Aluminum Alloys: Fabrication, Characterization and Applications II
Edited by: Weimin Yin, Subodh K. Das, and Zhengdong Long
TMS (The Minerals, Metals & Materials Society), 2009

Development of twin-belt cast AA5XXX series aluminum alloy materials for automotive sheet applications

P.Z. Zhao[1], T. Anami[1], I.Okamoto[1], K.Mizushima[1],K.M.Gatenby[2], M.Gallerneault[2], S.Barker[2]
K.Yasunaga[3], A.Goto[3], H.Kazama[3], N.Hayashi[3]
[1]Nippon Light Metal Company, Ltd. NRDC. 1-34-1 Kambara, Shimizu-Ku, Shizuoka-City, Shizuoka-Ken, 421-3203, Japan
[2]Novelis Global Technology Center. Box 8400,945 Princess Street, Kingston, Ontario, K7L5L9, Canada
[3]Honda R&D Co., Ltd. 4630 Shimotakanezawa, Haga-machi, Haga-gun, Tochigi, 321-3393, Japan

Keywords: Twin-belt cast, AA5XXX, Automotive sheet, Microstructure, Stretchability.

ABSTRACT

Process routes for 5XXX series aluminum alloy sheet produced with an advanced twin-belt caster (FLEXCASTER™) have been successfully trialed, and are now in production. The FLEXCAST™ 5XXX sheet has finer intermetallic compounds and grains compared to conventional DC processed 5XXX aluminum alloy sheet, as a consequence of the higher cooling rate during solidification. Optimization of composition and refinement of microstructure has resulted in superior dome stretchability and lower susceptibility to SCC than DC5182 sheets. Moreover, FLEXCAST 5XXX aluminum alloy sheet shows good performance in adhesive bonding and coating tests, critical for automotive structural parts.

INTRODUCTION

In an ongoing effort to reduce the impact on the global environment, automotive companies world wide are making substantial efforts to reduce gas emissions from their vehicles. Reducing the vehicle weight is one of the ways being used to achieve this objective. Aluminum alloys have great potential for replacing steel in automotive applications because of its light weight and ease of recycling [1]. However, formability of aluminum alloy sheets is generally inferior to steel, limiting its application in the automotive industry. Therefore, development of aluminum sheet with excellent formability is needed. In addition, an environmentally friendly fabrication route with reduced energy consumption is required to produce aluminum alloy sheet for mass–produced vehicles. Continuous casting technologies are being developed to meet this need [2,3]. Twin-belt casting is one of the more promising fabrication methods. In particular, the high cooling rate during solidification produces finer intermetallic compounds and grain sizes than with DC cast ingots, resulting in improved formability.

A 1st generation twin-belt casting process was successfully trialed for producing AA5182 aluminum alloy sheets for automotive parts [4]. However, hot rolling was necessary due to the thick slab gauge. Recently, an advanced twin-belt caster (FLEXCASTER™) has been set up by Nippon Light Metal Company to cast thinner gauge slabs without the need for hot rolling [5].

The objective of this study is to develop FLEXCAST™ 5XXX series aluminum alloy sheets for automotive applications. Microstructure, formability, stress corrosion cracking, adhesive bonding and coating performance, critical for automotive structural parts, are evaluated and compared with conventional DC processed materials.

EXPERIMENTAL PROCEDURES

Preparation of materials

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **FEB 2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**

4. TITLE AND SUBTITLE **Development of twin-belt cast AA5XXX series aluminum alloy materials for automotive sheet applications**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Nippon Light Metal Company, Ltd. NRDC,1-34-1 Kambara,Shimizu-Ku, Shizuoka-City,Shizuoka-Ken, 421-3203, Japan,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002300. Presented at the Minerals, Metals and Materials Annual Meeting and Exhibition (138th)(TMS 2009) Held in San Francisco, California on February 15-19, 2009. U.S. Government or Federal Purpose Rights.

14. ABSTRACT
Process routes for 5XXX series aluminum alloy sheet produced with an advanced twin-belt caster (FLEXCASTERTM) have been successfully trialed, and are now in production. The FLEXCASTTM 5XXX sheet has finer intermetallic compounds and grains compared to conventional DC processed 5XXX aluminum alloy sheet, as a consequence of the higher cooling rate during solidification. Optimization of composition and refinement of microstructure has resulted in superior dome stretchability and lower susceptibility to SCC than DC5182 sheets. Moreover, FLEXCAST 5XXX aluminum alloy sheet shows good performance in adhesive bonding and coating tests, critical for automotive structural parts.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

The chemical compositions of alloys used in this study are listed in Table 1. The FLEXCAST 5XXX sheet was cast with cooling rates in the range of 20-150°C /s.

Table1 Compositions of aluminum alloys used in the present study (mass%).

I.D.	Mg	Fe	Si	Mn	Cr	Ti	Al
FLEXCAST 5XXX	3.37	0.20	0.08	0.01	0.01	0.02	Bal.
DC5182	4.65	0.13	0.08	0.21	0.03	0.02	Bal.
DC5052	2.59	0.27	0.09	0.04	0.18	0.02	Bal.

The slab was cold rolled to final gauge (1mm) and then annealed at 460°C on a continuous annealing line. The comparison tests used 1mm thick DC5182 and DC5052 aluminum alloy sheets fabricated via a conventional DC process.

Evaluation of properties

Samples were prepared in accordance with shape No.5 in the JIS Z2201 specification. The 0.2% yield strength (YS), ultimate tensile strength (UTS), total elongation (EL), and r-average value at 15% plastic strain were measured by tensile testing specified by JIS Z2241. The stretching limit dome height (LDH) was measured by dome testing with a 100mm diameter hemispherical punch installed in a stamping machine. The test piece dimension was 200mm square, and the forming strain speed was about 1/s. The load-displacement curve was recorded and the displacement corresponding to maximum load was read as LDH.

Stress corrosion cracking (SCC) was also evaluated. To increase the susceptibility to SCC, 1mm sheets were additionally cold rolled to 0.7mm and sensitized at 120°C for 168 hours. They were then bent into a U-shape and immersed in 3.5%NaCl solution at a current density of 6.2mA/cm^2. The time to failure was taken as the SCC lifetime.

To evaluate the bonding performance, samples were bonded using structural adhesive and exposed to salt spray for 480 hours. The shear strength and morphology of fracture gave a measure of the bonding performance.

To evaluate the coating performance, samples were coated with a paint film and then observed after immersion in hot water for 240 hours.

Evaluation of Microstructures

The grain structure of longitudinal sections was observed by polarizing microscope after buff grinding and anodizing. After argon-ion polishing, a detailed analysis of the crystalline orientation was done by SEM-EBSP. Intermetallic compounds were observed by optical microscope and the size was measured with an image analyzer.

β phases precipitated during sensitization were observed in detail after etching the samples in 1%NaOH solution.

The fractures of stretch forming samples were observed by SEM. Shear bands were checked by etching the formed samples in 10% H_3PO4 solution after heating at 120°C for 168 hours.

RESULTS and DISCUSSION

Microstructure

Figure 1 shows the microstructures of the FLEXCAST 5XXX, DC5182 and DC5052 samples. FLEXCAST 5XXX has finer grain structure and intermetallic compounds than either DC5182 or DC5052. The measured average grain size was 10μm, 22μm, 19μm, respectively. The distribution of intermetallic compound particles is shown in Figure 2.

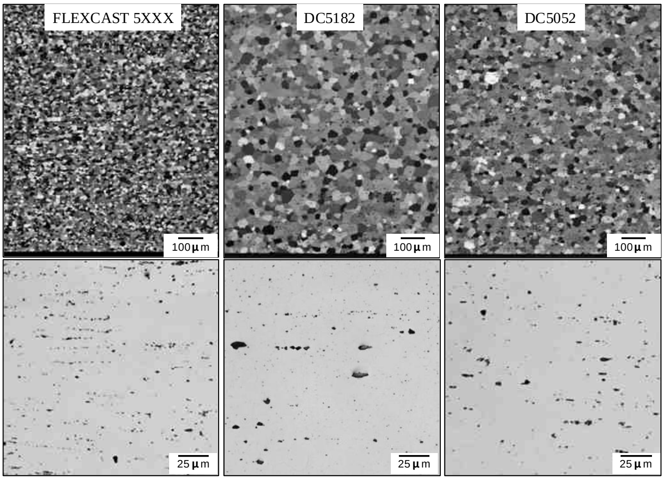


Fig.1 Grain structures and intermetallic compounds in FLEXCAST 5XXX, DC5182 and DC5052 aluminum alloy samples in the longitudinal direction.

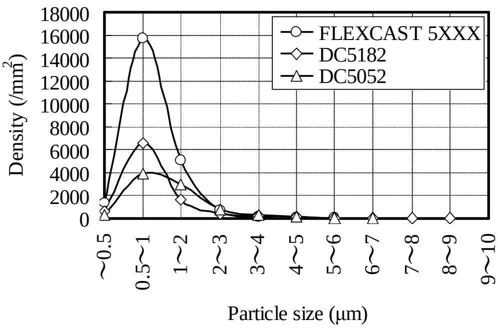


Fig.2 Distribution of intermetallic compounds in FLEXCAST 5XXX, DC5182 and DC5052 aluminum alloy samples.

The FLEXCAST 5XXX sample has a large number of 1μm particles which act as nucleation sites for recrystallization and pinning of the grain boundaries [6], resulting in the fine grain size.

Figure 3 shows the crystalline orientation maps measured by SEM-EBSP. The area fraction of the major orientations are listed up in Table 2. The FLEXCAST 5XXX sample has a higher volume of {112}, {110} and {111} oriented grains than either DC5182 or DC5052, indicating a different mechanism for recrystallization.

The distribution of subgrain and grain boundary misorientation angle is shown in Figure 4. All samples have almost the same distribution of misorientation. 90% of the grain boundaries have a misorientation angle greater than 15 degrees. Therefore, recrystallization can be considered to be almost completed. The size distribution of grains with more than 15 degree misorientation angle is shown in Figure 5. The grain size of FLEXCAST 5XXX is concentrated around 10μm, while the DC5182 and DC5052 samples have a grain size distribution with a peak of around 30μm and 20μm, respectively.

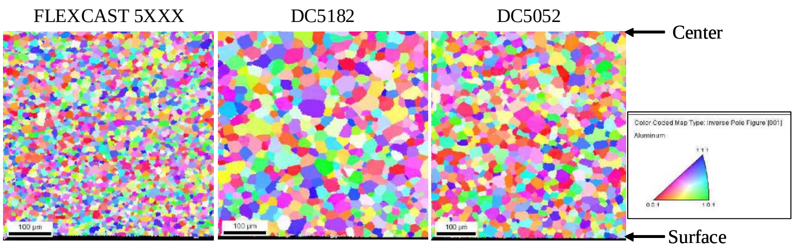
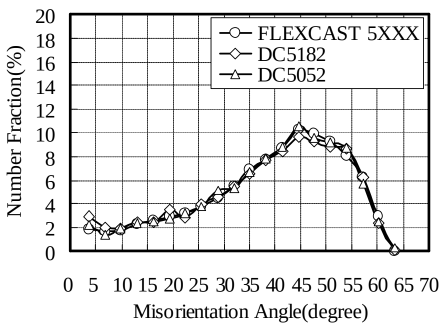


Fig.3 Orientation image maps of FLEXCAST 5XXX, DC5182 and DC5052 aluminum alloy samples in the longitudinal

Table2 Area fraction of major orientation (%).

I.D.	{100}	{112}	{110}	{111}
	11.5	41.2	18.1	14.1
DC5182	12.8	40.4	16.2	11.5
DC5052	16.4	36.2	14.8	8.1



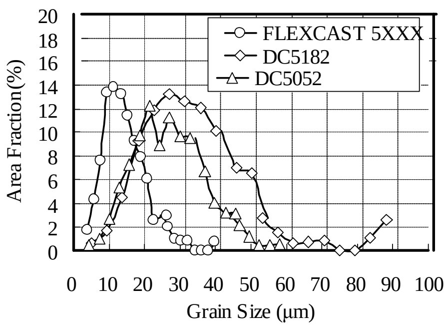


Fig.4 Distribution of grain boundary misorientation angle in FLEXCAST 5XXX, DC5182 and DC5052 samples.

Fig.5 Distribution of grain size in FLEXCAST 5XXX , DC5182 and DC5052 samples.

Mechanical properties and formability

Table 3 summarizes the measured YS, UTS, EL, r-average, and LDH values for the three alloy sets. FLEXCAST 5XXX samples have the highest YS due to the fine grain structure. However, its UTS value was lower than DC5182 due to lower Mg concentration. The r-average value of FLEXCAST 5XXX samples was higher than DC5182 and DC5052 due to the higher volume of {112}, {110}, and

{111} oriented grains.

Table3 Tensile properties and stretching formability of 1mm gauge sheets.

I.D.	YS (MPa)	UTS (MPa)	EL (%)	r-avg	LDH (mm)
FLEXCAST 5XXX	130	235	29	0.80	30.5
DC5182	118	260	29	0.66	29.5
DC5052	101	204	27	0.65	27.4

Surprisingly, the LDH value for FLEXCAST 5XXX was higher than DC5182. In order to understand the difference, the section of broken samples were observed in detail after dome testing. The results are shown in Figure 6. Shear bands in FLEXCAST 5XXX were not as visible due to the lower Mg concentration and finer grain size. Figure 7 shows the morphology of fracture. The FLEXCAST 5XXX sample has smaller dimples than DC5182, indicating that the smaller intermetallic particles suppress void nucleation and growth.

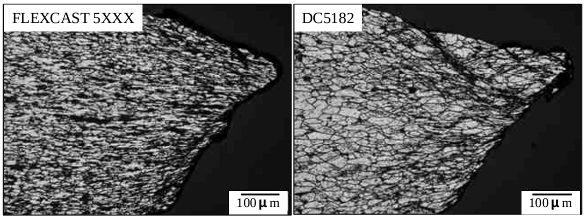


Fig.6 Shear bands observed in FLEXCAST 5XXX and DC5182 samples after dome testing. Shear bands are clearly visible in DC5182.

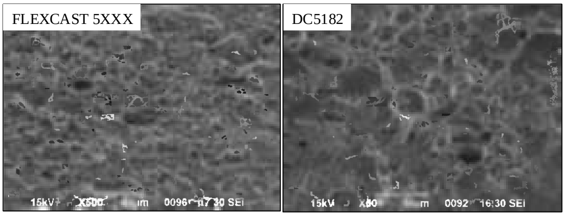


Fig.7 Fracture of FLEXCAST 5XXX and DC5182 samples after dome testing. Dimples in FLEXCAST5XXX are much smaller than in DC5182.

Stress corrosion cracking

Figure 8 shows the appearance of the SCC test pieces for FLEXCAST 5XXX and DC5182 samples after 960 minutes and 10 minutes, respectively. Rupture in FLEXCAST 5XXX samples occurred at the boundary between the aluminum sample and insulation seal, where current density is highest. In contrast, DC5182 samples failed at the top of the loop where stress is considered to be maximum.

FLEXCAST 5XXX DC5182

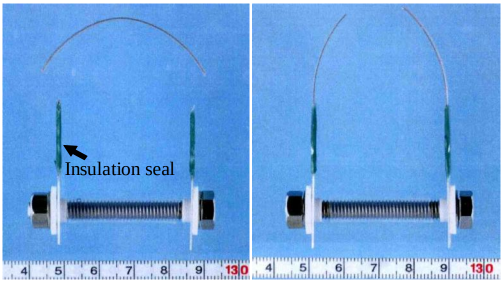


Fig. 8 Appearance of test samples after SCC testing.

Micrographs of the fractured surfaces are shown in Figure 9. DC5182 shows the typical SCC morphology, while FLEXCAST 5XXX shows many etch pits, indicating the sample was broken by metal dissolution rather than by SCC. β phases precipitated during sensitization are shown in Figure 10. It is obvious that the precipitate morphology at the grain boundaries differs between FLEXCAST 5XXX and DC5182 samples. The former precipitates β phases in the form of particles, while the latter precipitates β phases as a film. This is the reason why DC5182 was more susceptible to SCC [7].

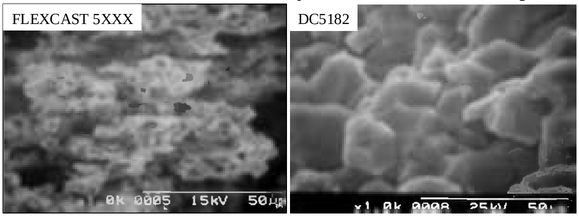


Fig.9 SEM photos of fracture after SCC testing.

FLEXCAST 5XXX DC5182

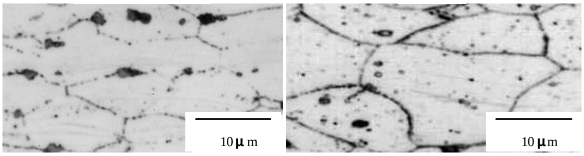


Fig.10 β phases precipitated along grain boundaries after sensitization

C h .

Adhesive bonding and coating performance

Table 4 summarizes the results of adhesive bonding and coating performance tests with FLEXCAST 5XXX and DC5XXX samples containing the same amount of Mg. They have almost the same shear strength and same cohesion failure model after salt solution spray testing, demonstrating that the adhesive bonding performance of FLEXCAST 5XXX is equivalent to that of DC 5XXX. In addition, both materials show good coating performance based on the results of adhesion testing in hot water.

Table4　Evaluation results of adhesive bonding and coating performance.

I.D.	Adhesive bonding	Coating
	Shear strength / Morphrogy of fracrture (salt spray for 480hr)	Adhesion of coating film (immersion in hot water for 240hr)
FLEXCAST 5XXX	12MPa/cohesion failure	GOOD
DC5XXX	11MPa/cohesion failure	GOOD

Stamping trials

FLEXCAST 5XXX aluminum sheet has been used successfully to stamp the HONDA hood inner of a ACURA RL, as shown in Figure 11. This was the first trial application of FLEXCAST 5XXX for automobile manufacturing, and the material is now in production. FLEXCAST 5XXX is expected to be used to manufacture other automotive parts in the future.

Fig.11　Hood inner of a ACURA RL stamped from FLEXCAST 5XXX aluminum alloy sheet.

CONCLUSIONS

(1) FLEXCAST 5XXX aluminum alloy sheet has finer intermetallic compounds and grains than conventional DC5XXX sheet. This is a consequence of the high cooling rate during solidification.
(2) Optimization of composition and refinement of microstructure of FLEXCAST 5XXX aluminum alloy sheets results in superior dome stretchability and lower susceptibility to SCC than DC5182.
(3) FLEXCAST 5XXX aluminum alloy sheet shows good adhesive bonding and coating performance.

REFERENCES

1. Aluminum International Today, January/February, 2004, 21-30.
2. S.Kim and A.Sachdev:Aluminium Alloys: Fabrication,Characterization and Applications, *TMS*, (2008),51-59.
3. M.Gallerneault and J.D.Lloyd: *EUROMAT2001*,Rimini,Italy,2001.
4. P.Z.Zhao, T.Moriyam, K.Yasunag and N.Hayashi: Proceeding of the 97th Japan Institute of Light Metal, (1997), 209-210.
5. Press release by Nippon Light Metal Company, Ltd., 2004.
6. F.J.Humphreys: Acta Met., 25 (1977), 1323-1344.
7. E.H.Dix, W.A.Anderson and M.Byron Shumaker: Corrosion, 15 (1959), 19-26.