Solid State Phenomena
ISSN: 1662-9779, Vol. 285, pp 24-30
doi:10.4028/www.scientific.net/SSP.285.24

Submitted: 2018-07-16
Accepted: 2018-08-14
Online: 2019-01-03

Semi-Solid Casting of Aluminium from an Industrial Point of View

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Keywords: Aluminium, Semi-Solid, Casting, Thixocasting, Rheocasting, Industrial Application

Abstract. Company SAG (Salzburger Aluminium AG) is a supplier of fuel tanks, LNG and hydraulic tanks, air reservoirs and structural applications for the commercial vehicle and automotive industry. The company's expertise is welding but SAG also has a 25 years history in Semi-Solid casting starting in 1993 when the first Thixocasting cell was installed in Lend/Austria. Since then SAG is participating on the diverse casting market and competes with other processes looking for applications for which Semi-Solid processing has a unique selling proposition.
This contribution gives examples of industrialized components and will outline their significant characteristics and advantages in comparison to conventional casting processes. Furthermore the development of Semi-Solid cast components, the production process chain as well as commercial aspects will be outlined.
The bottom line is that usually it is not a single advantage of Semi-Solid casting that will make a product attractive for the customer but a combination of several of them. Moreover it is not just the casting process itself but the efficiency of the whole production process chain that will result in a commercially successful product.

The History of Semi-Solid Casting at SAG

SAG was founded by the Swiss Metallurgical Company (later Alusuisse) in 1897 as one of the first aluminium smelters in middle Europe in Lend, Salzburg, Austria. Until the 1970ies the company produced raw aluminium in the form of ingots, foundry alloys, wrought alloys and carbides. Until then SAG has become a world leading manufacturer in the production of aluminium compressed air tanks and fuel tanks.

In the 1990ies, among other companies like Alu Singen, Stampal and Vforge, SAG started to industrialize Thixocasting of aluminium as a supplement to its portfolio at that time being one of just a very few companies providing feedstock material and readymade casting products [1, 2]. The serial production started with a 840 t Idra die casting machine in 1993. Another Bühler die casting machine was installed in 2001. Until 2009 the production capacity was up to 400.000 pcs per year. Most of the products were structural applications like door hinges and mounting brackets with high demands on strength, ductility and weldability. Other than that an electronic filter housing, parts with high demands on surface quality as well as pressure tight welded applications were produced.

After the economic crisis in 2009 huge production capacities in foundry industry were released making it considerably harder to gain profit from castings. Starting in 2010 the production in Austria was reduced but slowly gained volumes until 2018.

During the recovery phase after the economic crises it became obvious that Thixocasting was not competitive anymore because of a higher premium for the feedstock material that is related to a very limited number of thixo billet suppliers, additional process cost for billet production in comparison to conventional ingots and the impossibility of direct recycling. That's why investigations started on how to industrialize Rheocasting for high volume production. The outcome was the implementation of two Rheocasting cells at the SAG subsidiary Fueltech AB in Ronneby, Sweden using an adjusted Rheometal process [3]. Since 2014 Fueltech produces 3 different components for Volvo Trucks with a maximum annual volume of of 250000 pcs/a [4]. Following the Swedish subsidiary SAG Austria industrialized Rheocasting in 2017.

The production in Sweden focused on thick-walled structural parts for the commercial vehicle industry whereas the production in Austria is specialized in thin-walled castings for welded assemblies as well as pressure tight applications for the automotive industry.

Characteristics of Semi-Solid Cast Components

Fig. 1 shows examples of Semi-Solid cast components that have been industrialized by SAG starting from 1993 until 2018. They have succeeded over competing processes such as HPDC, LPDC, sand casting and forging because of the following advantages:

Lightweight potential resulting from enhanced mechanical properties: By preferably using the hardenable alloy AlSi7Mg the strength of the as-cast material can significantly be increased with T5 heat treatment, that is immediate quenching after casting followed by artificial aging at approx. 180 °C for several hours [5]. In contrast to T6 heat treatment, that is preliminary for gravity, LPDC and sand casting, where dissolution of the Mg containing phases at around 500 °C is necessary and adjacent straightening processes cannot be avoided, T5 heat treatment enables near net shape casting.
In comparison to HPDC, where a typical yield strength of 170 MPa at 7 % elongation can be achieved with Silafont36 (AlSi10MnMg) in T5 condition [6], Semi-Solid casting with AlSi7Mg and elevated Mg content of 0.6 % can reach more than 200 MPa in yield strength and still maintain 6 % in elongation. In order to achieve highest strength and ductility the low gas content of Semi-Solid castings enables T6 heat treatment as well. Typical values are ranging from 260 MPa in yield to 350 MPa in tensile strength maintaining 7 % in elongation [7, 8]. That is possible because of low shrinkage and minimized gas porosity moreover resulting in enhanced fatigue resistance [9]. High mechanical properties together with the ability to realize thin-walled geometries results in a significant lightweight potential of Semi-Solid cast components [10] (see Fig. 1a, c, d, e, g, k, m, x, y, z, aa).

Superior weldability and pressure tightness: Some of the below depicted components are only feasibly in Semi-Solid casting. This refers especially to air pressure vessels that need to be helium leakage tested. There is no other casting process that can provide complex shaped thin-walled (< 3 mm) castings that are pressure tight and moreover can be welded pressure tightly. That is because of the laminar filling behaviour that avoids turbulence and hence gas inclusions. The low shrinkage of the Semi-Solid cast aluminium enables the usage of less die release agent that is also beneficial for welding [11].
In order to industrialize pressure tight or weldable aluminium components with conventional HPDC that are close to Semi-Solid quality, costly additional processes like vacuum assisted casting, minimized spraying with sophisticated spraying equipment, impregnating or HIP need to be applied Examples of pressure tightly welded Semi-Solid cast components are given in Fig. 1f, i, j, u, v, w.

Near Net Shape Casting: By injecting melt that has already partially solidified, shrinkage during solidification in the die can be minimized resulting in high dimensional accuracy and the ability to use small draft angles. In this way together with the high surface quality, functional features like bolt head contact surfaces or welding joint geometries can be realized without costly additional machining (see Fig. 1e, k, m, x, y, z, aa).

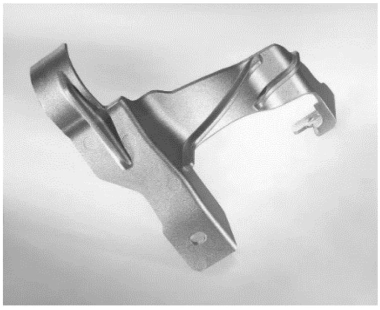
Enhanced surface quality: In comparison to other casting processes the smooth surface of the permanent mold, high solidification pressure and low gas content is characteristic for Semi-Solid casting resulting in a very good surface quality of the readymade product. This enables powder coating and chrome plating. Some of the components depicted below have been resourced from HPDC to Semi-Solid casting because the high demands on surface quality couldn't be met (Fig. 1h, l, n, o, p, q, r, u). The reason for that in many cases was that gas porosity close to the surface blistered during coating processes involving heat input e.g. powder coating.
Machined surfaces will be almost pore free which makes them applicable for functional sealing applications (see Fig. 1h, l, n, o, q, r, s, t).

Increased die life: Due to the low heat input of the partially solidified material the thermal shock of the die is reduced during filling. Less shrinkage tendency enables the usage of little die release agent reducing the thermal cooling shock during spraying. The result is a stable and homogeneous temperature distribution in the tool steel that helps to avoid heat checking and enables increased die life in comparison to conventional HPDC.

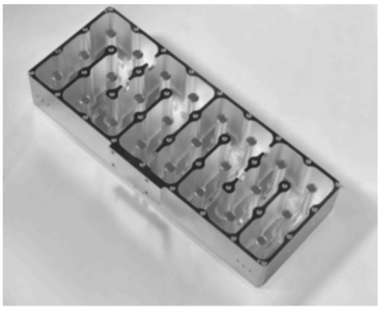
Functional integration: The component in Fig. 1m is a hinge for the trunk lid of a convertible that needs to absorb kinetic energy in case of a rear crash scenario. The initial design consisted of a sheet metal that was welded to a forged part. Because of its superior mechanical properties the Semi-Solid cast component could replace the forging and integrate the sheet metal part (further examples of functional integration are depicted in Fig. 1s and w).

Higher thermal and electrical conductivity: The usage of alloys with comparably low Si content and the inherent low porosity results in high thermal conductivity of Semi-Solid cast components. The ability to fill very thin-walled ribs makes Semi-Solid casting advantageous for the production of radio filters, electronic or intercooler housings and other electric or internal combustion engine cooling devices (see Fig. 1b).

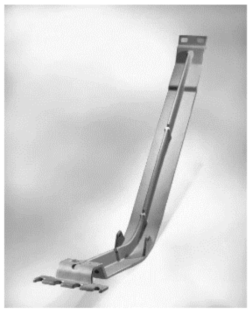
High productivity: Semi-Solid casting can replace thick-walled sand casting, gravity or low pressure die casting. By using permanent molds that enable rapid solidification, a high pressure die casting machine and a production cell with a high degree of automation and hence low cycle time, the efficiency of the production of thick-walled components can be improved [4] (see Fig. 1y, z, aa). In this regard Semi-Solid casting is competing with Poralguss of company Frankenguss from Kitzingen/Germany [12] which is capable of casting thick-walled components in HPDC machines in fully liquid state by using directional solidification with adjusted ingate design and advanced die cooling techniques.



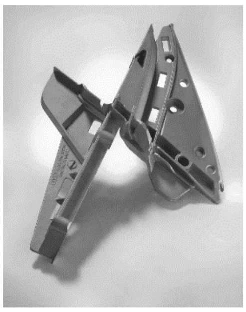
(a) Intercooler pipe bracket (automotive)



(b) Filter housing (electronics)

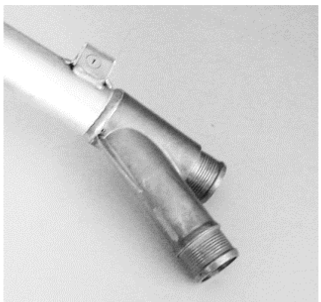


(c) Roof reinforcement (rail)



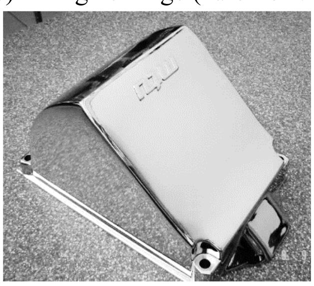
(d) Door hinge (automotive)

(e) Tailgate hinge (automotive)



(f) Intercooler pipe (automotive)

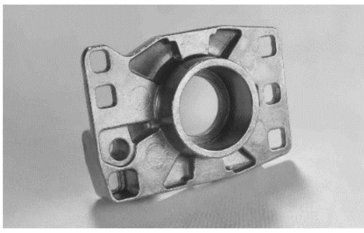
(g) Structural frame bracket (motorcycle)



(h) Cylinder head cover (marine)

(i) Air pressure vessel cap (automotive)

(j) Air pressure vessel nozzle (automotive)



(k) Bumper support bracket (automotive)

(l) Seat belt pillar loop (automotive)

(m) Tailgate hinge (automotive)

(n) Cooler top frame (automotive)

(o) Convertible roof hinge cover (automotive)

(p) Temperature sensor bracket (automotive)

(q) Cylinder head cover (motorcycle)

(r) Luggage rack (motorcycle)

(s) Tray table holder (aerospace)

(t) Armrest (aerospace)

(u) Integrated Air pressure compartment

(v) Air pressure vessel with nozzle on top (automotive)

(w) Air pressure compartment end caps (automotive)

(x) Subframe casting node (automotive)

(y) Exhaust bracket I (commercial vehicle)

(z) Exhaust bracket II (commercial vehicle)

(aa) Cab Anchorage (commercial vehicle)

Fig. 1. Examples of Semi-Solid cast components industrialized by SAG from 1999 until 2018

The Position of Semi-Solid Applications on the Casting Market

The advantages of Semi-Solid casting over conventional casting processes come at a cost that is mainly attributed to higher investment in equipment like induction heating, melt stirring devices, additional heating or cooling for the melt and the ladle as well as slurry or billet handling machinery. On the other hand, in order to come close to Semi-Solid casting quality, additional investment needs to be taken into account for HPDC as well, e.g. vacuum equipment including pressure tight molds as well as jet cooling or minimized spraying with sophisticated spraying equipment.

The piece price, and that is the most significant item of a casting in the automotive and commercial vehicle industry, is inherently higher for Thixocasting because of a higher premium for the billet resulting from additional process steps like MHD stirring and cutting, a very limited number of billet suppliers and the inability to recycle material onsite. Rheocasting on the other hand should have no drawbacks in variable production cost in comparison to other high volume casting processes.

The experience of SAG participating on the very competitive casting market revealed that it is not enough to add just one of the above mentioned advantages to the performance of a casting in order to compensate for additional investment or a higher piece price. In order to create a unique selling proposition and monetize the characteristics of Semi-Solid processing there must be several advantages available that contribute to enhanced properties in comparison to conventional processes. As an example Fig. 2 shows a cutaway model of an integrated air pressure compartment with pronounced thin-thick transitions, high demands on mechanical properties, two circumferential helium leak tested welding seams and several machined sealing surfaces which makes it almost irreplaceable with other casting techniques.

It is important to introduce these characteristic properties and specific design guidelines in an early stage in the development process of a casting in order to be able to fully exploit the potential of Semi-Solid processing and maximize its cost performance ratio. A build-to-print design that was developed for a conventional casting process is not competitive with Semi-Solid casting especially when it is compared to HPDC. When a design is feasibly in HPDC there will be at least one out of a great number of potential suppliers with idle production capacity to quote below cost.

Preliminary for a successful market penetration of a Semi-Solid cast component is an efficient inhouse production process chain according to automotive standards including a tool workshop, automated ingate removal, deburring, barrel finishing, abrasive blasting, milling, threading, CNC-machining, washing, heat treatment as well as quality inspection equipment like a x-ray unit and crack testing.

Development of Semi-Solid Cast Components

Semi-Solid casting with its characteristic advantages is quite unknown in industry. That’s why in a casting company there needs to be a profound knowledge base available to help new customers to benefit from Semi-Solid processing. That involves design guidelines, topology optimisation tools, available material data for FEM simulation like flow and S-N curves, casting simulation, prototype manufacturing and inhouse testing capabilities (see Fig. 3).

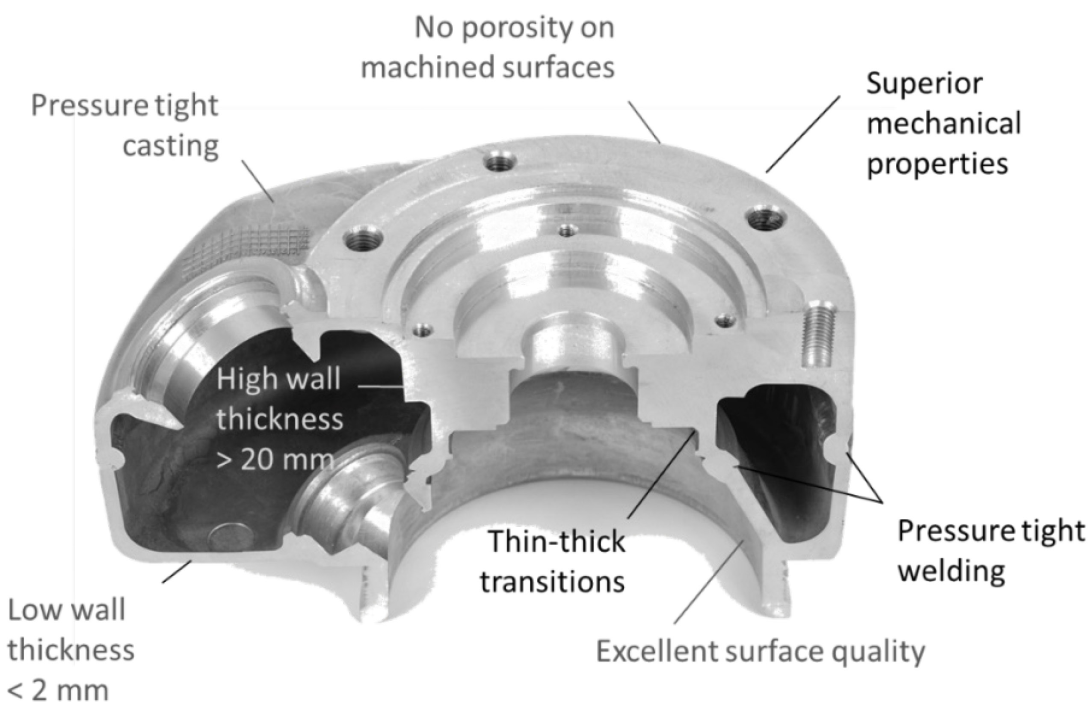


Fig. 2. Cutaway model of an integrated air pressure cap

Regarding casting simulation the goals are to identify and avoid potential defects like cold shuts, cold welds, incomplete filling, gas entrapment, isolated solidification hot spots and to adjust part and ingate geometry and process parameters like filling speed, tool temperature distribution and solidification pressure. In this regard it needs to be taken into account that the material models for Semi-Solid casting need to be more sophisticated than for conventional casting because they need to take temperature-dependent viscosity and time-dependent shear-thinning into account. State of the art is that these models are 1-phase models whereas 2-phase models would be preferable in order to be able to identify phase separation and as a result excessive liquid segregation that is a defect causing inhomogeneous microstructure an thus a scatter of mechanical properties [13].

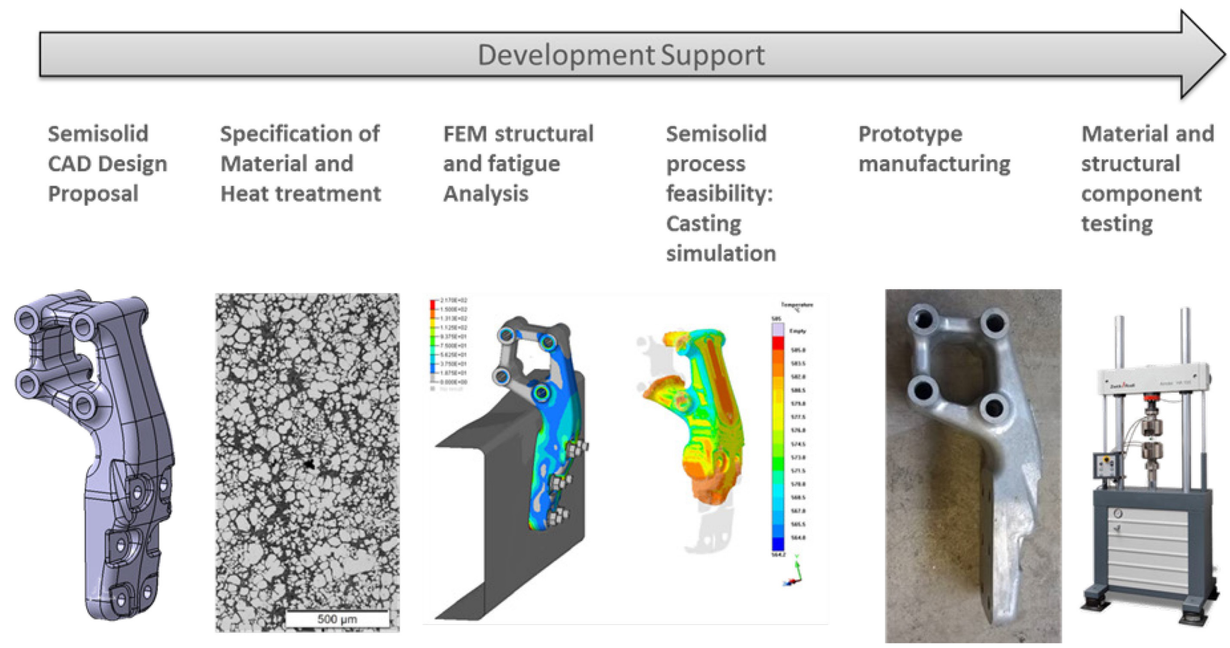


Fig. 3. Development support for the industrialization of a Semi-Solid cast component

Summary

Company SAG has more than 25 years of experience in the industrialization of Semi-Solid casting and put more than 30 applications into practice. The advantages that made these components favourable in comparison to conventional processes like gravity casting, LPDC, HPDC and forging result from a sound, low porosity microstructure, good surface quality and complex shapes. These advantages need to be tailored into the design of a Semi-Solid cast component at an early stage in the development process in order to create a competitive cost-benefit ratio. Preliminary for the economic success of a Semi-Solid casting is an efficient production process chain as well as a profound development support.

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