THE INFLUENCE OF ADDITIONAL ELEMENTS OF ALUMINUM ALLOY ON MACHINABILITY

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Abstract The influence of additional elements of aluminum alloy, especially of the elements other than conventional low melting point metals on machinability was investigated. Namely, the respective influences of Si, Ni, Mn and Fe on the machinability of AA6061 alloy used as base material were investigated. With the increase in the amount of each element the machinability of the alloy was improved. Si was the most effective among them, and Ni, Mn and Fe followed it in this order. It was found by microscopic observation that machinability was improved in proportion to the dispersion density of the second phase particles formed by the respective additional elements.

Keywords: *machinability, additional element, second phase particles, Si-compound, microstructure*

1.Introduction

Recently, from the standpoint of environmental protection of the earth, fuel saving of transports, especially of automobiles is greatly required, resulting in the increased application of aluminum to automobile parts [1]. Machining is a usual way to make parts of metallic materials. However, aluminum alloys are of inferior machinability. They are inferior in fragility of the chip among others and thereby of low productivity when machined. Therefore, free-cutting aluminum alloys such as AA2011 and AA6262 alloy have been developed and are used widely, in which the fragility of the chip is improved by the addition of low melting point elements like Pb and Bi as in the case of free-cutting steels or brasses. The fragility of the chip in these alloys is improved supposedly because Pb or Bi is softened or melted due to the increased temperature during machining, which makes cracks in the chip easy to be generated [2].

On the other hand, since there is a movement to restrict the use of the material containing harmful Pb for environmental protection, a free-cutting aluminum alloy without low melting point element such as Pb is desired to be developed[3].

In this paper are reported the results of investigation on the influence of additional elements other than low melting point elements on the fragility of the chip in reference to mechanical properties and microstrucrures.

2. Experimental procedure

Using a typical 6000 series alloy, AA6061 alloy as the base material, the respective effects of Si, Ni, Mn, and Fe on the machinability of the alloy were investigated. The conventional AA6262 and AA2011 alloy containing Pb and Bi were also used for comparison. The test materials, the chemical compositions of which are shown in Table 1, were DC-cast into ¢ 155 ingots, homogenized and extruded into bars of ¢ 46. The extruded bars were subjected to a solution treatment of 530 ℃ x 1hr, water-cooling, and an aging treatment of 170 ℃ x 6hr. Tensile and hardness test of the materials were carried out. Tensile test was done at a nominal strain rate of 1.7 x

Table1 Chemical composition of specimens (mass%)

No.	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Ni	Pb	Bi	Al
1	2.16	0.21	0.24	tr.	0.62	0.04	tr.	0.03	tr.	tr.	tr.	rem.
2	4.23	0.17	0.26	tr.	0.66	0.05	tr.	0.03	tr.	tr.	tr.	rem.
3	6.11	0.16	0.28	tr.	0.68	0.05	tr.	0.02	tr.	tr.	tr.	rem.
4	0.61	0.16	0.22	tr.	0.61	0.04	tr.	0.03	1.02	tr.	tr.	rem.
5	0.62	0.17	0.25	tr.	0.63	0.04	tr.	0.02	1.97	tr.	tr.	rem.
6	0.61	1.02	0.24	tr.	0.61	0.04	tr.	0.03	tr.	tr.	tr.	rem.
7	0.62	2.06	0.26	tr.	0.65	0.05	tr.	0.02	tr.	tr.	tr.	rem.
8	0.59	0.16	0.25	1.04	0.65	0.05	tr.	0.02	tr.	tr.	tr.	rem.
9	0.62	0.17	0.27	2.05	0.7	0.05	tr.	0.03	tr.	tr.	tr.	rem.
AA6061	0.69	0.15	0.27	tr.	0.89	0.03	tr.	0.03	tr.	tr.	tr.	rem.
AA6262	0.74	0.17	0.29	tr.	0.87	0.04	tr.	0.04	tr.	0.61	0.58	rem.
AA2011	0.03	0.14	5.14	tr.	tr.	tr.	tr.	tr.	tr.	0.44	0.57	rem.

$10^{-3}sec^{-1}$ at room temperature using JIS No.4 specimens (GL = 50 mm), which were taken so that the tensile direction was parallel to the extrusion direction. Hardness test was done at room temperature with a Rockwell hardness tester (AKASHI ATK-F3000) using F-scale of 588N load.

Machining test was carried out by drilling the materials using a straight shank drill of ¢ 10, the state of the chips fractured in pieces was evaluated by the number of pieces per unit weight (100 g), and thus a test material with a larger number of the pieces was judged to be superior in machinability [4]. The test materials and the fracture surfaces of the chips were microscopically observed with an image analyzer (MITANI corp. MAC SCOPE), and the particle size, the number, and the area ratio of second phase particles were measured. The microscopic observation was carried out with a magnification of 200, the particle size was expressed by the diameter of equivalent circle, and measurements were made 10 times for each specimen and the average of them was calculated.

Table2 Machinability test condition

Drilling
Tool : straight shank drill
Tool geometry : ϕ 10mm, pointangle 118° helix angle 30°
Tool material : high speed steel
Rotational speed : 1500rpm
Feed : 0.2mm/rev
Drilling depth : 15mm
Weting agent : used

3. Results

3.1Mechanical properties

Fig.1 shows the results of tensile test. As compared to the base material AA6061, the tensile strength and the proof stress of the alloy is increased by the addition of Si or Ni, but, on the contrary, is decreased by the addition of Fe or Mn. The elongation is decreased by the addition of Si, Ni or Fe, and is increased remarkably by the addition of Mn.

The hardness of the alloy, as in the case of the tensile strength and the proof stress, is increased by the addition of Si or Ni, and decreased by the addition of Fe or Mn.

3.2Machinability

Fig.2 shows the results of machining test, and Fig.3 shows the photographs of appearance of chips. The number of fractured pieces of chips increases with the increase in the amount of addition of Si or Ni. As for the effect of the addition of Fe or Mn, when 1mass% of each is added the number is decreased, but when the addition is increased up to 2mass% the number is increased. Si is the most effective to improve machinability as compared with Ni, Fe and Mn at the same adding amount of 2mass%. In addition, the Si- containing alloy is favorably compared with the conventional AA6262 alloy containing Pb or Bi in machinability under the present machining conditions.

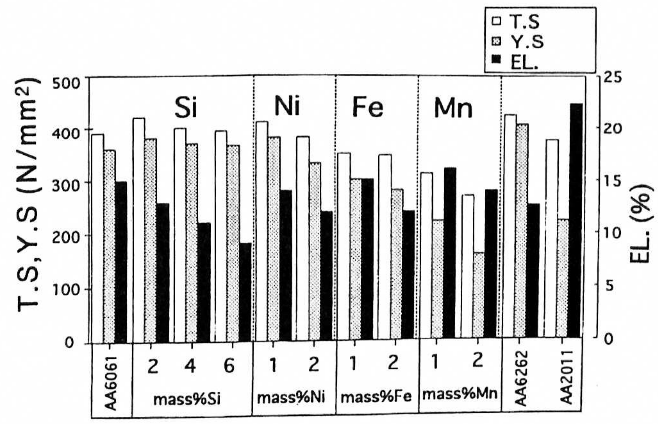

Fig.1 Results of tensile test

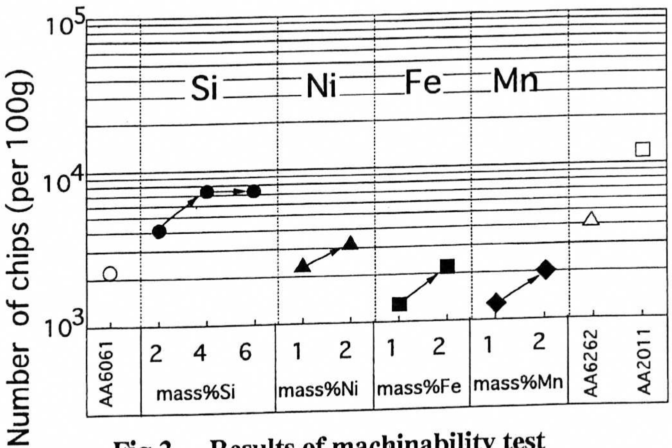

Fig.2 Results of machinability test

3.3 Microstrucuture

Fig.4shows the results of quantitative measurement of second phase particles with the image analyzer. The material containing, for example, 2mass% Si has second phase particles of 3300/mm^2 with the average size of 2.9 μ m, and the area ratio of 3.1%. The material containing increased amount of Si of 6mass% has increased number of second phase particles of 5900/mm^2 with the increased average size of 3.5 μ m, the area ratio of which is increased up to 8.3%. Also in the case of the materials containing Ni, Fe or Mn, the size, the number, and the area ratio of second phase particles increase with the increase in the amount of these elements.

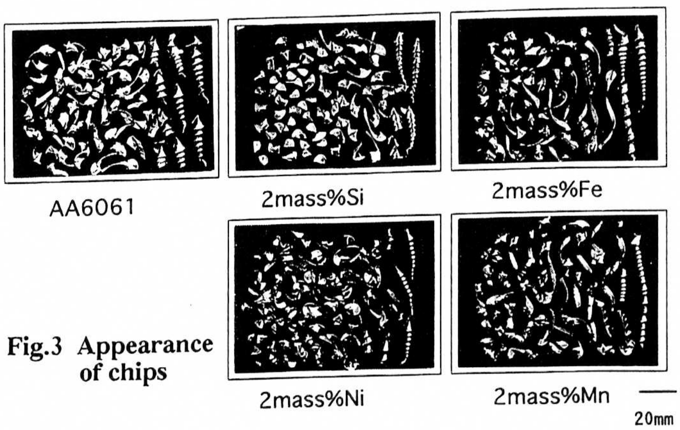

Fig.3 Appearance of chips

4. Discussions

4.1 Relation to mechanical properties

Fig.5 shows the relationship between hardness and machinability. Roughly speaking, the material with higher hardness has better machinability. However, when examined in detail, in the case of Ni-, Fe- or Mn-containing alloy, an inverse trend is observed that the material with lower hardness has better machinability. On the contrary, in the case of the Si-containing alloy, the material with higher hardness has better machinability. This phenomenon implies that there may be other factors that affect machinability more strongly than mechanical properties such as hardness and tensile strength. Referring to the numerals attached to the plotted points in Fig.5 that indicate the amounts of additional elements, it is observed that machinability is improved with the increase in the amount of every additional elements. It is very likely that machinability is affected most strongly by the change of the microstructure due to the increase in the amount of additional elements.

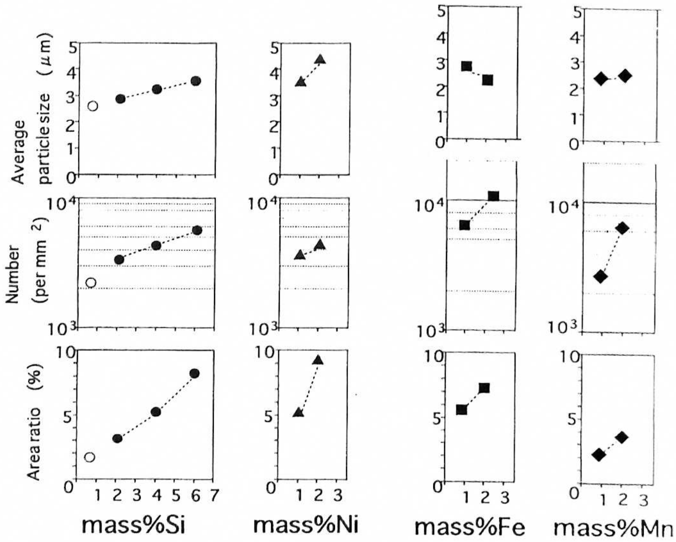

Fig.4 Results of image analyze test for second phase particles

4.2 Microstructure of chip

Fig.6 shows the microstructure of cross sections of the chips. Many second phase particles are found on the paths of propagation of cracks in the chips. This suggests that they may act as the origin of crack.Fig.7 shows the area ratio, determined by image analyzer, of the second phase particles on the fracture surfaces of chips.Those on the polished surfaces of the materials before machining are also shown in this figure for comparison. It is found that the area ratio on the fracture surface is larger than on the polished surface. As for the difference between the area ratio on the fracture surface and that on the polished surface, the difference for the second phase particles in the Si-containing material (Si-compound) is the largest, and the difference for Ni- or Fe-containing material is comparably small.

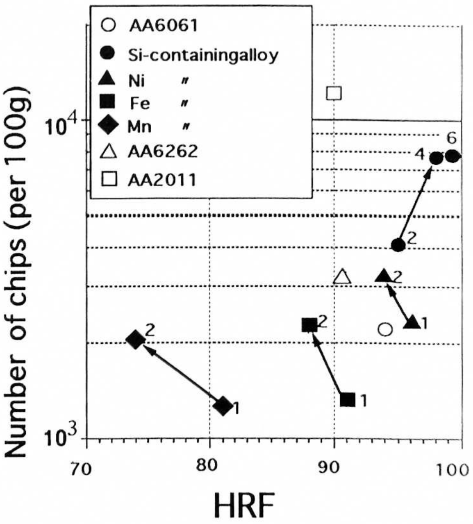

Fig.5 Relation between hardness and machinability

(Referring to numerals attached to plotted points indicate amount of additional element)

The difference can be understood as an indirect index of the degree, to which the second phase particles of each test material has acted as the origin of fracture of the chip. Therefore, Si-compound is supposed to be an effective origin of fracture of the chip. The result is that more particles of Si-compound are exposed on the fracture surface than those of Ni- or Fe-compound, which are less effective as the origin of fracture.

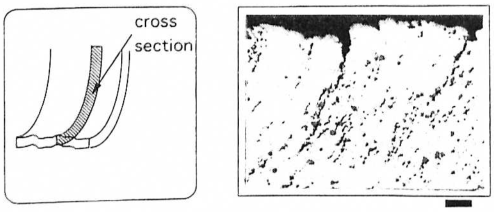

Fig.6 Cross section ofchip(specimen No.3)

4.3 Relation to microstructure

Fig.8 shows the relation between the average size of second phase particles and machinability, and Fig.9 shows the relationship between the number of second phase particles and machinability. The numerals attached to the plotted points in these figures indicate the amounts of additional elements. It is observed in Fig.8 that machinability of Si- and Ni-containing material is improved with the increase in the average particle size. On the other hand, machinability of Mn-containing material is improved even though the average particle size is kept approximately constant, and that of Fe-containing material is improved in spite of the decrease in the average particle size.

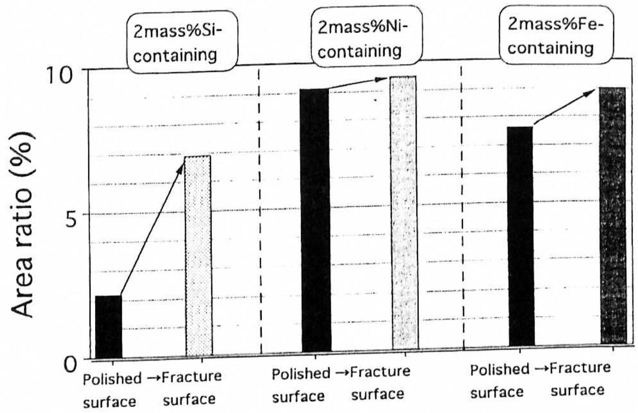

Fig.7 Area ratio of second phase particles

Regarding the effect of the number of second phase particles shown in Fig.9, machinability of the material with any additional element is improved with the increase in the number of second phase particles. Referring to Fig.8 and Fig.9 together, the increase in the amount of additional element in Si- and Ni-containing material causes the increase in the average size as well as the number of second phase particles, resulting in improved machinability. The increase in the adding amount of Mn in Mn-containing material does not change the average particle size but causes the number of particles to increase. This increase in the number of particles has led to the improvement of machinability. In the case of Fe-containing material, the increase in the number of particles with the increase in the amount of Fe has resulted in improved machinability despite of the decrease in the average size.

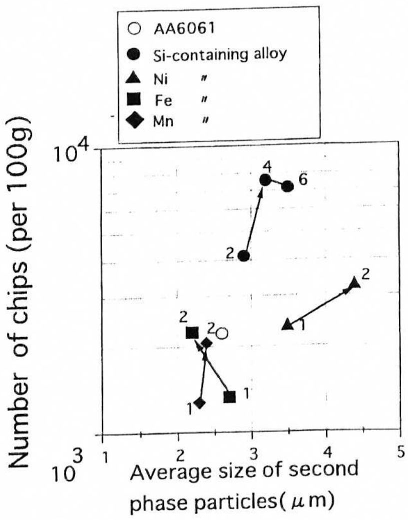

Fig.8 Relation between the average particle size of second phase particles and machinability
(Referring to numerals attached to plotted points indicate amount of additional element)

Fig.10 shows the relation between the area ratio of second phase and machinability. Machinability is improved with the increase in the area ratio. This phenomenon implies that the increase in the area ratio has resulted from the increase in the number of particles shown in Fig.9.

It is clear from the above that a parameter representing the number of second phase particles can be most suitably used as an influential factor in the discussion of the influence of microstructure on machinability. Concerning the materials with the same additional element in Fig.9, the materials having larger number of particles have higher frequency of fracture due to larger number of possible origins of cracks and thus are superior in machinability. Comparing the materials having the same number of particles in Fig.9, the compound of the additional element of the materials locating at upper positions in the figure can be judged to be more effective to act as the origins of fracture of the chip.

It is concluded from the above discussions that the addition of Si is most effective to improve machinability and the addition of Ni, Mn and Fe follow in this order under the present experimental conditions.

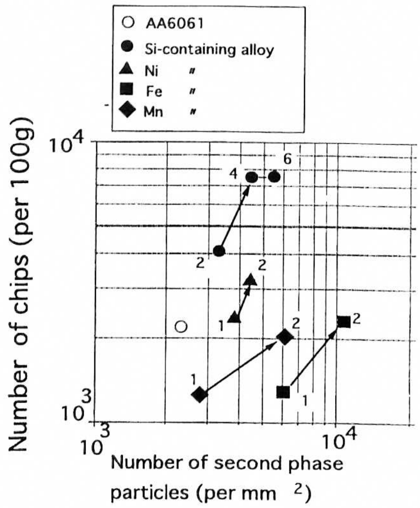

Fig.9 Relation between number of second phase particles and machinability
(Referring to numerals attached to plotted points indicate amount of additional element)

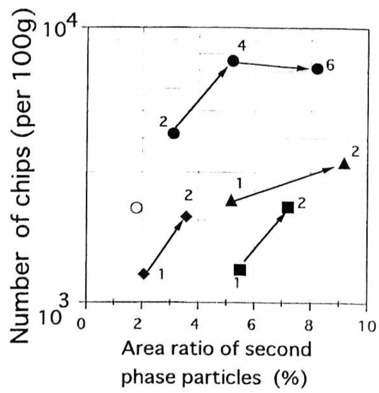

Fig.10 Relation between the area ratio of second phase particles and machinability

5. Conclusions

To study the influence of additional elements different from the conventional low melting point metals on the machinability of aluminum alloys, the respective influence of addition of Si, Ni, Mn, and Fe was investigated using AA6061 alloy as the base alloy. The conclusions obtained are as follows:

(1) Si is most effective to improve machinability as compared to Ni, Mn, or Fe.

(2) The above tendency can be understood by the dispersion number of second phase particles in the microstructure.

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