Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 17
ISSUE 1-2
July-August
2006

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

T. Haga [a,*], M. Ikawa [a], H.Watari [b], S.Kumai [c]
[a] Osaka Institute of Technology, 5-16-1 Omiya Asahiku Osakacity, 535-8585 Japan
[b] Oyama National Technical College of Technology,
771, Nakakuki, Oyama city, Tochigi, 323-0806, Japan
[c] Tokyo Institute of Technology, 4259, Nagatsuda, Midoriku, Yokohama city,
Kanagawa, 226-8502, Japan
* Corresponding author: E-mail address: haga@med.oit.ac.jp

Received 15.03.2006; accepted in revised form 30.04.2006

Manufacturing and processing

ABSTRACT

Purpose: Purpose of this paper is to clear the possibility of high speed roll casting of thin strip of Al-3%Si-0.6%Mg alloy. Investigation of the mechanical properties of the roll cast 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 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.
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 Mg2Si becomes deficient. 3%Si was enough for Mg2Si if AlSiFe was precipitated. Al-3%Si-0.6%Mg is suitable for recycle.
Originality/value: The result means the roll cast Al-3%Si-0.6%Mg has ability to be used as the body sheet of the auto mobile.
Keywords: Casting; High speed twin roll casting; Strip casting; Sheet metal

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 ally is very important, but it is heavy work. The cost of the recycled aluminum alloy increases by the fractionation. The 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, 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 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.

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 contains 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%. 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 used by recycle.

The content of Fe as impurity increases in the recycled aluminum alloy. The intermetallic including 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. A high speed twin roll caster (HSTRC) was used in the present study to realize the high speed and high cooling rate [6-10]. Some devices (i.e. cooling slope) to increase the cooling rate were introduced to the HSTRC[11-13]. 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, which was model of aluminum alloy suitable for recycle, 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

6016 and 6022 aluminum alloys typical 6000series alloy for the plate of the automobile. The content of the Fe is restricted less than 0.2 mass%. Fe content of Al-3%Si-0.6%Mg was set less than 0.2 mass%, too. 2.7kg of aluminum alloy was melted in the electric furnace. The HSTRC is shown in Fig.1. 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 0.14 kN/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^{O}C, and was water-quenched (until here, T4). After T4, strip was kept for 6 hours at 160 ^{O}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.

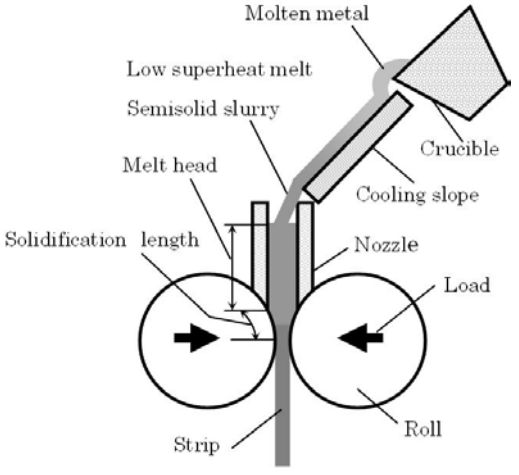

Fig. . High speed twin roll caster [6-10]

3. Result and discussions

3.1. Roll casting of Al-3%Si-0.6%Mg

The Al-3%Si-0.6%Mg could be cast into the strip at the speed of 60 and 90 m/min. The ability of roll casting became better than 6016 and 6022. Continuity of the strip could be improved by addition of the Si. This means that castability became better. In the high speed twin roll caster (HSTRC) of the present study, casting of mushy solidification type aluminum alloy is easier than skin formation solidification type aluminum 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. This shows that there is no problem in the high speed roll casting of Al-3%Si-0.6%Mg 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. When the roll speed was 90 m/min, the surface condition was better than the surface of the strip cast at 60 m/min. 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. The surface of the strip cast at superheat of 50 ^{O}C was worse than that the strip cast at superheat of 15 ^{O}C. The oscillation of the meniscus might be remarkable. Starting point of the solidification was not steady and oscillation remarkable mark occurred. The low superheat casting was suitable to make surface fine. When the Si content was less than 2mass% or greater than 4mass%, the oscillation mark of the meniscus did not occur. When the Si content w3mass%, solidification type was neither skin formation nor mushy solidification type. Content of Si influenced the metallic luster of the strip surface. The metallic luster of Al-3%Si-0.6%Mg became higher than that of 6016 as Si content increased. This is the effect of the Si. The oscillation mark was no problem to cast strip of Al-3%Si-0.6%Mg continuously. When the melt head was set longer, the strip surface showed the improvement condition. Because the stastic pressure became high and the oscillation mark of the meniscus was inhibited by the hydrostatic pressure. There were no defects made by the influence of Si content on the strip surface.

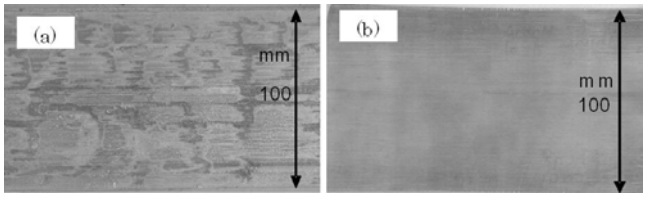

Fig.2. Surface of Al-3%Si-0.6%Mg strip. (a) as cast 60 m/min, superheat 15 ^{O}C, (b) cold rolled strip

3.2. Cold rolling of cast strip

The as-cast strip could be cold-rolled down to 1.0 mm without the homogenization and the intermediate annealing. On the other hand, the cracks occurred when the ingot cast using insulator mold 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, and the surface of the strips had metallic luster. The surface of the strip after cold rolling was shown in Fig.2.

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, and there was no interface at center between the upper and lower solidification layers like the CTRCA. This tendency was not affected by the content of the Si. The low superheat casting and small load of the rolls affect the characteristic of the microstructure. This is the characteristic of the strip cast by the HSTRC. Enlarged view of the microstructure of the cross section was shown in Fig. 3 (b) and (c). The microstructure of the center area was spherical structure. This structure was typical microstructure of the low superheat or low solidification rate 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 shown in Fig. 3 (d) and (e). Modifying treatment of the eutectic Si was not operated. However, the eutectic Si became spherical. This is the effect of high cooling rate at the solidification. There was no difference in the size and morphology of the eutectic Si between the middle and the surface. This fine eutectic Si contributed to the improvement of the ductility. The microstructure became almost uniform at thickness direction after cold rolling and T4 heat treatment as shown in Fig 4 (b).

3.4. Mechanical properties

Mechanical properties were investigated by the180 degrees bending test and the tension test. Figure 4 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. The Si content affects the result of the 180 degrees bending test. The Si content was restricted under 1.5 mass% to prevent the occurrence of the crack. Usually, the crack occurs at outer surface of the strip contains 3mass%Si after 180 degrees bending. However, crack did not occur at the plate cast using by the HSTRC. This was the effect of fine and spherical eutectic Si. The occurrence of the crack depends on size and shape of the eutectic Si. The crack does not occur when the eutectic Si is fine and spherical. The eutectic Si became fine and spherical by the effect of rapid solidification of the HSTRC. As the result, the crack did not occur.

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 retrogession heat-treatment is introduced to improve the crack. If the retrogession heat-treatment is permitted in the production system, the content of Si can be increased more than 4 mass%. The castability becomes better as the Si content increases.

The result of the tension test was shown at Table 1. 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.

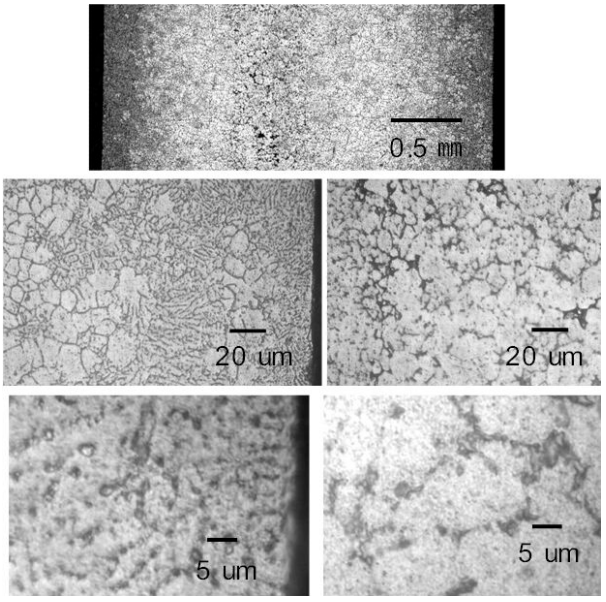

Fig. 3. Microstructure of as-cast Al-3%Si-0.6%Mg strip cast at 60 m/min and 15^{O}C of superheat. (a) cross section of as cast strip, (b) near surface, (c) middle of thickness direction, (d)eutectic Si near surface, (d)eutectic Si in the middle of the thickness direction

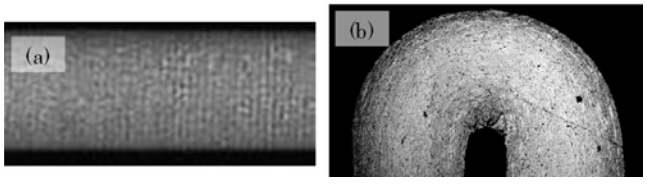

Fig. 4. Result of 180 degrees bending. Thickness was 1mm and heat treatment was T4. (a) outer surface, (b) cross section

Table 1
Result of the tension test. Gage length was 50 mm, and thickness was 1mm. (T4 heat treatment) 4 hours at 540^{O}C, water-quench. (T6 heat treatment)after T4, strip was kept for 6 hours at 160°C

Heat treatment	Tensile stress [MPa]	Proof stress [MPa]	Elongation [%]
T4	211	108	32.6
T6	299	220	20.2

4. Conclusions

The strip of Al-3%Si-0.6%Mg could be cast by the high speed twin roll caster (HSTRC) at the speed up to 90 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 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. The eutectic Si was smaller than 5 um. In the 180 degrees bending of the 1mm-thick T4heat-treated strip, the crack did not occur at outer surface. The elongation of the 1mm-thick T4heat-treated strip was 32.6%. These result show that there is 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, J .Mate. Process, Technol., 172 (2006) 271-276.
[6] T. Haga, S.Suzuki, Roll casting of aluminum alloy strip by melt drag twin roll caster, ibid., 118 (2001)165-168.
[7] T. Haga, S.Suzuki, Melt ejection twin roll caster for the strip casting of aluminum alloy, ibid., 137 (2003)92-95.
[8] T. Haga, S.Suzuki, Strip casting of A5182 alloy using a melt drag twin roll caster, ibid.,133(2003)103-107.
[9] T. Haga, S.Suzuki, Study on high-speed twin-roll caster for aluminum alloys, ibid.,143(2003)8
[10] T.Haga, K.Takahashi, M.Ikawa, H.Watari, Twin roll casting of aluminum alloy strips, ibid., 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, J.Mater. Process.Technol.,130(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.