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The 'full sleeve' application in the horizontal cold-chamber machine for pressure die casting of aluminium alloys

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Abstract

The 'full sleeve' construction has been designed and accomplished in the horizontal cold-chamber pressure die casting machine. Main part of this solution is a counter plunger placed in a movable die half which allows for full filling of the shot sleeve and precisely fixes the metal quantity needed for casting. The purpose of this new construction solution is mainly the reduction of the casting porosity caused by air entrapment and the improvement of both castability and accuracy of the die cavity reproduction. For such a redesigned machine there have been performed examinations consisting in pressure casting of AlSi9Cu alloy (EN AC-46000) at varying plunger velocity in the second stage of injection and varying intensification pressure. The alloy castability (the die filling ability) has been measured for each parameter setting. For the purpose of comparison, similar measurements have been performed also for the conventional system without a counter plunger. The castability examination has been done by means of a specially designed die with an impression of a trial casting of variable wall thickness. The experiments have been held according to the assumed factor design 2^2, what allowed for determining the mathematical models describing the influence of die filling parameters on the castability and the die cavity reproduction level. Both alternatives of the experiment confirmed the positive influence of plunger velocity and intensification pressure increase on the improvement of castability, the measure of the latter being the filled length of the impression. Applying of the new 'full sleeve' solution has improved castability for each experiment by about 20% as compared with conventional alternative. Castability in the 'full sleeve' system has been increased even for low values of plunger velocity and intensification pressure. For both alternative systems the influence of plunger velocity has been found, as an average, by four times greater than the influence of intensification pressure. The possibility of applying lower pressure values has been noticed for the shot sleeve construction with the counter plunger. This can influence favourably both the die and the machine durability. The obtained results have been explained and it has been pointed out that the 'full sleeve' construction can be widely adopted in pressure die casting of metal alloys.

Keywords: Pressure die casting, Aluminium alloys, Pressure chamber

1. Introduction

Limitations of pressure casting and casting defects are caused mainly by the way of die cavity filling and solidification of castings in this process. The stream of metal injected at a great speed fills the die cavity in a turbulent way, and the casting solidifies simultaneously, and not directionally, because the solidification time is relatively short and therefore feeding of the casting is impossible. Rapid die cavity filling makes also impossible the complete escape of the air from the die cavity.

Such conditions of casting and solidification result in the entrapment of the gaseous phase by the molten metal so that pressure castings exhibit both gas and shrinkage porosity, as well as oxide inclusions, and because of this they are not pressure-tight and they lack resistance to the elevated temperature. The allowable working temperature for aluminium alloy castings is 573 K, and for zinc alloy castings 393 K [1, 2]. On the other side, the rapid cavity filling makes possible obtaining the thin-walled castings with high surface smoothness and excellent dimensional accuracy, and the fine structure of castings provides for their higher strength [3].

A significant source of porosity of pressure castings is entrapment of the air from above the liquid metal surface in the shot sleeve. The plunger movement at the period of air escape from the sleeve through the venting system has a basic significance for the subsequent porosity of a casting. The plunger velocity is controlled at this stage and it is technologically dependent from the level of the sleeve filling. For conventional systems, the plunger velocity is constant at this stage, what results in metal wave forming in front of the plunger and air entrapment by the breaking forward wave [4]. This phase ends when the metal front reaches the runners in the gating system. In the case of stage-lacking system, e.g. the Parashot system, at this stage the plunger undergoes uniformly accelerated motion, which makes easier the gas escape from the sleeve and do not cause its entrapment. The beginning of the filling stage is closely related to the accuracy and repeatability of liquid alloy dosing to the sleeve. Changes in the metal quantity results in beginning of the filling stage either before the gas escapes from the sleeve (this occurs when the metal quantity is too small) or after partially filling of the cavity (when the metal quantity is too large). In both cases defected castings are produced: the first case gives castings with significant porosity, the latter leads to the misruns occurring [5,6].

Special pressure casting methods are of still greater importance due to the limited development of conventional machines construction on the one side, and to the necessity of porosity restriction and optimisation of casting parameters on the other. Especially intensification pressure and plunger velocity are here to be considered as they greatly influence the alloy ability of die cavity filling [3]. The phenomenon of air entrapment is noticeably intensified if the cavity is filled at the high speed, and therefore at the extremely short filling time which practically leads to failure in proper venting of the die. The attempts of decreasing gas porosity in pressure castings take generally one of the two directions: either applying multi-stage (or stage-lacking) injection systems enabling plunger speed and intensification pressure to be controlled by means of the new digital systems [14,15]; or producing special physical and chemical conditions in the die cavity, e. g. diminishing the atmospheric pressure (VACOX technology) [8, 10, 11, 13], filling the cavity with active gas ('pore free' technology) [7], or casting the semi-solid phase (Semi Solid Metal Casting technology of thixotropic casting) [9,12].

Next innovation aimed to the quality improvement of the pressure casting is 'full sleeve' technology [14,15] which enables reduction of the quantity of gas entrapped by metal at the injection moment by removing the air from the shot sleeve of the pressure casting machine. The advantages of 'full sleeve' applying, which result mainly from the total filling of the sleeve, include constant and exact dosing of molten metal, reduced gas content in the casting, lower pressure value applied to the metal, improvement of the metallurgical quality of metal, reduced size of pressure casting machine, cut down production cost, possibility of heat treatment of the castings [14].

2. Methodics and the results of investigation

The purpose of the work has been determining the influence of pressure casting process parameters and applying of the special 'full sleeve' technology with a new solution including the counter plunger on the die filling ability. The range of the work has included the design of construction and technology for the 'full sleeve' method applying the additional plunger (counter plunger) enabling total filling of the shot sleeve with molten metal in the quantity corresponding to the injection mass, as well as measuring of the injection parameters, namely the plunger speed during the second stage of injection and the intensification pressure, both for conventional and the redesigned machine.

The pressure die for production of casting intended for castability examination has been designed and constructed, thus enabling the assessment of the influence of the casting parameters on the die cavity filling ability. The horizontal cold chamber pressure die casting machine has been redesigned and adapted for casting at the totally filled shot sleeve, this method being referred to in professional literature as the 'full sleeve' one. The basic innovation of the employed construction solution is a special counter plunger moving in the shot sleeve during the first stage of injection. The solution is shown schematically in Fig. 1. The counter plunger is placed in the movable part of the die and at the moment of die closing it is pushed forward with a set of ejectors. The reach of the counter plunger is controlled, thus enabling the precise dosing of molten metal needed for a shot. Employing of the additional counter plunger along with the plug closing the shot sleeve (the so called stopper) allows for total filling of the shot sleeve during the plunger movement. The quantity of metal in the sleeve corresponds to the metal mass needed for complete filling of the die cavity. After the molten metal is poured into the shot sleeve, the hole in it is closed with a stopper and the injection cycle proceeds with both plungers moving to their extreme positions at which filling of the cavity through the gating system is possible. The solidified casting is removed by means of ejector system.

Trial castings of tensile specimens, impact test pieces and castability test castings of AlSi9Cu (EN AC-46000) alloy have been produced using the horizontal cold chamber die casting machine made by Polak Company, exhibiting the clamping force of 160 MN, at various values of second phase plunger velocity and intensification pressure. The injection plunger with 40 mm diameter has developed a constant speed of 0.3 m/s in the first stage of injection. The total area of runners leading to the tensile specimens and impact test pieces has been 60 mm^2. The gate thickness for the castability test castings has been possible to adjust within the range of 0.5 to 2.0 mm at intervals of 0.1 mm and at the constant width of 15 mm, what gives the range of gate area adjustment from 7.5 to 30 mm^2. The constant thickness equal to 2 mm has been used during the investigations.

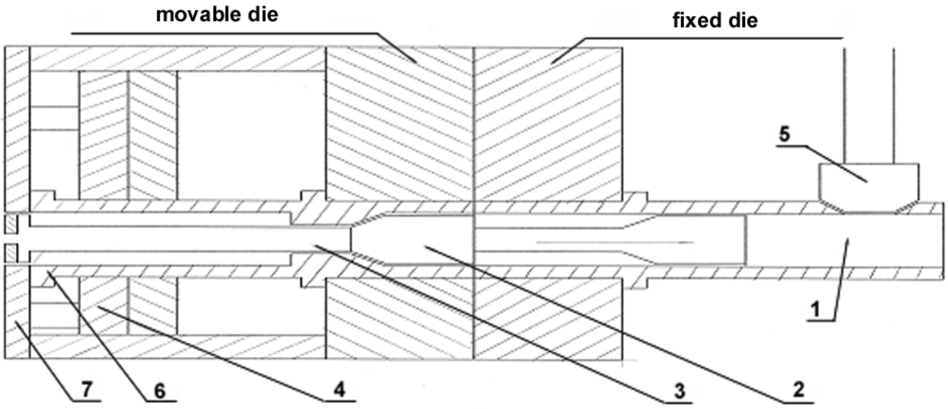

Fig.1. 'Full sleeve' construction with a counter plunger; 1-shot sleeve, 2-counter plunger, 3-counter plunger rod, 4-ejector plate, 5- stopper closing the shot sleeve, 6-sleeve, 7- mounting plate.

The metal injection temperature has been maintained at the constant level of 993 K. The influence of injection parameters on the die filling ability has been investigated, the measure of which has been assumed the length of the castability test casting. This casting shown in Fig. 2 is designed as a wedge consisting of 15 sections of 1 cm length and 2 cm width each, varying in thickness from 3 mm at the gate to the 0.2 mm at the overflow.

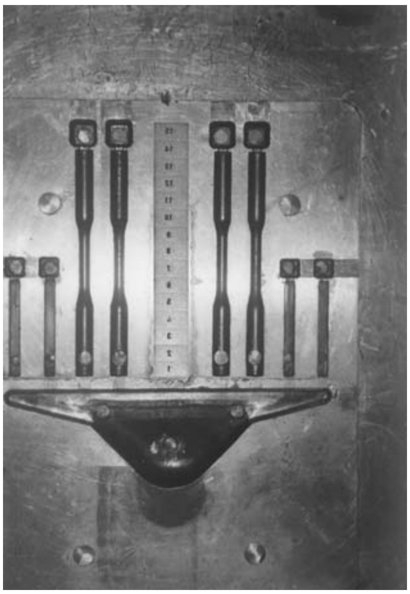

Fig.2. Pressure die with an insert for the castability test

The castings have been produced applying the same casting parameters for conventional pressure casting technology and for the full sleeve technology with counter plunger. The experiments has been carried out according to the factor design of the 2^2 type. For each experiment 10 shots (castability test bars) have been made. The measurement of injection parameters have been carried out by the DMC 200 type sensors made by EMTEC. The results of the castability test in the form of arithmetic mean taken from 10 measurements have been presented along with the applied injection parameters in Table 1.

Table 1.
Results of castability measurements and the injection parameters

Casting method	Exp. Nº	v m/s	p MPa	L cm	s_L cm
conventional system	1	3,5	20	13.6	0.89
	2	1,2	20	8.8	1.19
	3	1,2	10	7.0	1.10
	4	3,5	10	12.4	1.02
'full sleeve' system	5	3,5	20	15.0	0.00
	6	1,2	20	11.2	0.88
	7	1,2	10	9.4	0.75
	8	3,5	10	14.2	0.81

The obtained results of castability examination have been statistically analysed and the regression equations describing the influence of both the plunger speed in the second phase of injection and the intensification pressure on the alloy castability (the die filling ability) have been found. For the case of the conventional pressure technique the following castability equation has been derived:

L = 3.00 + 2.22 v + 0.15 p (1)

where: v is plunger speed in m/s and p denotes the intensification pressure in MPa.

For the case of 'full sleeve' construction employing the counter plunger, the castability equation takes the form:

L = 6.10 +1.87 v + 0.13 p (2)

Both equations use real variables explained in units announced in Table 1. The above equations are graphically represented in Figs 3 – 6.

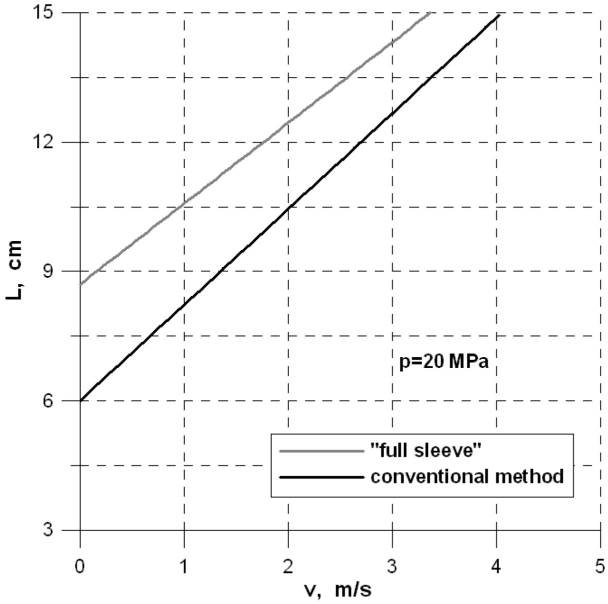

Fig.3. Dependence of alloy castability on the plunger speed in the second phase of injection at the pressure of 20 MPa

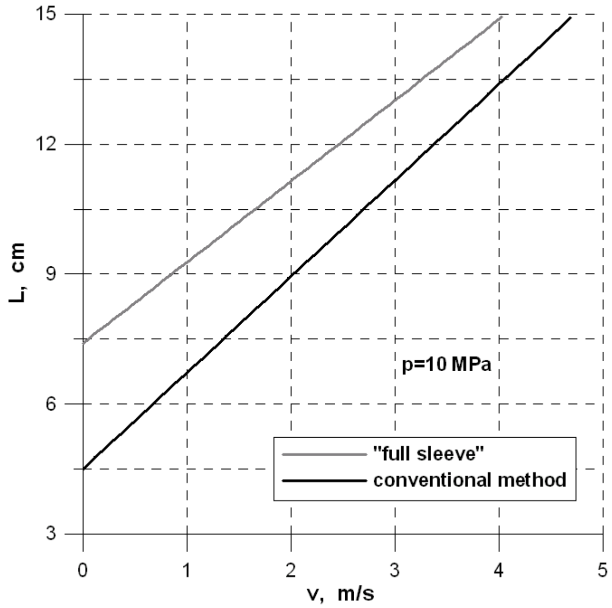

Fig.4. Dependence of alloy castability on the plunger speed in the second phase of injection at the pressure of 10 MPa

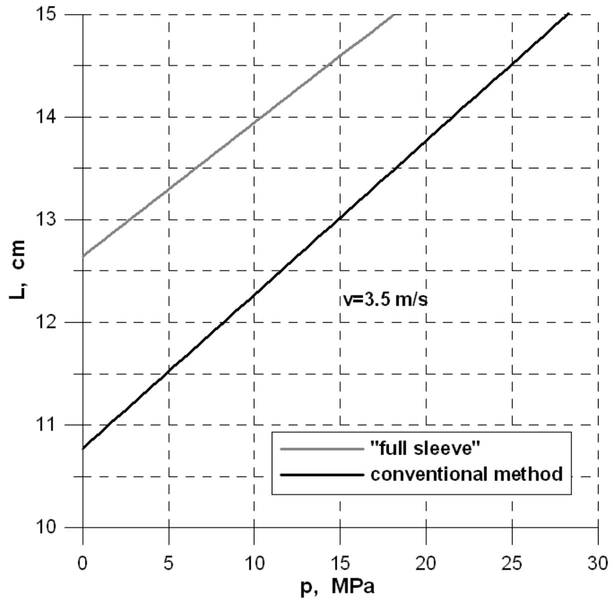

Fig.5. Dependence of alloy castability on the intensification pressure at the plunger speed equal to 3.5 m/s

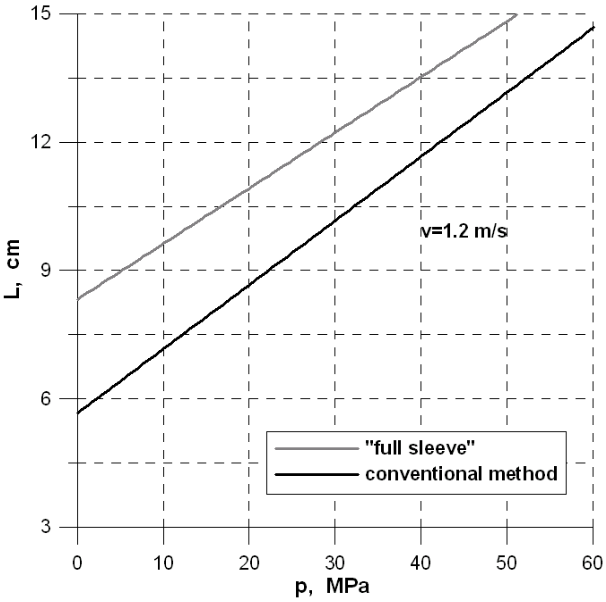

Fig.6. Dependence of alloy castability on the intensification pressure at the plunger speed equal to 1.2 m/s

3. Conclusion

The obtained results of castability examination for experiments performed according to the new 'full sleeve' method which applies an additional counter plunger allow for a well reliable stating that the advantages of the presented method have been confirmed. The castability of the alloy has been distinctly increased at the same parameters of casting as compared with the conventional pressure method. The improved castability is equivalent to the improved casting quality and reduction or even elimination of gas porosity, the characteristic defect in pressure casting of metals. The derived mathematic models confirm without any doubt the positive influence of plunger speed and intensification pressure on castability increase. For both cases of pressure casting technology, the power of influencing the castability is similar for the investigated parameters, what is confirmed by the similarity of coefficients at the variables. This power is, however, fifteen times greater for the plunger velocity than for the intensification pressure. Such a difference is obvious when one notice that the time of die cavity filling for the test casting (of the average thickness equal to 1.6 mm) ranges from 0.115 s to 0.019 s. So short filling time leads to the rapid solidification of metal without the possibility of structural changes during the solidification. Therefore it is not astonishing that only a weak effect of intensification pressure on the composite castability is observed. It is worth noticing that the free term in castability equation for the 'full sleeve' case is twice as great as the corresponding term for the conventional pressure casting. It means much better die filling and confirms the high effectiveness of the new construction employing. For each experiment performed at a certain setting of parameters in the 'full sleeve' method the castability is by about 20% greater than the one for conventional casting method. The improvement of the die cavity filling conditions in the 'full sleeve method' gives the possibility of pressure die casting of aluminium alloys at the parameters which are more advantageous for the machine and the process. This means also the possibility of casting at lower values of speed and pressure, and – as far as simple shapes with relatively thick walls are concerned – even the possibility of reducing the injection temperature at a given set of injection parameters, what can advantageously influence the die lifetime and improve the casting structure.

Applying of the 'full sleeve' enhances the repeatability of the obtained properties of pressure castings, what is testified by the significantly smaller values of castability standard deviation as compared with the values for conventional casting. It can be stated on the basis of the obtained results that the further optimisation of metal pressure die casting is possible, where such parameters as the gate area and the injection speed derived from the equation of stream continuity can be taken into account.

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