

The continuous casting of aluminium automotive alloys

M. Gallerneault, D. Lloyd

The present aluminium automotive alloys are 5000 series Al-Mg alloys for the inner structural applications and 6000 series Al-Mg-Si alloys for outer skins. The DC casting of thick ingot conventionally produces both series of alloys, but they can also be cast continuously as thinner gauge slab. In this paper the continuous casting of a 5000 series alloy on a belt cast is considered. By modelling the fluid flow and thermal history associated with continuous casting, the as-cast slab microstructure can be anticipated, and the response of this microstructure to subsequent processing can be investigated. Since continuously cast slab is unhomogenized prior to fabrication, and the fabrication route is very different to that associated with DC cast material, differences in microstructure and final mechanical properties might be expected. The present paper suggests that while there are differences in behavior between DC and CC sheet, the latter has considerable potential in automotive applications.

Parole chiave: alluminio e leghe, colata continua, modelli

INTRODUCTION

The Al-Mg 5000 series alloys and the Al-Mg-Si 6000 series are finding increasing application in automotive structures and skins [1-3]. High levels of formability are required for structural applications, which is the reason for using 5000 series alloys, whereas higher strength, good corrosion resistance, and a high quality surface finish are required for outer skin panels. The 6000 series alloys, which exhibit age hardening during the paint bake, develop higher strengths than 5000 series alloys, and are more appropriate for outers. The sheet is usually produced by Direct Chill (DC) casting of large ingots, which are subsequently scalped, homogenized, and then hot and cold rolled to gauge, prior to final heat treatment.

An alternative production route is by continuous strip casting (CC), which produces an as-cast slab requiring less processing to achieve the final gauge. However, along with the simplification of the CC processing route there are several factors that need consideration:

- (1) CC material is not scalped after casting, which means that the as-cast surface persists through to the final product.
- (2) CC material is not homogenized, so that the microstructural changes which normally occur during homogenization – modification of as-cast intermetallics, removal of solute concentration gradients etc – have no opportunity to occur in CC processed strip.
- (3) The extent of hot and cold rolling is more restricted in CC strip because the initial as-cast gauge is closer to the final strip gauge. As a result there is less opportunity to modify the as-cast microstructure in CC material.

The limited application of continuous casting for more complex alloys and applications that are demanding in terms of mechanical property performance, is mainly due to these three factors. This paper considers continuous casting of AA5754 on a laboratory scale Alcan Belt Caster (ABC), which produces slab at 12mm gauge and 0.5m wide.

EXPERIMENT

AA5754, with a nominal composition of Al-3wt%Mg-0.2wt%Mn-0.1wt%Si-0.2wt%Fe, was cast at 5m/min to produce 12mm thick slab. The slab was reheated to 500°C and rolled to different final gauges, followed by annealing to produce O-Temper final sheet. Microstructure and mechanical properties were examined.

BELT CASTING

Fig. 1. is of the laboratory twin belt caster. The caster shares much in common with its commercial counterpart [4], but has evolved significantly in terms of mechanical stability of the belt, data acquisition and a number of other process improvements. This facility is capable of producing commercial quality slab over a range of slab thickness and casting speeds. A computational fluid dynamic model of the fluid and heat transfer in the caster invaluable contributes to our ability to produce continuously cast ingot with a high quality as-cast surface. Using both microscopic and macroscopic models it is possible to analyze the microscopic and bulk

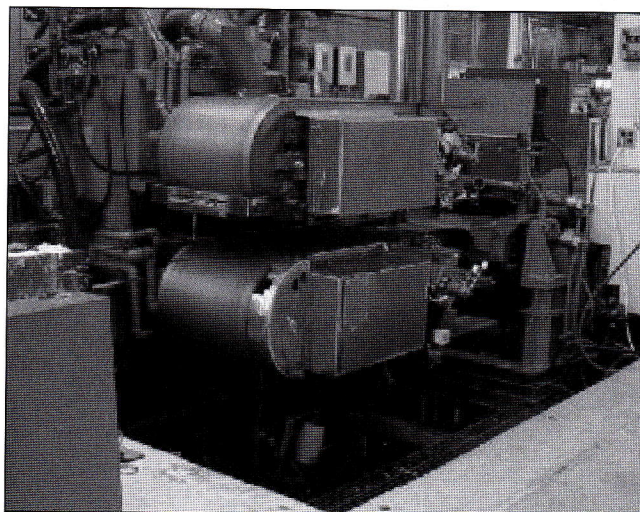


Fig. 1 Laboratory Twin Belt Caster

Fig. 1 Macchina da colata di laboratorio a due cinghie

Mark Gallerneault, David Lloyd
Alcan International, Ontario, CANADA

Paper presented at the 7th European Conference EUROMAT 2001,
Rimini, 10-14 June 2001

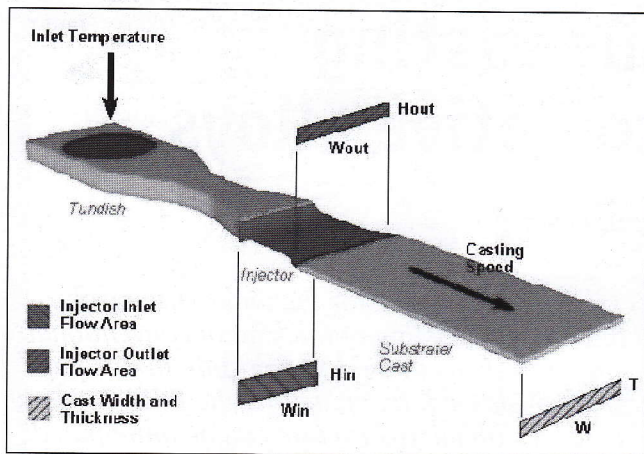


Fig. 2. Solution Space of Macro Model

Fig. 2 Spazio di soluzione del macro modello

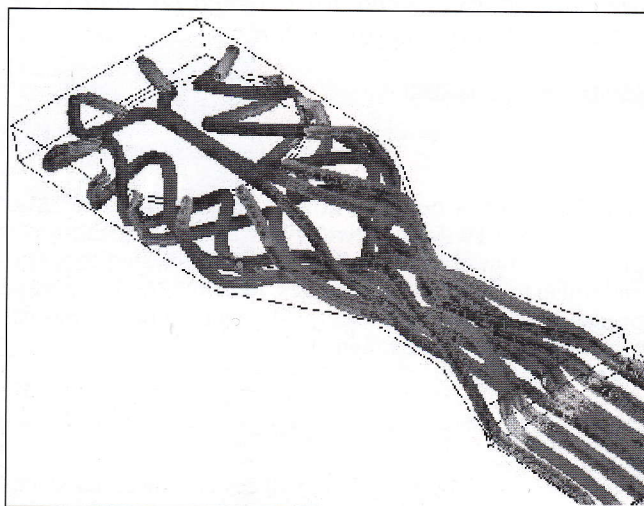


Fig. 3. Streamline Flow from Macro Model

Fig. 3 Linea di flusso ottenuta con il macro modello

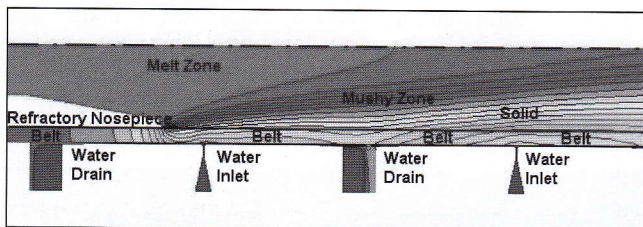


Fig. 4. Temperature Field from Micro Model

Fig. 4 Campo di temperature ottenuto con il micro modello



Fig. 5. a) As-Cast Plan View

b) Transverse at Surface

c) Transverse at Centreline

Fig. 5. a) Vista in piano della superficie As-Cast

b) Sezione trasversale alla superficie

c) Sezione trasversale lungo l'asse centrale

details of the continuous casting process, including melt delivery, solidification and sensible heat extraction.

By considering a modelling space comprised of only the melt, see Fig. 2., rather than the surrounding structures, it is possible to perform relatively complicated analyses in reasonable periods of time, typically only a few hours on a current modeling workstation.

A typical macroscopic model result might describe the flow distribution inside the melt injector system, such as in Fig. 3., to identify regions of restricted or circulatory flow. From the microscopic model, which uses a slightly different approach to solve the heat evolution equation, it is possible to analyze important interactions during the early stages of melt/belt contact [5], Fig. 4.

Regardless of which model is used, using the instrumentation in the laboratory ABC, it is straight-forward to obtain reliable boundary condition values for either of the models. Thus the modeling results tend to be very close to the observations; e.g. predicted temperature values are typically with 2% of measured. Such models make it possible to perform relatively inexpensive software "casts" of the strip casting process; the model also provide us the ability to test various situations where measurements and/or construction of the parts may not be otherwise possible.

It is of utmost importance that the surface of the as-cast in belt cast materials be the highest quality possible; scalping of any surface segregate is not economically viable. Fig. 5.a is an optical micrograph of an unpolished cast surface of AA5754 from the laboratory caster. The fine structure persists through about 40% into the ingot, Fig. 5.b, though there is some coarsening at the cast centerline, Fig. 5.c. The inter-metallic phases in the belt cast material are identical to those in the DC material, except they are finer and vary through the cross-section. There is very little identifiable shrinkage porosity in the cast ingot.

The grain size of the final sheet is a function of the cold work that is applied prior to the re-crystallization/annealing process. By varying the amount of cold work it is possible to obtain a wide range of grain sizes – Fig. 6.a & 6.b. After rolling the inter-metallic particles, especially near the cast centerline, are aligned in the rolling direction.

MECHANICAL PROPERTIES

As noted previously, the degree of working has a major influence on the final microstructure of CC sheet, and the tensile properties in 5000 series alloys are also very dependent on the grain size, which is a function of the cold reduction and annealing conditions. Therefore, the grain size, and hence yield strength, is expected to be a function of the final gauge sheet. Fig. 7. shows the grain structure in the final O-Temper sheet for CC5754, and Fig. 8. the variation in grain size, and corresponding yield strength, for different final gauges.

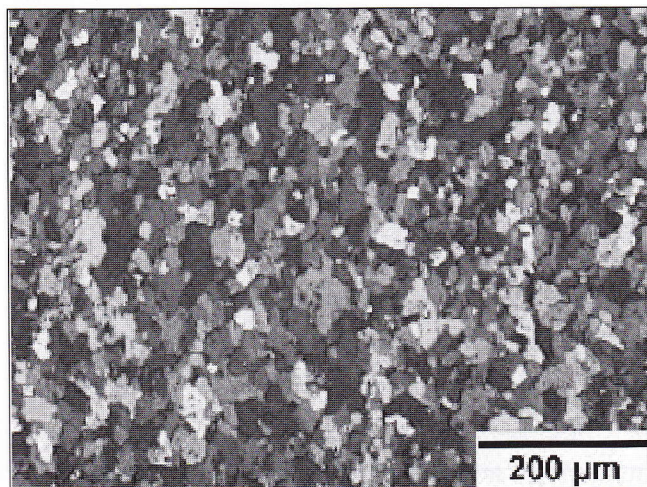


Fig. 6.a) AA5754 with 90% Cold Work

Fig. 6.a) AA5754 con lavorazione a freddo al 90%

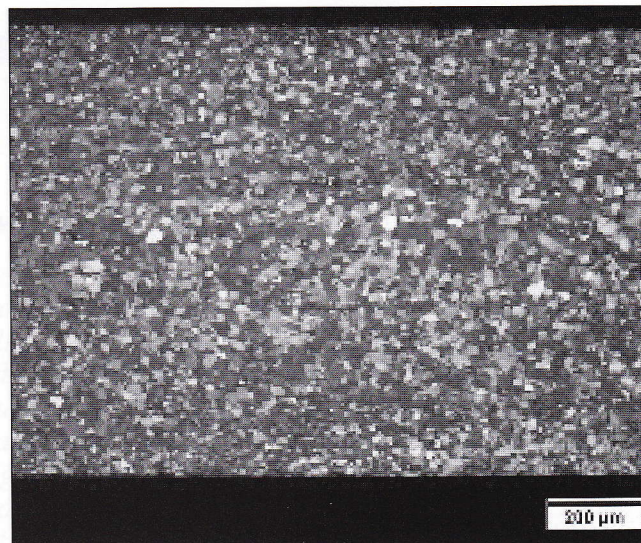


Fig. 7. O-Temper Grains CC5754

Fig. 7. Struttura dei grani; CC5754 nello stato O-Temper

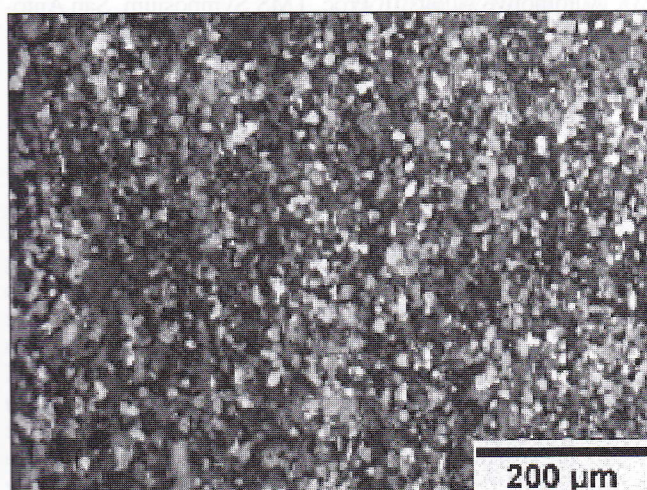


Fig. 6.b) AA5754 with 65% Cold Work

Fig. 6.b) AA5754 con lavorazione a freddo al 65%

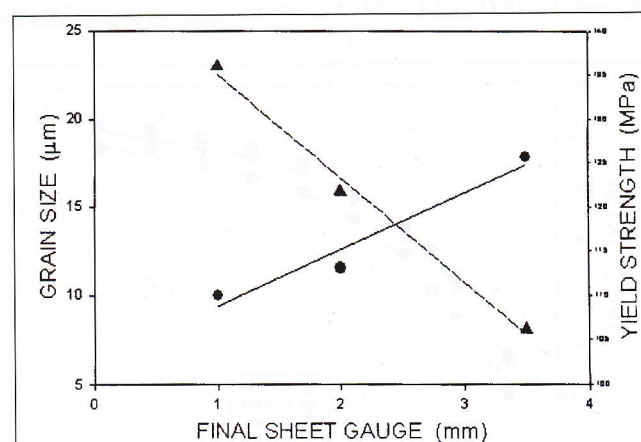


Fig. 8. Grain Size and YS with Final Sheet Gauge

Fig. 8. Dimensione del grano e carico di snervamento in funzione del calibro finale della lamiera

The grain structure tends to coarsen slightly towards the center, but is generally quite uniform. The yield strength is usually considered in terms of the Hall-Petch equation:

$$\sigma_y = \sigma_0 + Kd^{-1/2} \quad (1)$$

where σ_y is the yield strength, σ_0 is the frictional stress, d is the grain size, and K is a constant.

Fig. 9. shows that the yield strength of CC5754 falls on the same plot as DC material, but at finer grain sizes. Reducing the level of cold work, or increasing the annealing temperature can increase the grain sizes of CC material if desired. While the strength of the CC tends to be greater than the conventional DC product, which is a result of the finer grain size, the general stress-strain and work hardening behavior are equivalent, as shown in Fig. 10. The tensile properties are quite isotropic, which is important in regards to forming behavior.

Fig. 11. shows the variation in bendability, expressed as the minimum radius, r , through which the sheet can be bent without fracture, normalized to the sheet thickness, t , for different orientations in the sheet. Conventional DC 5754 has $r_{min}/t = 0$, which the CC material matches at the thinner gauge. In general, the CC material exhibits equivalent, or slightly inferior formability to DC material. Since the microstructural development is a function of the level of work, formability may also depend on gauge, and this is shown in

Fig. 12., for the limiting dome height (LDH). Conventional DC material at 3.5mm would have a LDH of about 44mm.

SUMMARY

The automotive alloy AA5754 can be continuously cast on the Alcan Belt Caster, and the fluid flow associated with the casting process can be modeled. The sheet produced from this process has mechanical properties that are to some extent dependent on gauge, reflecting the transformation of an as-cast microstructure to one more representative of a wrought product.

REFERENCES

- 1) G.B. Burger, A.K. Gupta, P.W. Jeffrey and D.J. Lloyd, "Microstructural Control of Al Sheet Used in Automotive Applications", *Materials Characterization*, 35, (1995), p. 23.
- 2) D.J. Lloyd and A.K. Gupta, "Aluminum Alloys and the Thermal Processing Associated with Automotive Sheet", *THERMEC'97, Int. Conf. on Thermomechanical Processing of Steels & Other Materials*, ed. T. Chandra and T. Sakai, The Minerals, Metals & Materials Society, (1997), p.99.

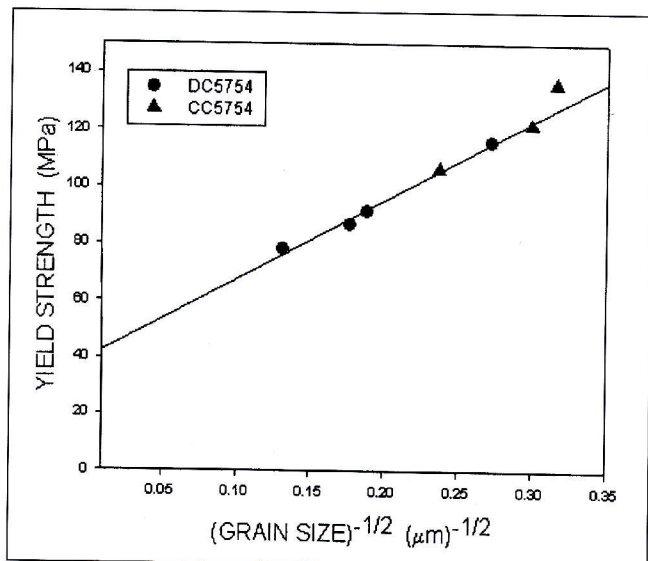


Fig. 9. Grain Size Dependence of YS in DC and CC5754

Fig. 9. Correlazione tra dimensione del grano e carico di snervamento in DC e CC5754

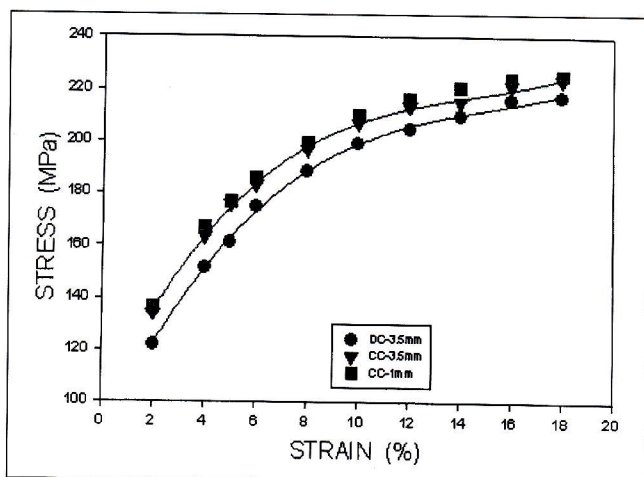


Fig. 10. Stress-Strain Curves for DC and CC5754

Fig. 10. Curve di cedimento per DC e CC5754

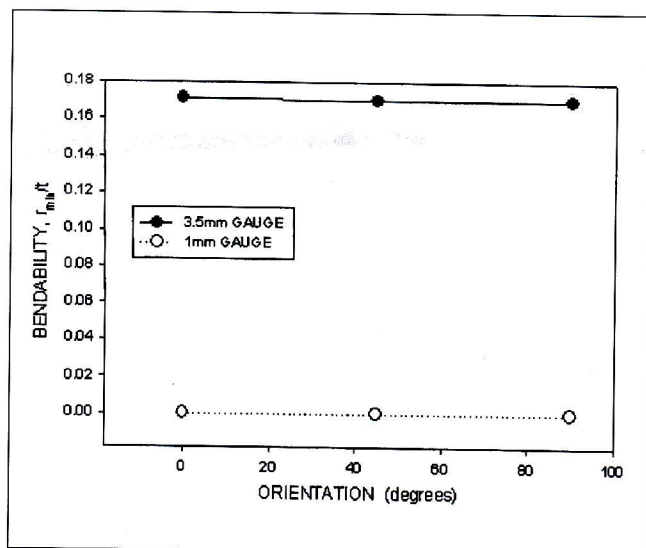


Fig. 11. Bendability with Orientation and Sheet Gauge

Fig. 11. Piegabilità in funzione della direzione di piega e calibro della lamiera

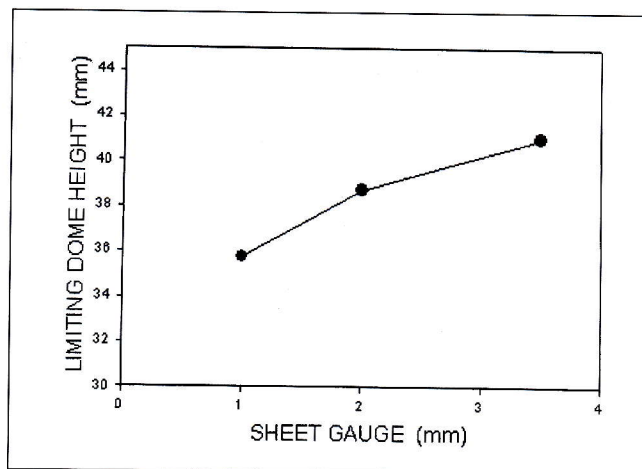


Fig. 12. Variation in LDH with Sheet Gauge

Fig. 12. Variazione del LDH con calibro per lamiera

- 3) Automotive Alloys II, Proc. TMS Symposium, San Antonio, USA, Feb. 16-19, ed. S.K. Das, The Minerals, Metals & Materials Society, (1998).
- 4) G. Leone, Y. D'Anjou and J. Sulzer, Proceedings of Ingot and Continuous Casting Process Technology Seminar for Flat Rolled Products, New Orleans, May 10-12, Aluminium Association, (1989), p.579.
- 5) M. Gallerneault and A. Gerber, "A Surface-Oriented Fluid and Thermal Micro-Model of a Strip Casting Process", Proceedings of the 7th International Conference ICAA7, Aluminium Alloys - Part 1, Virginia, USA, April 9-14, (2000), ICAA-7, Trans Tech Publications, (2000), p.319.

— A B S T R A C T —

LA COLATA CONTINUA DELLE LEGHE DI ALLUMINIO PER L'INDUSTRIA AUTOMOBILISTICA

Le leghe di alluminio attualmente impiegate nell'industria automobilistica sono le leghe Al-Mg della serie 5000 per le applicazioni strutturali interne e le leghe Al-Mg-Si della serie 6000 per le coperture esterne. Solitamente entrambe le serie di leghe vengono prodotte mediante colata diretta in piastroni, ma possono anche essere prodotte mediante colata continua nel caso di lamiere di calibro più sottile. In questa memoria si analizza la colata continua d'una lega di alluminio della serie 5000 su cinghia di colata. Mediante un modello del flusso di fluido e termico della colata continua, possono essere fatte anticipazioni sulla microstruttura della lastra as-cast ed è possibile studiare la risposta di questa microstruttura a successive lavorazioni. Poiché la lamiera colata in continuo non è omogeneizzata prima della laminazione e il processo di fabbricazione è molto differente da quello del materiale prodotto mediante colata diretta, si possono prevedere differenze nella microstruttura e nelle proprietà meccaniche finali. La presente memoria suggerisce che mentre vi sono differenze nel comportamento fra la lamiera prodotta mediante colata diretta e colata in continuo, quest'ultima ha un considerevole potenziale nelle applicazioni automobilistiche. La lega AA5754 può essere colata in continuo sull'impianto di colata a cinghia dell'Alcan e si può elaborare un modello per la quantità di fluido associata al processo del pezzo fuso. La lamiera prodotta mediante questo processo ha proprietà meccaniche che sono fino a un certo punto dipendenti dal calibro, riflettendo la trasformazione della microstruttura as-cast in una più rappresentativa di un prodotto laminato.