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EFFECT OF SOLID FRACTION ON THE MECHANICAL PROPERTIES OF THIXOMOLDED MAGNESIUM ALLOYS

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Abstract

The higher the fraction of solid phase in the partly solidified melt during pouring, the poorer the mechanical properties of thixocast components. The solid fraction decreases as the pouring temperature rises. Recommended temperature profiles for the pouring cylinder are shown. The flow characteristics of the partly solidified melt hardly changes as the content of solid matter increases.

Keywords: Thixomolding, magnesium alloys, solid fraction, creep-resistant

1. Introduction

When metal alloys are processed in a semi-solid or partly liquid state, i. e. within the solidus/liquidus solidification interval, it is particularly important to know the solid-phase fraction during pouring. In this temperature range, metals are suspensions showing liquid and solid phase constituents and a thixotropic behaviour. Metals only behave thixotropically when the structure at the time of shaping is marked by the fact that solid particles with a higher melting point are embedded in an already liquid phase. The transition between high viscosity and thixotropic behaviour is at approx. 60 % solid content [1-5] (Fig. 1).

Thixomolding makes it possible to

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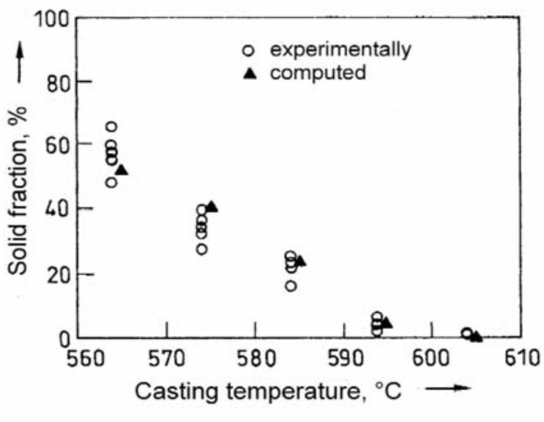

Fig. 1. Dependence of the amount of solid phase on the temperature in magnesium alloy AZ91D [6]

manufacture high-quality castings with good mechanical properties at low cost [7].

As a rule, magnesium alloys are used for Thixomolding. However, reports are known about successful tests with zinc and aluminium materials [8] as well as moulded foams from magnesium alloys [9].

Apart from cold magnesium granulate, alloy shavings of a defined size distribution manufactured with a special cutting process are used as base materials. A conveyor transports these shavings to a rotating screw at room temperature. Under an argon atmosphere, the screw conveys the shavings through a heating line to the screw tip at a speed of a maximum 210 rev/min. The screw conveyor is situated within a cylinder with external heating. Since magnesium and its alloys tend to oxidize easily in the liquid state, it is important that the cylinder is flushed with argon during heating and shut-down and/or cooling.

As the screw chamber is heated in a controlled way throughout a number of temperature zones distributed along the length of the screw, the moulding material, by continuous rearrangement, is heated continuously on its way to the screw tip. By consistent shearing off, the dendrites of the solidified part of the moulding material are destroyed, and a viscous pulp is formed with solid, rounded constituents. The shearing effect makes the material flowable, and, different from the usual pressure die casting, laminar die filling is possible. The alloy, in its semi-solid state, shows a thixotropic behaviour. By a rapid axial feeding movement of the screw the semi-solid melt is injected through the gate at high speed (between 10 and 100 m/s) and high pressure (~ 800 MPa) into a pre-heated metal die.

When manufacturing very different components with a wide range of dimensions, it was generally found that thin-walled castings have to be cast with a semi-solid melt containing a low amount of solid phase [6] to guarantee sufficient die filling. In the case of thick-walled components, however, a high amount of solid phase (i. e. low temperature) should prevail to be able to produce dense castings (Fig. 2).

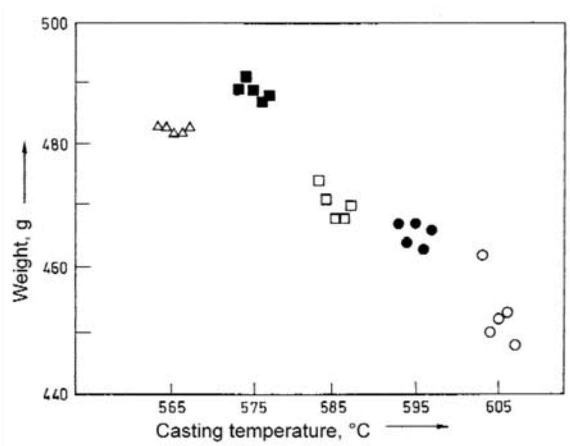

Fig. 2. Dependence of the weight of an automotive casting made of AZ91D on the pouring temperature [6]

The content of solid matter is in the first place affected by the set cylinder temperature. The temperature profile along the cylinder is the most important parameter in Thixomolding and significantly influences the processing conditions and component characteristics. This was investigated by K. Saito [10], R. Carnahan [11], and A. Dworog [12] in a temperature range between 565 and 605 °C (Fig. 3).

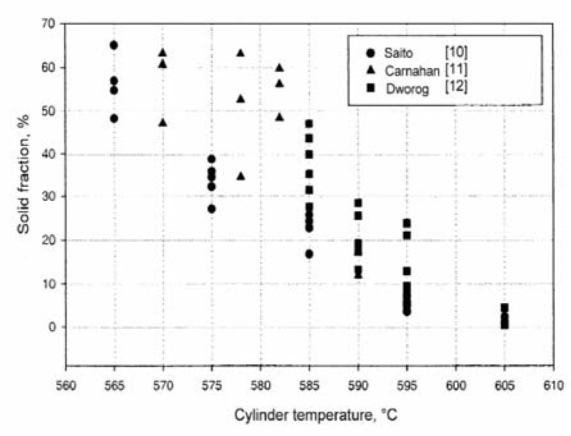

Fig. 3. Effect of the cylinder temperature on the content of solid matter [12]

It was found that the component strength increases mostly as the amount of solid phase decreases [4]. A rise in solid content frequently leads to a deterioration of the mechanical characteristics. In this respect, the experimental data of the different researchers are in agreement. D. Ghosh e. a. [13] observed a reduction of tensile strength (from 275 to 242 MPa) and elongation at fracture (from 7.5 to 4.5 %) when the amount of solid phase was increased by 2 to 16 %. R. Carnahan [14] reports on the reduction of tensile strength from 230 to 190 MPa when the amount of solid phase was increased by 17 to 60 %. According to F. Czerwinski e. a. [4], this effect is particularly noticeable when the content of solid matter is exceeded by approx. 20 % (Fig. 4).

Apart from its mechanical properties, the

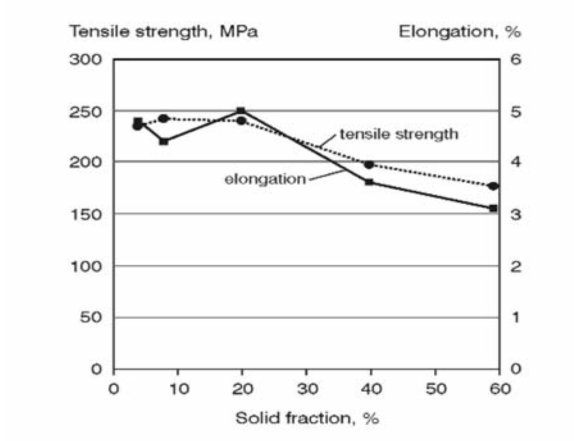

Fig. 4. Tensile strength and elongation of the thixomolded AZ91D alloy plotted as a function of the volume fraction of the primary solid particles [4]

porosity of the casting also has to be considered. Fig. 5 shows some commendable temperature profiles. They differ from the other temperature profiles by a higher nozzle temperature, constant temperature in the front area of the cylinder to achieve an even structure and a local temperature maximum in the catchment area to support an even transport process and to achieve higher plasticising streams [12].

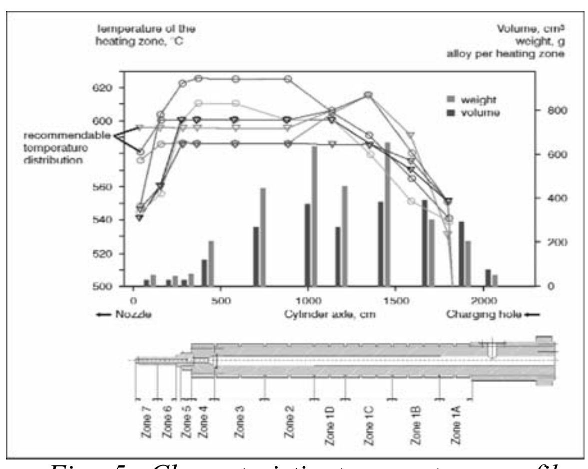

Fig. 5. Characteristic temperature profiles along the cylinder axis [12]

The higher the set temperature, the lower the number of solid-phase particles, and vice versa. By varying the temperature by 35 K, the amount of solid phase in the heating chamber can be set between 5 and 60 % (or a maximum 45 to 50 % according to [15]). This is why, at ten locations in the chamber, the temperature has to be kept with an accuracy of ± 2 K. In the process, the diameter of the individual particles varies between 35 and 65 µm according to [4, 14], or between 30 and 120 µm according to [16].

Table 1 compares the effect of the cylinder temperature profiles on the content of solid matter achieved.

Other variables influencing the solid content are shot speed, pressure, die temperature, screw speed, and the possible use of a vacuum pump for the die [12].

Measurements of the flow length in a die with a 3 m long, spiral-shaped die cavity (cross section: 3 × 15 mm) were carried out and were fundamental investigations on the flow characteristics of magnesium alloys in a thixotropic state. Fig. 6 shows the measurement results achieved with alloy AZ91D in a temperature range of 585 to 620 °C, and shot speeds of 0.8 m/s or 1.4 m/s.

The amount of solid phase increases as

Table 1. Comparison of the cylinder temperature profiles and the solid content achieved [17]

Litera-ture source	Solid con-tent, %	Cylinder temperature, °C Direction of transport of the thixotropic mass									
		Nozzle tip	Nozzle	Step	Cylinder head	Zone 6	Zone 5	Zone 4	Zone 3	Zone 2	Near f. s.*
[18]	30-Oct	565		585	584				582	580	575
[14]	<10	n. i.	614	618	618	627	626	608	600	598	538
[19]	46.3	n. i.	n. i.	585	585			570	550	520	500
[19]	29.1	n. i.	n. i.	595	595			570	550	520	500
[19]	2.5	n. i.	n. i.	605	605			570	550	520	500
[20]	5.4	n. i.	n. i.	610	610			610	613	571	521
[20]	15	n. i.	n. i.	602	602			602	607	571	521

**f. s. – filling slot*

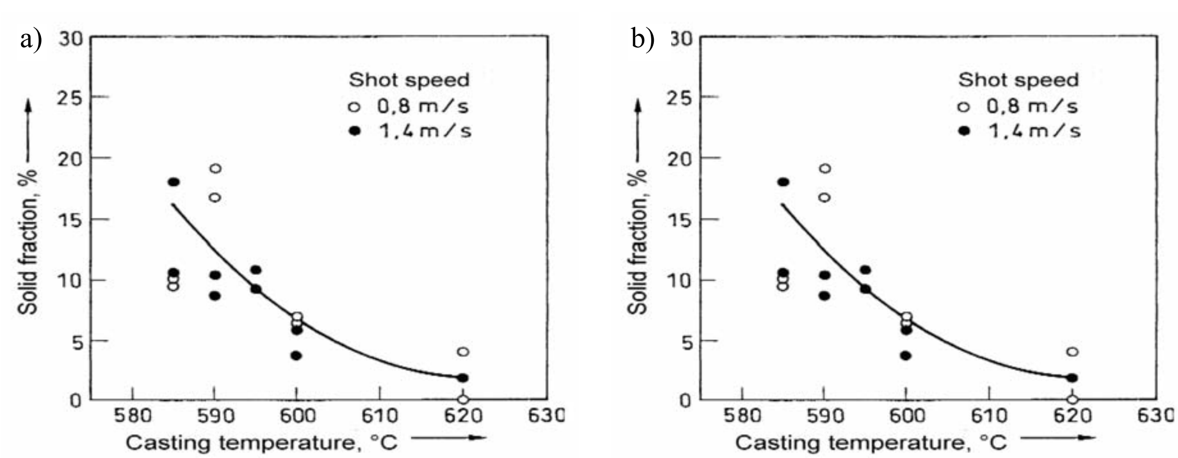

Fig. 6. Dependence of solid-matter content on the pouring temperature for AZ91D during measurements of the flow length in a spiral die cavity (a), and dependence of the flow length from the pouring temperature for two shooting rates (b) [6]

the temperature decreases (Fig. 6 a), while the flow length hardly changes (Fig. 6 b). These findings correspond to the results that D. Ghosh [21] determined from the analysis of the effective viscosity and explain the good die-filling properties this alloy has even at low temperatures in a thixotropic state.

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