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High speed twin roll casting of recycled Al-3Si-0.6Mg strip

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ABSTRACT

Purpose: Purpose of this paper is to clear the possibility of high speed roll casting of thin strip of recycled Al-3%Si-0.6%Mg alloy. Investigation of the mechanical properties of the roll cast recycled Al-3%Si-0.6%Mg strip was purpose, too.
Design/methodology/approach: Method used in the present study was high speed twin roll caster and low temperature casting. These methods were used to realize rapid solidification, and increase of casting speed.
Findings: Findings are that recycled Al-3%Si-0.6%Mg was could be cast at speed of 60 m/min. This strip was 3.1 mm-thick. As cast strip could be cold-rolled down to sheet of 1 mm-thick. 180 degrees bending test was operated on the sheet after T4 heat treatment and crack was not occurred at the outer surface. This result means the roll cast recycled Al-3%Si-0.6%Mg can be used as the body of the auto mobile.
Research limitations/implications: Research limitation is that the width of the strip was 100 mm and investigation of the properties was not enough for practical use. Wider strip must be cast using the twin roll caster of the size for production.
Practical implications: Practical implications are as below. The economy sheet for the auto mobile can be produced by the high speed twin roll caster. Al-3%Si-0.6%Mg can be used both the casting and plastic forming. Therefore, fractionation in the recycle of the aluminum alloy will becomes easy. The content of Fe in the recycled aluminum alloy increases. Fe becomes intermetallic of AlSiFe. Si for Mg_2Si becomes deficient. 3%Si was enough for Mg_2Si if AlSiFe was precipitated. Al-3%Si-0.6%Mg is suitable for recycle.
Originality/value: The economy sheet of Al-3%Si-0.6%Mg can be made by the high productivity of the HSTRC. The result of this report contributes to make the economy aluminum alloy sheet for the automobile.
Keywords: Casting; High speed twin roll casting; Sheet metal; Al-3%Si-0.6%Mg; Recyclee

1. Introduction

The reduction of the weight of the automobile is very important problem to be solved immediately from the view point of the environment of the earth. The use of the aluminum alloy instead of steel is most useful way to solve this problem. Aluminum alloy sheet for the body of the automobile is very expensive. The low cost of the aluminum alloy sheet must be realized. There are two ways to decrease the cost of aluminum alloy sheet. One is adoption of economy process and the other is use of recycle aluminum alloy. In the recycle, the fractionation of alloy is very important, but it is heavy work. The cost of the recycled aluminum alloy increases by the fractionation. The

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number of the alloys must be reduced to reduce the cost of the fractionation. If the uni-alloy can be used for both casting and plastic forming, the fractionation becomes very easy, and the recycled aluminum alloy becomes more economy. The difference between the alloys for the casting and plastic forming is content of the Si. The Si content of the alloy for casting is greater than that of the wrought alloy. Si is essential for good melt-flow ability of the alloy for casting. However, Si makes ductility worse. Therefore, Si content of 6000 series alloys for sheet metal is less than 1.5 %. The Si content must be greater than 3% for casting. If Al-3%Si-0.6%Mg can be used as sheet metal for the auto mobile, the number of the aluminum alloy can be reduced extremely, and the recycle becomes easy and economy. The reason is that Al-3%Si-0.6%Mg can be used both for casting and sheet forming, and the fractionation is not needed.

When the recycle is operated, increase of the Fe content makes the mechanical properties worse. Poor mechanical properties must be improved. The poor mechanical properties of the recycled aluminum alloy may be improved by rapid solidification. The twin roll caster has both abilities of rapid solidification and economy process. Therefore, the twin roll caster is suitable to cast economically the strip from the recycled aluminum alloy. However, there are few repots of the roll casting concern to the recycled 6000 series aluminum alloy [1-5]. Si content of 6000 series aluminum alloy for body sheet is usually less than 1.5%. Impurity Fe becomes AlSiFe intermetallic. Therefore, Si, which is use as Mg_2Si, becomes insufficient, and age hardening becomes less. The Si content, which is greater than 1%, is better. In this point, Al-3%Si-0.6%Mg is suitable for the body sheet alloy used in recycle.

The content of Fe as impurity increases in the recycled aluminum alloy. The intermetallic, which includes Fe, was crystallized, and it decreases the ductility of the recycled aluminum alloy. When the size of the intermetallic becomes fine, the influence of the intermetallic on the decrease of the ductility becomes smaller. The rapid solidification is useful to make the intermetallic fine. The cooling late of the twin roll caster is very high. Therefore, the roll caster is useful to reduce the influence of the intermetallic of impurity. However, the casting speed of the conventional twin roll caster for aluminum alloy (CTRCA) is slower than 10 m/min. This shows the CTRCA has poor productivity. This disadvantage must be improved. The increase of the cooling ability is useful to increase the casting speed. The high cooling ability is better to make the impurity harmless as mentioned above. A high speed twin roll caster (HSTRC, Fig.1) was used in the present study to realize the high productivity and high cooling rate. Some devices to increase the cooling rate were introduced to the HSTRC. The cooling rate of the HSTRC is higher than that of the CTRCA by the effect of these devices. The low productivity was improved in the HSTRC. The ability of the improvement of the deterioration by intermetallic of the impurity increased in the HSTRC, too.

In the present study, strip casting of the Al-3%Si-0.6%Mg aluminum alloy, to which impurity-Fe was added from 0.2 mass% up to 1.2 mass% as the model of recycled aluminum alloy, was operated by the high speed twin roll caster. Castability of Al-3%Si-0.6%Mg strip by the HSTRC, and the mechanical properties of the strip were investigated.

2. Experimental conditions

A high speed twin roll caster (HSTRC) was used in the present study [6-10]. The schematic illustration of the HSTRC is shown in Fig. 1. Some devices were adopted to the HSTRC in order to increase the cooling rate of the strip. HSTRC was vertical type twin roll caster. The nozzle was introduced to the HSTRC.

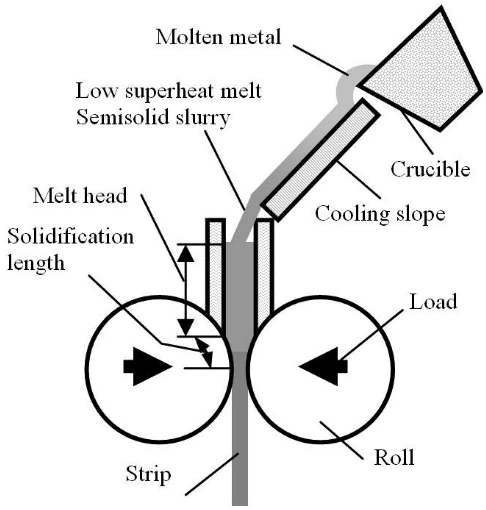

Fig. 1. High speed twin roll caster

The nozzle was useful to increase the heat transfer between the roll and the melt by the hydrostatic pressure of the melt head. The higher the melt head, the better the heat transfer. The oscillation of the meniscus at the tip of the nozzle makes strip-surface worse. The hydrostatic pressure prevents the meniscus from oscillation. Therefore, the strip surface became better. The solidification length can be controlled precisely by the nozzle. The solidification length is not influenced by the bouncing of the meniscus of the melt-surface. This shows the strip thickness can be kept uniform. In this way, the use of the nozzle improves, heat transfer, strip-surface and the strip thickness. The copper roll was used and lubricant (parting material) was not used in order to increase the cooling rate. The thermal conductivity of the copper is about eight times larger than that of the steel. Therefore, the copper roll is better for rapid solidification. The roll diameter was 300 mm, and the width was 100 mm. The roll was water-cooled from inside. The lubricant becomes heat resistant between the roll and the melt, between the roll and the strip. No-use of the lubricant improves the heat transfer. The lubricant is used to prevent the sticking of the strip to the roll in the conventional twin roll caster for aluminum alloy (CTRCA). The steel roll is used in the CTRCA. The temperature of roll surface influenced the sticking of the strip. The strip easily sticks to the roll as the roll temperature increases. The temperature of roll-surface of the copper roll is lower than that of the steel roll. The temperature of the copper roll does not increase up to the temperature at which the sticking happens. The strip does not stick to the copper roll. The rolling road of the HSTRC is from a ten to a hundred times smaller than that of the CTRCA. Small rolling road acts better to prevent the sticking of the strip. However, the rolling road of the HSTRC is enough large to get good heat transfer between the roll and the strip. The rolling load could be set at range from 0.1 to 0.5 kN/mm (per unit width). Low temperature casting was useful to increase the cooling rate. In the present study, a cooling plate was used for the low temperature casting. When the molten metal was poured from the crucible to the cooling slope, the superheat of the molten metal was 15^{O}C, and the superheat decreased down to 5~10 ^{O}C after through the cooling slope [11-13]. The cooling slope was made from mild steel and was water cooled from inside. BN was sprayed on the surface of the cooling slope as the lubricant. The length was 300 mm, the width was 100 mm, and the inclination angle was 60 degrees.

6016 and 6022 aluminum alloys typical 6000series alloy for the plate of the automobile. The content of the Fe is restricted less than 0.2mass%. Fe content of Al-3%Si-0.6%Mg was set less than 0.2mass%, too. Fe was added as impurity up to 1.2 mass% of total content to investigate the deterioration when Al-3%Si-0.6%Mg is recycled. 2.7kg of aluminum alloy was melted in the electric furnace. The roll surface was polished by #1200 emery paper before every casting. The one roll was attached strictly, and the other roll was supported by the spring. At the start of the casting, the roll gap was set at 1.0 mm. The roll gap varies along the strip thickness for the casting. The roll speed was 60 m/min. The roll speed of CTRCA was slower than 10 m/min. Therefore, this casting speed is very high. The rolling road was 0.14kN/mm (per unit width). The tension test and 180 degree bending test was operated to investigate the mechanical properties. The as cast strip was cold rolled down to 1.0 mm, and T6 heat treatment was operated before the tension test. The 180 degrees bending test was operated to T4 heat treated specimen at 1.0 mm thickness. T4 and T6 heat treatment conditions were as below. As-cast strip was cold-rolled down to 1.0 mm without the homogenization and intermediate annealing. Cold-rolled strip was kept for 4 hours at 540°C, and was water-quenched (until here, T4). After T4, strip was kept for 6 hours at 160°C. The gage length was 50 mm and thickness was 1.0 mm of test piece for tension test. The metalography of as cast strip was observed.

Table 1.
Experimental conditions

Roll material	copper, diameter 300 mm width 100 mm speed 60 m/min
Aluminum alloy	Al-3%Si-0.6%Mg Fe: 0.2, 0.45, 0.7, 0.95, 1.2 mass% super heat 15 °C
Cooling slope [11-13]	mild steel, length 300 mm, width 100 mm inclination angle 60°
Separating force	0.14 kN/mm
Solidification length	100 mm
Melt head	100 mm

3. Result and discussions

3.1. Roll casting of Fe added alloy

Fe added Al-3%Si-0.6%Mg could be cast into the strip at the speed of 60m/min. The ability of roll casting became better than 6016 and 6022 by the effect of increase of Si content. Continuity and surface of the strip could be improved by addition of the Fe. This means that castability became better by addition both of Si and Fe. In the high speed twin roll caster (HSTRC) of the present study, casting of mushy solidification type aluminium alloy is easier than skin formation solidification type aluminium alloy. The Al-3%Si-0.6%Mg became near to mushy solidification type alloy than 6012 and 6022 as the content of Si was larger. Moreover, added Fe made the alloy the mushy. This shows that there is no problem in the high speed roll casting of Al-3%Si-0.6%Mg and Fe added alloy strip.

Figure 2 shows surface of the as-cast strip. The width of the strip was as same as that of the roll. Ripple mark like horizontal type conventional twin roll caster for aluminum alloy (CTRCA) was not occurred on the surface. This is the one of good characteristics of the HSTRC. However, oscillation mark of the meniscus was not inhibited by the hydrostatic pressure of the molten metal. The surface condition became better as the Fe content increased. The starting point of the solidification was apart from the nozzle and the influence of the wetting condition between the nozzle and the melt became small as the Fe content increased. Starting point of the solidification was not steady and oscillation remarkable mark occurred. Impurity Fe did not make the surface of the strip worse. The oscillation mark was no problem to cast strip of Al-3%Si-0.6%Mg continuously.

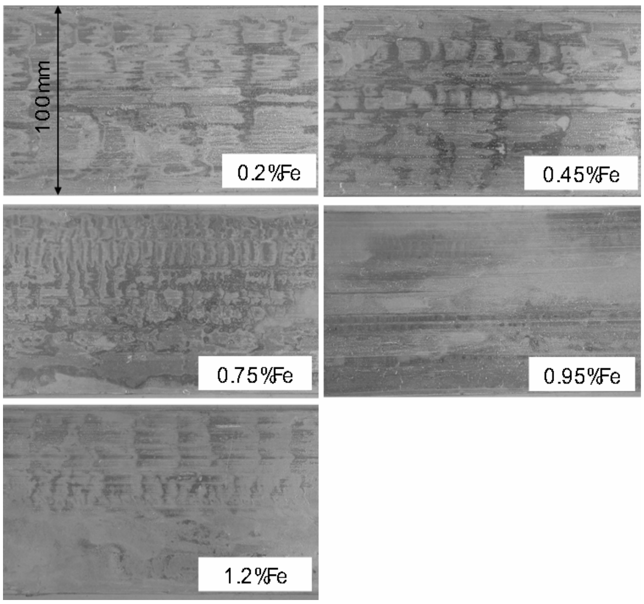

Fig. 2. Surfaces of Fe added Al-3%Si-0.6%Mg as-strips

3.2. Cold rolling of as cast Fe added strip

The as-cast strip could be cold-rolled down to 1.0 mm without the homogenization and the intermediate annealing. Fe content did not affect the result of the cold rolling. On the other hand, the cracks occurred when the ingot cast using insulator mould was cold-rolled without homogenization. This shows that high speed roll-cast strip had good ductility by the effect of microstructure cast at higher cooling rate. The cooling rate of the strip cast by the HSTRC is estimated at about 4000^{O}C at near the surface, and about 1000^{O}C in the middle at thickness direction [14]. The cooling rate of the strip cast by the CTRCA was usually lower than 1000^{O}C. The cooling ability of the HSTRC is better than that of the CTRCA. After cold rolling, the oscillation mark was erased. The metallic luster of the rolled strip was not affected by the Fe content.

3.3. Microstructure

Figure 3 shows microstructure of the cross section of the as-cast strip. It is clear that the microstructure was very fine by the effect of the high cooling rate. The microstructure was not uniform at thickness direction. The center area was different from other areas. The microstructure of the strip cast by CTRCA is usually columnar structure. In the HSTRC, the microstructure was not columnar structure. There was no interface between the solidification layers like the CTRCA. This tendency was not affected by the content of the Fe. The low superheat casting and small load from the rolls affected the characteristic of the microstructure. This is the characteristic of the strip cast by the HSTRC.

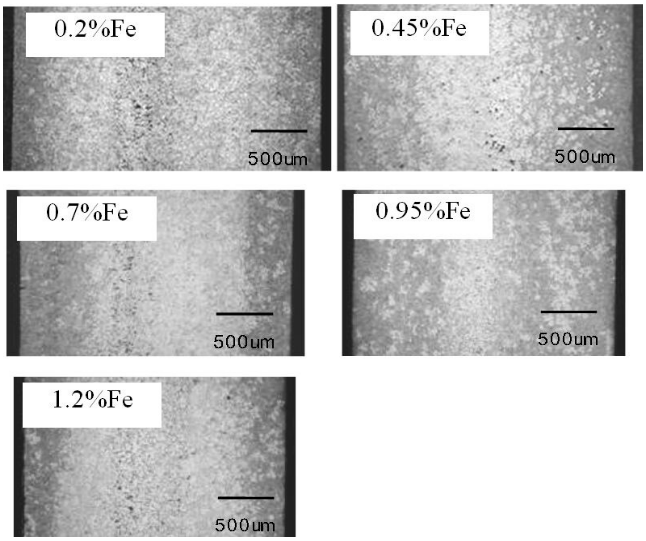

Fig. 3. Microstructure of cross section of Fe added Al-3%Si-0.6%Mg as-cast strip

The microstructure of the center area was spherical structure as shown in Fig. 4 of enlarged view of Fig.3. This structure was typical microstructure of the low superheat casting or semisolid casting. The microstructure expect for center area was duplex structure of dendrite structure and globular structure. The globular crystal existed in the dendrite structure. This globular crystal was crystallized on the cooling slope or on the nozzle. This duplex structure was typical microstructure of the low solidification rate semisolid casting. The eutectic Si was fine and globular. Modifying treatment of the eutectic Si was not operated. This is the effect of the rapid solidification, too.

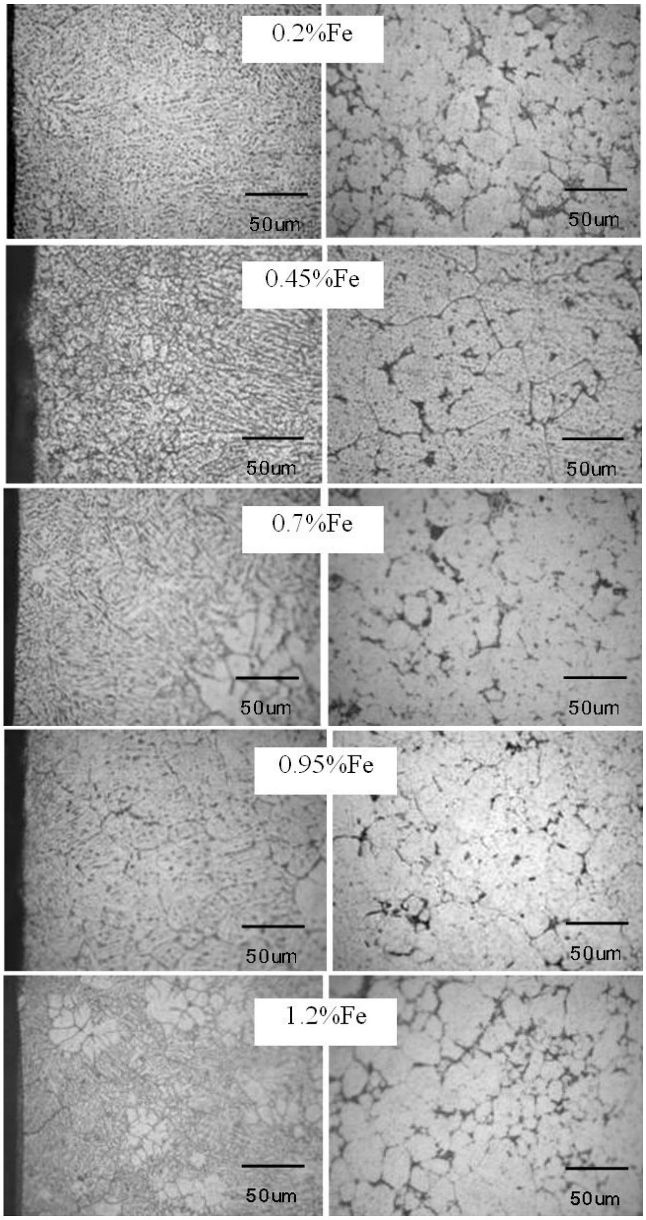

Fig. 4. Enlarged view of structure of the cross section. Left side is near surface and right is middle

3.4. Mechanical properties

Mechanical properties were investigated by the180 degrees bending test and the tension test. Figure 5 shows the result of bending test. The hemming process is operated of the end of the plate in the manufacturing of the automobile. The plate is suitable for hemming process or not can be estimated by the bending test. Thickness of the strip was 1mm, and heat treatment was T4. There was no crack at outer surface and inside when the content of the Fe was less than 0.7mass%. The Fe content affects the result of the 180 degrees bending test. The Fe content was restricted under 0.2 mass% to prevent the occurrence of the crack in the aluminum alloy for the automobile-sheet like 6022. The Si content was restricted under 1.5 mass% to prevent the occurrence of the crack in the aluminum alloy for the automobile-sheet, too. Usually, the crack occurs at outer surface of the strip contains 3mass%Si and 0.7mass%Fe after 180 degrees bending. However, crack did not occur at the plate cast using by the HSTRC. This was the effect of fine Si and intermetallic including inpurity Fe. The occurrence of the crack depends on size and shape of the eutectic Si and intermetallic. The crack does not occur when the eutectic Si and intermetallic are fine. The eutectic Si and intermetallic became fine by the effect of rapid solidification of the HSTRC. As the result, the crack did not occur.

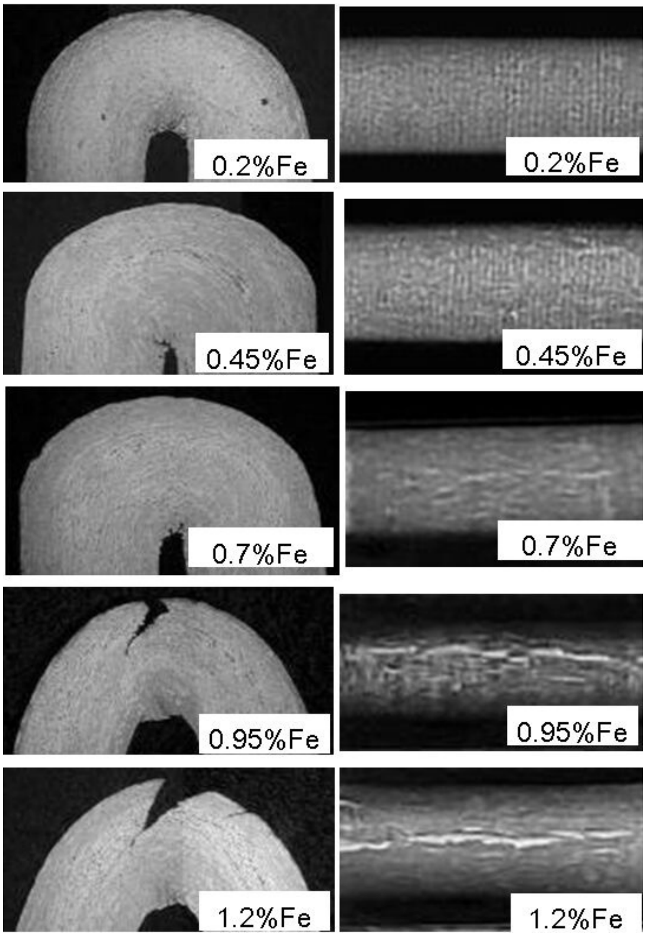

Fig. 5. Result of 180 degrees bending test. Thickness was 1mm, and heat treatment was T4

In the 6111 plate made from DC casting, crack usually occurred at the outer surface of 1mm-thick plate of T4 heat treatment after the 180 degrees bending [15]. The recovery heat-treatment is introduced to improve the crack. If the recovery heat-treatment is permitted in the production system, the contents of Si and Fe can be increased more than 3 mass% and 0.7 mass%. The castability of the strip becomes better as the Si and Fe content increases.

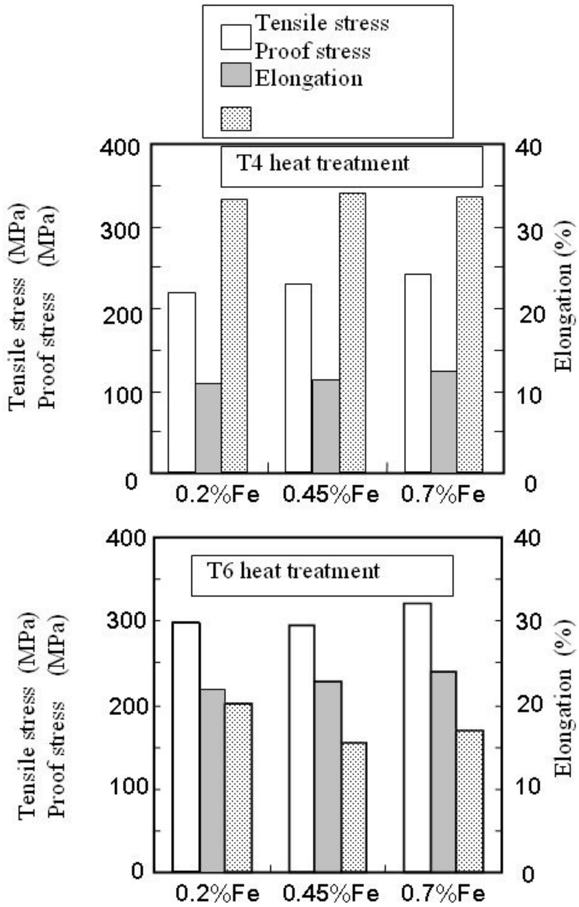

Fig. 6. Result of tension test of T4 and T6-heat treated 1mm-thick plate

The result of the tension test was shown in Fig.6. The elongation of the T4-heat treated strip was 32.6%. This result is almost same as the result of 6016 and 6022. The increase of the Si content did not make ductility worse. Fe content did not make worse the elongation when Fe content was less than 0.7 mass%. The tensile stress and proof stress increased gradually as the Fe content increased. The result of the tension test of T6-heat treated strip is shown, too. When the Fe was added as impurity up to 0.7 mass%, the tensile stress did not decrease. Age-hardening occurred. Si was enough to precipitate the Mg_2Si, although Al-Si-Fe intermetallic crystallized. This was the effect of the 3 mass% of sufficient Si. The tensile strength became greater as the Fe content increased. This might be effect of dispersion strengthening by the fine Al-Si-Fe intermetallic. The results of bending test and tension test shows that roll-cast Al-3%Si-0.6%Mg strip could be used as sheet metal, and the ductility and strength did not become worse when impurity Fe contaminated.

4. Conclusions

The strip of Al-3%Si-0.6%Mg and impurity-Fe added Al-3%Si-0.6%Mg could be cast by the high speed twin roll caster (HSTRC) at the speed of 60 m/min. The cast ability of Al-3%Si-0.6%Mg was better than that of 6016 and 6022 by the effect of increase of the Si content. The impurity-Fe made castability better, too. The 3.2 mm-thick as-cast strip could be cold-rolled down to 1 mm without homogenization. The surface of as-cast strip could be improved by the cold-rolling. The primary crystal and eutectic Si were very small. In the 180 degrees bending of the 1mm-thick T4heat-treated strip, the crack did not occur at outer surface when Fe content was added up to 0.7mass%. The elongation of the 1mm-thick T4heat-treated strip was 32.6%, and impurity-Fe did not make the elongation worse. Age-hardening occurred when the T6-heat-treatment was operated to impurity-Fe added Al-3%Si-0.6%Mg. Si was enough for precipitation of Mg_2Si, although Al-Si-Fe intermetallic crystallized. These result show the possibility that the Al-3%Si-0.6%Mg strip cast using the HSTRC can be used for the body sheet of the auto mobile. This is the effect of the ability of the high cooling rate of the HSTRC.

The Al-3%Si-0.6%Mg can be used for the sheet forming and for the casting. Therefore, the energy of the fractionation in the recycle becomes small. The economy sheet of Al-3%Si-0.6%Mg can be made by the high productivity of the HSTRC. The result of this report contributes to make the economy aluminum alloy sheet for the automobile.

References

[1] S. Kumai, K. Suzuki, Y. Saito, T. Haga, Significance of rapidly solidified aluminum alloy strips for high quality recycling, Trans. MRSJ, 29 (2004) 1817-1822.

[2] T. Haga, M. Ikawa, S. Kumai, A high speed twin roll caster for aluminum alloy thin strip, ibid., 29 (2004) 1823-1828.

[3] T. Haga, M. Ikawa, S. Kumai, High-speed twin roll casting of thin aluminum alloy strips containing Fe impurities, Materials Ransactions 46 (2005) 2596-2601.

[4] K. Suzuki, S. Kumai, Y. Saito, T. Haga, High-speed twin roll casting of Al-Mg-Si alloys with high Iron content, ibid., 46 (2005) 2602-2608.

[5] T. Haga, M. Ikawa, S. Kumai, 6111 aluminum alloy strip casting using an unequal diameter twin roll caster, Journal of Materials Processing Technology 172 (2006) 271-276.

[6] T. Haga, S. Suzuki, Roll casting of aluminum alloy strip by melt drag twin roll caster, Journal of Materials Processing Technology 118 (2001) 165-168.

[7] T. Haga, S. Suzuki, Melt ejection twin roll caster for the strip casting of aluminum alloy, Journal of Materials Processing Technology 137 (2003) 92-95.

[8] T. Haga, S. Suzuki, Strip casting of A5182 alloy using a melt drag twin roll caster, Journal of Materials Processing Technology 133 (2003) 103-107.

[9] T. Haga, S. Suzuki, Study on high-speed twin-roll caster for aluminum alloys, Journal of Materials Processing Technology 143 (2003) 8-14.

[10] T. Haga, K. Takahashi, M. Ikawa, H. Watari, Twin roll casting of aluminum alloy strips, Journal of Materials Processing Technology 153 (2004) 42-47.

[11] T. Motegi, N. Ogawa, Continuous casting of semisolid Al-Si-Mgalloy, Proc. of the International Conference on Aluminum Alloys"ICAA-6" Toyohashi Japan, 1998, 297-326.

[12] T. Haga, P. Kapranos, Billetless simple thixoforming process, Journal of Materials Processing Technology130 (2002) 581-586.

[13] T. Haga, P. Kapranos, Simple rheocasting process, ibid.,130 (2002) 594-598.

[14] K. Suzuki, S. Kumai, Y. Yuichi, A. Sato, T. Haga, Refined Solidification structure and improved formability of A356 aluminum alloy plate produced using a high-speed twin roll strip caster, Materials Transactions 45 (2004) 403-405.

[15] Aluminum International Today, Nov./Dec. (2002), 36.