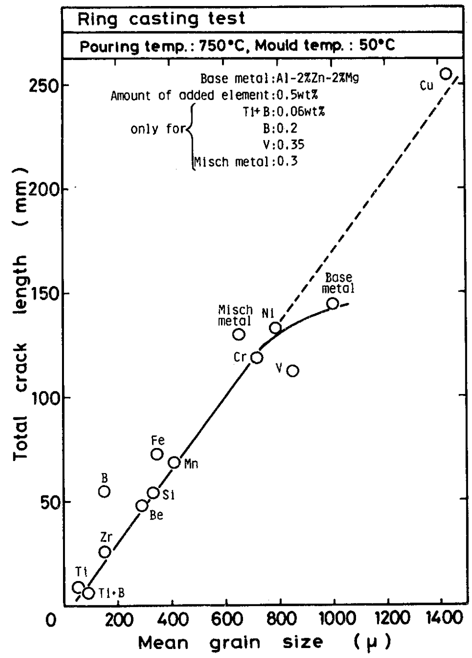


Fig. 9 Relation between mean grain size and total crack length of ring casting of Al-2%Zn-2%Mg alloy without and with additional elements

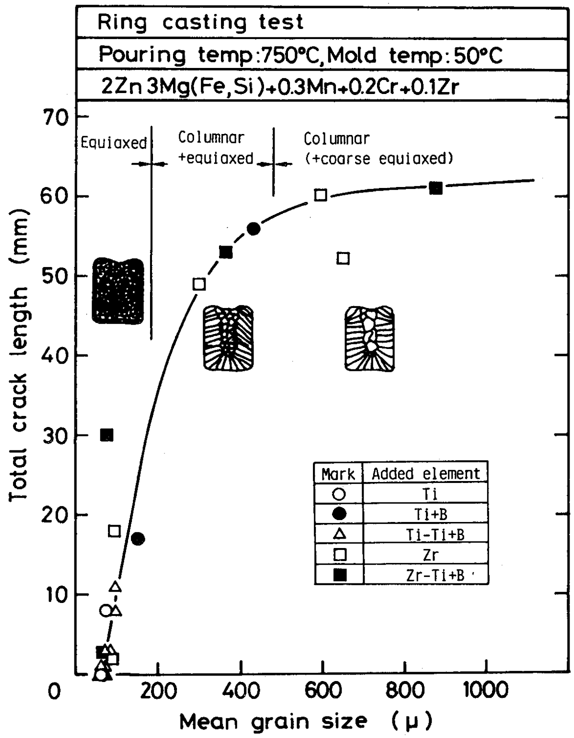


Fig. 10 Relation between mean grain size and total crack length of Al-2%Zn-3%Mg synthesized-weld-metal alloy without and with Ti+B, Ti and Zr

increase in grain size independent of the kinds of additional element and their amounts, though crack length was likely to reach the saturated value when large columnar sturcture became dominant as shown in Figs. 9 and 10. In Fig. 9, addition of Cu extremely increased the crack susceptibility of grain boundary of casted metal. Therefore, if the data is inserted to the curve, the crack susceptibility should be shown as broken line in Fig. 9.

These results clearly indicate the existence of the deep dependence of the crack susceptibility on the grain size in casting for individual aluminum alloy in the case of that grain size is controlled by the additional element.

Of course other possible factors to affect the cracking such as liquidus and solidus temperature difference, shape and amount of the remaining liquid in grain boundary at the last stage of solidification process were also examined on the ring-casting of the synthesized-weld-metal alloy with and without Ti+B, Ti and/or Zr. However there was no obvious change in these factors caused by the addition of these grain refining elements.

## 5. Conclusions

Solidification cracking of the synthesized-weld-metal

Al-2%Zn-2 to 3%Mg alloys in casting have been examined by means of the ring casting cracking test in order to select the favorable additional element and decided its optimum amount to improve the registance to the solidification cracking occurred in GMA weld metal of 7N01 Al-Zn-Mg high strength aluminum alloy with 5356 filler wire.

The conclusive results obtained are as follows;

(1) Among 13 kinds of additional element added up to 0.5% (except for Ti+B of 0.06%) in this experiment, Ti+B, Ti and Zr showed the most beneficial effect to reduce the crack susceptibility in ring-casting of Al-2%Zn-2%Mg alloy. Fe, Mn, B, Si and Be showed beneficial effects though they were less effective than Ti+B, Ti and Zr. Ni, Cr, V and misch metal showed almost no effect, but Cu showed detrimental effect.

(2) Optimum amount of Ti+B, Ti and Zr to reduce the crack susceptibility of Al-2%Zn-3%Mg-0.1%Zr synthesized-weld-metal alloy were decided to be more than 0.05, 0.14 and 0.24% for Ti+B, Ti and Zr additions, respectively in this experiment.

(3) Small amount of Ti addition was also favorable in addition to Ti+B to promote the beneficial effect of Ti+B to reduce the cracking. However, small amount of Zr addition was likely to cancel this beneficial effect of Ti+B. The latter is very important to consider the development of welding filler wire for 7N01 alloy because Zr element near 0.16% is usually added to 7N01 alloy to be welded in order to improve the stress corrosion behavior of base metal. Therefore addition of Ti+B in filler wire should be carefully intended.

(4) It proved that crack susceptibility of ring-casting closely depended on grain size in case that grain size was controlled by the additional element.

Further more investigation will be performed to confirm the beneficial effect of these grain refining elements in case of the actual welding process.

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