Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 18
ISSUE 1-2
September–October
2006

High speed twin roll casting of 6016 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: of this paper is to clear the possibility of high speed roll casting of thin aluminum alloy strip. 6016 aluminum alloy is used for sheet metal of the automobile. Therefore, casting of 6016 was tried in this study. Castability and characteristics of roll cast 6016 strip were investigated.
Design/methodology/approach: was a high speed twin roll caster. The high speed twin roll caster was designed to overcome the low castability of the twin roll caster.
Findings: are as below. The 6016 could be cast at speed of 60 m/min. The thickness of the 6016 was 3 mm. The microstructure at as-cast and after T6 heat treatment was shown. The microstructure was very fine by the effect of the rapid solidification. The mechanical properties were investigated by the tension test and 180 degrees bending test. The as-cast strip could be cold rolled down to 1 mm without homogenization. The result of tension test (gage length 50mm) of T4 strip was as below, tensile stress was 242 MPa, proof stress was 123 MPa and elongation was 26%. There was no crack at the outer surface of 180-degree-bent strip until contact. This shows the strip endure the hem forming.
Research limitations/implications: is the width of the strip was 100 mm. The test using a large scale twin roll caster must be operated.
Practical implications: are as below. The mechanical properties of the roll-cast 6016 were enough for the sheet metal for the automobile. The low productivity of the twin roll caster could be improved, and economy 6016 strip was able to produce.
Originality/value: is that 6016 strip could be cast at speed 60 m/min and this strip had good mechanical properties.
Keywords: Casting; High speed twin roll casting; Strip casting; Sheet metal

1. Introduction

The fuel consumption of the automobile must be better for the environmental protection of the earth. The light weight has great advantage for the decrease of the fuel consumption. The amount of aluminum alloy sheet used for the automobile is increasing. However, the use of the aluminum alloy sheet has disadvantage in the point of cost and formability. The aluminum alloy sheet is more expensive than steel sheet. The formability of the aluminum alloy sheet is poor than that of the steel sheet. Especially, high price is very important problem to be solved immediately. They say the continuous casting has the ability to solve the problem of high cost of the aluminum alloy sheet. In the continuous casting, a belt caster, a block caster and a twin roll caster are representative.

The twin roll caster has an advantage that the cooling rate of the roll cast strip is high than that of other two kinds of continuous caster. The cooling rate of the roll cast strip reached up to 700°C/s. The ability of rapid solidification is very useful to improve the properties of the strip. For example, intermetallic impurities become very fine and be dispersed. This means that the twin roll caster is can be used for recycled aluminum alloy. This reason is that the deterioration caused by the impurity can be improved, as the impurity becomes fine. The eutectic Si becomes fine by the rapid solidification, too. This means the roll cast strip is suitable for hem forming. The hem forming is operated to the edge of the plate; the edge is bent at 180 degrees. When the eutectic Si is large and not spherical, the crack occurs at the outer surface when the hem forming is operated.

In this way, the twin roll caster has some advantages. However, the twin roll caster has disadvantages, too. For example, they are slow casting speed and limitation of castable alloy. The casting speed of the conventional twin roll caster for aluminum alloy is slower than 6 m/min. Usually, the casting speed is 1 or 2 m/min. The casting speed must be increased to increase the productivity. If productivity increased, the economy sheet can be made. High Speed Twin Roll Caster (HSTRC) was devised in order to break through the problem of low productivity [1-5].

6016 is one of the typical 6000 series aluminum alloys for sheet of the automobile [6-11]. In the present study, high speed casting of 6016 at 60 m/min was tried. Castability of 6016 by the HSTRC was investigated. Tension test and 180 degrees bending test were operated to investigate the mechanical properties of cast strip.

2. Experimental conditions

A high speed twin roll caster is shown in Fig.1. In the present study, low super heat casting was tried. A cooling slope was used for the low superheat casting [12-15]. The cooling slope is very simple, and mounting of the cooling slope on the twin roll caster is very easy. Experimental conditions are shown in Table 1.

2.7kg of 6016 alloy was melted in the electric furnace. 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 5 m/min. Therefore, this casting speed is very high. The rolling road was 0.07 and 0.14 kN/mm (per unit width). The tension test and 180 degrees 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. 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 of the high speed roll casting

Roll material	copper, diameter 300 [mm], width 100 [mm], speed 60 [m/min]
Aluminum alloy	6016 super heat is lower than 15°C
Cooling slope	mild steel, length 300 mm, width 100 mm inclination angle 60°
Separating force	0.07, 0.14 kN/mm (per unit width)
Solidification length	100 mm
Melt head	100 mm

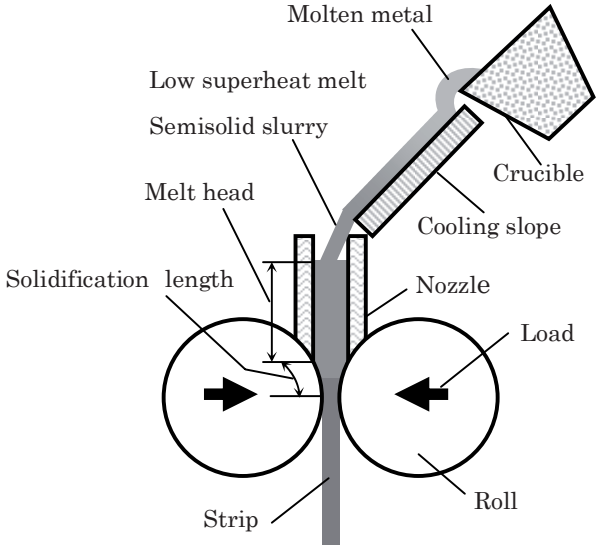

Fig. 1. Schematic illustration of the experimental apparatus

3. Result and discussions

3.1. Roll casting of 6016

The 6016 could be cast into the strip at the speed of 60 m/min. The ability of high speed roll casting of 6016 was poor than A356 or 4045. Immediately release of the 6016 strip from the roll, the 6016 strip was brittle and attention was paid not to be bent. However, A356 and 4045 are not broken easily like 6016. This reason is that the mushy solidification type alloy is not so brittle like the skin formation solidification type alloy at the temperature around the solidus line.

In the CTRCA, casting of skin formation solidification type alloy like 1050 and 3003 is easy, and mushy solidification type alloy like A356 and 4045 is difficult. In the skin formation

solidification type alloy, the flow stress in semisolid condition is large at low solid fraction. Therefore, load of the hot rolling reaches some mount of force and heat transfer between the roll and metal becomes effective to cool the metal in some area at the roll bite. On the other hand, in the mushy solidification type alloy, the flow stress in semisolid condition is small until high solid fraction. Therefore, load of the hot rolling is too small, and the heat transfer between the roll and metal does not become effective to cool the metal. The cooling ability of the roll of the CTRCA is not large enough to solidify the mushy solidification type alloy.

In the high speed twin roll caster (HSTRC) of the present study, load of the roll is not large enough to roll the skin formation solidification type alloy at semisolid. Therefore, the area, in which the heat transfer between the roll and metal is effective, does not exist. As the result, the strip can not be cooled enough. The cooling ability of the roll of the HSTRC is large enough to solidify the mushy solidification type alloy.

The surface of the as-cast strip and the surface after cold-rolling are shown in Fig.2. The width of the as-cast strip was as same as the width of the roll. There was no crack at the edge of as-cast strip, as the strip was not hot rolled. The surface of the as-cast 6016 strip had metallic luster. There were small grooves kike scratched in the casting direction. These small grooves were formed at the point where the nozzle contacted to the roll. there were small dents, too. These are shrinkage. The shrinkage was affected by Si content. The shrinkage becomes smaller as the Si content becomes greater. These surface defects could be improved by the cold-rolling.

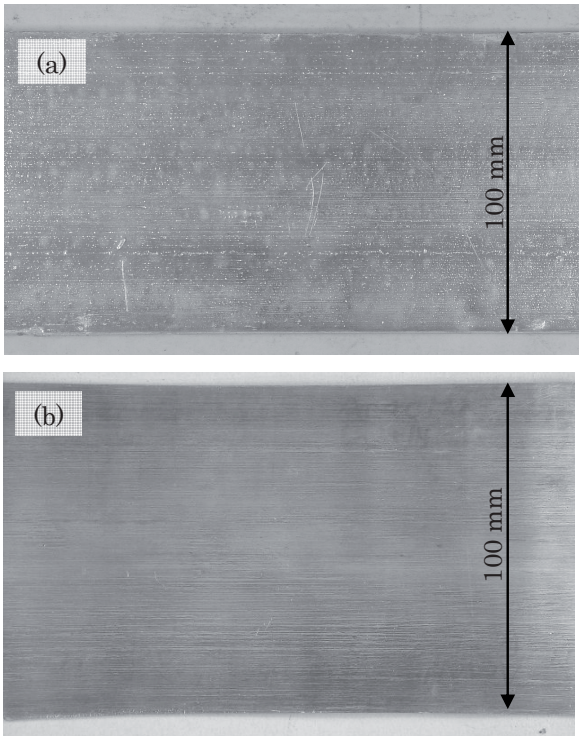

Fig. 2. Surface of 6016 strip cast by HSTRC. (a) as cast strip, (b) after cold rolling of (a)

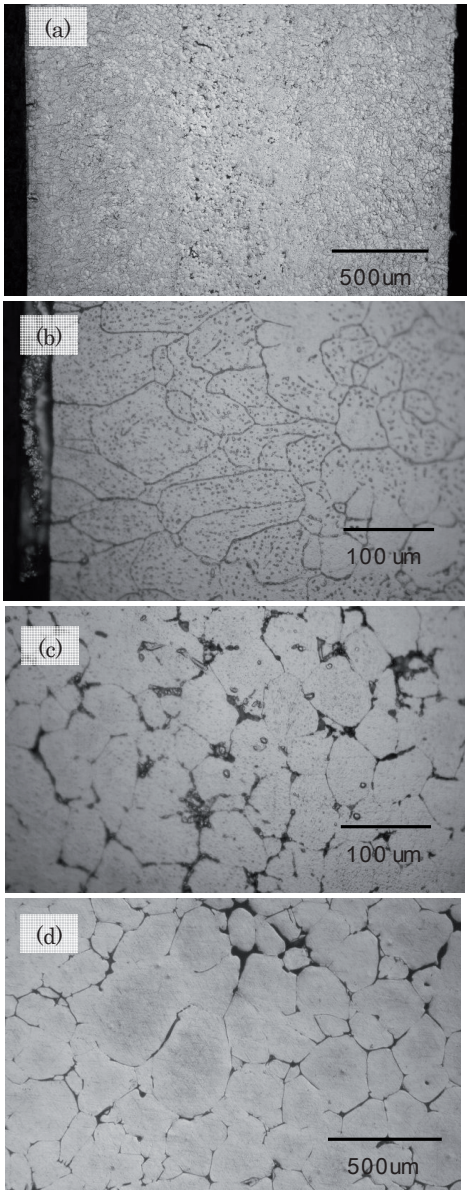

Fig. 3. Microstructure of as-cast 6016 alloy (a) cross section of as-cast 6016 strip, (b) enlarged view of near the surface of (a), (c) enlarged view of center area of (a), (d) ingot cast by insulator mold

3.2. Microstructure

Figure 3 shows microstructure of the cross section of the as-cast strip. It is clear that the microstructure of the roll-cast 6016 was very fine by the effect of the high cooling rate comparing with insulator mold casting. The microstructure was not uniform at thickness direction. The center area was different from other areas. 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. This duplex structure was typical microstructure of the low solidification rate semisolid casting.

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 is the characteristic of the strip cast by the HSTRC. The non-uniformity of the microstructure at thickness direction was improved after cold rolling and T4 heat treatment. The grain of near surface was smaller than middle area of thickness direction.

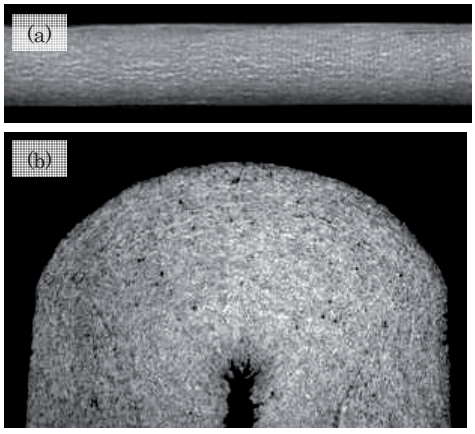

Fig. 4. Result of the 180 degrees bending of the T4 heat treated strip. Thickness of the strip was 1mm. (a) outer surface, (b) cross section

Table 2.
Result of tension test of roll-cast 6016

Heat treatment	Tensile stress	Proof stress	Elongation
T4	245 MPa	125 MPa	27 %
T6	293 MPa	230 MPa	23 %

3.3. Mechanical properties

Mechanical properties were investigated by the tension test and 180 degrees bending test. The result of the tension test was shown at Table 2. The result of the tension test of the roll cast 6016 strip was almost as same as the result of strip made from DC cast slab. 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. Thickness of the strip was 1mm, and heat treatment was T4. Crack did not occur at outer surface of 180 degree-bent-strip. The roll cast 6016 strip using the HSTRC has ability to be used for press forming.

4. Summary

6016 aluminum alloy could be cast into the strip of 3 mm thickness by a high speed twin roll caster (HSTRC) at speed of 60 m/min. Productivity of the HSTRC was more than 10 times greater than that of the conventional twin roll caster for aluminum alloy (CTCRA). The HSTRC has possibility of the production of the economy 6016 sheet. As cast strip could be cold-rolled down to 1mm without homogenization. T4 heat-treated strip of 1 mm thickness could be bent until 180 degrees without cracks at outer surface. The strip cast by the HSTRC has ability to be used for press forming.

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