EXPERIMENTAL VALIDATION OF THE EFFECT OF PISTON SPEED ON THE HOMOGENEITY OF DIE CASTINGS

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One of the most progressive technologies in foundry is die casting, where a significant part is formed by die casting of castings of a lower weight category. In the case of castings cast by pressure casting technology, one of the important quality indicators is the internal quality of the casting presented by internal defects. In addition to the alloy used, the shape of the mold and the filling chamber also affect casting defects. Casting parameters such as pressure and speed significantly affect the quality of the resulting casting. The resulting homogeneity of the castings is very important in terms of mechanical properties.

KEYWORDS

Diecasting, pressure casting, casting parameters, homogeneity

1 INTRODUCTION

Foundry is one of the important industries that significantly participates in industrial production. Castings produced by foundries are supplied to all branches of the engineering, electrical and consumer industries. One of the most progressive technologies in foundry is casting under pressure, where a significant part is made up of castings under pressure of a lower weight category [Bohacik 2002, Laudar 1961].

Table 1. Influence of parameters on defects in castings

The influence of mold							Influence of chamber filling and machine parameters									Influence of the alloy				
Thickness and diameter of the notch	Location of notch	Type and size of venting	Cooling system	Mold cavity accuracy	Mold temperature	Quantity and type of dividing spray	Pressure build-up time	Mold cavity filling time	Metal speed in the notch	Press piston speed	Cycle time	Diameter of the filling chamber	The temperature of the filling chamber	Freezing of the press piston	The closing force of the casting machine	Iron content in Al alloys	Alloy composition	Pouring temperature		
10	10		10		5		10							1			5	5	Porosity	Casting defects
10	1	10	5		5	10	5	5	5	5		5		1			1	1	Air and gas porosity, bubbles	
										1				5				1	Impurities	
5	10		5		5	1	5	10	5	5	1		5	1			10	5	Not refueling	
			1		1	5					5					5			Deformation	
			1		1		1				5				1			1	Pitfalls	
		5	1		5		5	5	5	1	1	5						5	Blisters	
					5	10			1							10		10	Sticking	
1					5	1			1									1	Map-like surface	
	10				5			10	5	1			5				1	1	Cold joints	
					1														Traces of bouncers	
					5	10			1							10		1	Scratches	
					1	10							5						Traces of a separating agent	
			5		5					5						5		1	Cracks	
				10	5		1			5					5			1	Dimensional deviations	
					5		1								10		1	5	Burrs	

10 very strong

5 strong

1 weak

Metal casting under pressure has many advantages comparing the other conventional casting modern methods, e.g. significantly higher performance, better accuracy of castings, better surface quality of castings in larger series, lower production costs and better use of metals are achieved. Castings also require almost no modifications and very little additional machining. A number of factors affect the quality of castings produced by pressure casting technology [Bechny 1989, Gedeonova 1990, Ragan 1997].
Table 1 shows the weightings of the influence of parameters on defects in castings, which are influenced by the mold, machine and filling chamber, and last but not least, the alloy [Malik 2009, Ragan 2007a]. One of the important parameters is the piston movement speed. At Fig. 1 is shown the course of pressure *p* and pressing speed *v* [Ragan 2007a].

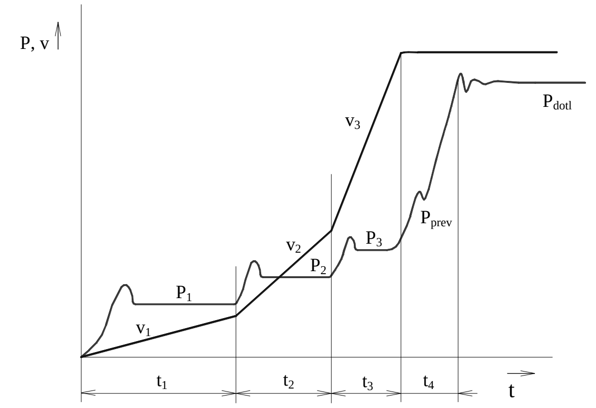


Figure 1. Course of pressure *p* and pressing speed *v*

As it follows from the works [9, 41, 27], at the beginning, the pressure overcomes the resistance when starting the piston at a slow speed from the safety point of view, so not to spray the metal from the pouring hole of the chamber. Next, the pressure is increased to overcome the resistance of the piston to a speed until the liquid metal reaches the notch. Then a further increase in pressure is needed to overcome the resistance of the press piston to a higher speed and fill the mold cavity. After the cavity is filled, the pressure increases, firstly by a hydraulic shock at a small stop of movement, secondly by the so-called pressure for perfect filling of the cavity, during which solidification of the metal occurs. From practical experience, if the pressure is to be effective, the time of onset of the pressure must be less than 20 milliseconds. Otherwise, the metal in the notch will solidify and the pressure will not be transferred to the mold cavity.
In the production of die castings, increased attention is given to the internal quality of the castings, which is characterized by the type and extent of casting defects. In accordance with the specifics of this production technology, the most common defects of castings are cavities and internal fillings [Ragan 2007b, Valecky 1963, Vinarcik 2003].
The most common method of non-destructive inspection of castings is X-ray analysis, which reliably makes the position, shape and dimensions of internal cavities visible without their more precise identification. Therefore, usually all observed voids are included in one group of defects, referred to as porosity, rare spots, and other. Subsequently, macroscopic analysis of longitudinal or transverse sections through the wall of the casting makes it possible to obtain information on the size of the voids and their distribution [Ragan 2007a, Malik 2006, Mascenik 2014, Majernik 2020].
The aim of the contribution is the analysis of the technology of casting under pressure of castings of a lower weight category in the form of an assessment of the influence of technological parameters on the mechanical properties of pressure castings. Experimental tests of the effect of piston speed on the homogeneity of pressure castings of a lower weight category were carried out.

2 MATERIAL AND METHODS

2.1 Experimental evaluation

Individual experimental castings were realized on a semi-automatic machine for pressure casting of non-ferrous metals with a cold horizontal filling chamber CLH 400.01. The basic technical parameters of the casting machine are listed in Tab. 2. The casting machine is equipped with a dosing device, a treatment device and a selection device. The casting was cast in a double pressure casting mold with automatic ejection (Fig. 2).

Figure 2. A group of realized castings with a marked sampling point for analyses and the direction of the load force F_L

Table 2. Technical parameters of the machine used in the experiments

Technical parameters	CLH 400.01
Closing force [kN]	4 000
Stroke of the form carrier [mm]	350 – 600
Dim. clamp. boards [mm]	990 x 990
Clearance between columns [mm]	605 x 605
Column diameter [mm]	125
Force of the hydraulic rammer [kN]	14 – 200
Pusher stroke [mm]	130
Pressing force [kN]	90 – 390
Press piston stroke [mm]	470
Diameter of filling chambers [mm]	50/100
Max. mass of poured metal [kg]	6.15
Part of the no-load cycle [s]	7
Power of electric hydrogenator [kW]	22

The experiment was carried out based on the conditions listed in Tab. 3. The piston movement speed was changed in the interval from 1.7 ms^{-1} to 2.1 $m.s^{-1}$. The evaluation of the quality parameters of the castings was based on monitoring the occurrence of internal defects of the castings and monitoring the required mechanical properties using the residual deformation test. The analysed castings were marked as casting 1 to 5 for further processing.

Table 3. Casting parameters for castings

Pressure casting machine CLH 400.01		
1	1.92 $m.s^{-1}$	Final pressure 28 MPa (pressure 53 MPa)
2	2.08 $m.s^{-1}$	Final pressure 28 MPa (pressure 53 MPa)
3	1.8 $m.s^{-1}$	Final pressure 28 MPa (pressure 53 MPa)
4	1.7 $m.s^{-1}$	Final pressure 28 MPa (pressure 53 MPa)
5	1.5 $m.s^{-1}$	Final pressure 28 MPa (pressure 53 MPa)
Metal temperature		660 °C
Mold temperature		320 °C
Pressing time		5s
Solidification time		3s

An aluminium alloy with a chemical composition according to Table 4 was used. The actual analysis of the chemical composition was carried out in laboratory conditions (at a temperature of 21 °C and a relative humidity of 60%) using a SPECTROCSAT emission spectrometer. The stated values are determined from the average of three sample measurements. At the same time, the table shows the values of the content limit intervals for individual elements according to the STN 42 4331 standard.

Table 4. Chemical composition of the alloy

An elemental composition of an alloy [%]	Al	86.88	Difference up to 100
	Si	8.49	8.0 - 11.0
	Fe	0.88	0.60 - 1.10
	Cu	2.34	2.0 - 4.0
	Mn	0.23	Max 0.55
	Mg	0.21	0.05 - 0.55
	Cr	0.05	Max 0.15
	Ni	0.09	Max 0.55
	Zn	0.70	Max 1.20
	Pb	0.09	Max 0.35
	Ti	0.04	Max 0.25

2.2 *Evaluation of castings*

Before performing laboratory analyses, an optical inspection of the castings was performed. No external faults or other defects were identified in castings of series 1 to 4. In castings cast at a speed of 1.5 $m.s^{-1}$, an undercasting was identified, casting group 5 (Tab. 5). Due to the significant deficiency, these castings were not evaluated further.

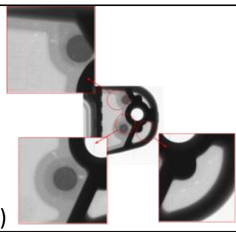
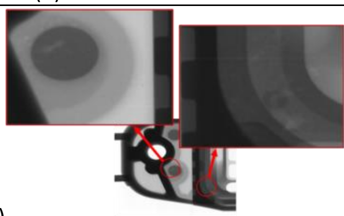
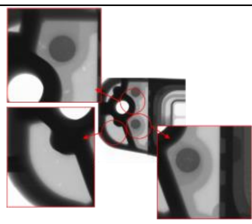
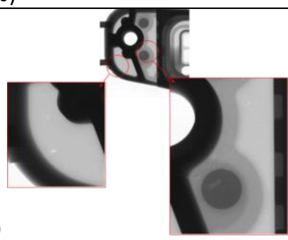
1(a) 	1(b) 
2(a) 	2(b) 
3(a) 	3(b) 
4(a) 	4(b) 
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Table 5. Photo (left) and X-ray (right) images of samples

The subsequent analysis of the castings includes the detection of casting defects such as primary porosity, bubbles and voids that have arisen due to changes in casting parameters. Two methods were chosen a non-destructive method for evaluating bubbles and cavities and a destructive method in the form of metallographic analysis. X-ray analysis was chosen as a non-destructive method. X-ray images (Table 5, samples 1(b) to 4(b)) were obtained using the VX1000D device, which is designed for testing small and medium-weight castings, while allowing continuous adjustment of the casting position. X-ray examinations were performed in such a way that the entire profile of the monitored location was captured. The critical places on the given casting are the attachment points (Fig. 2).

For the complex implementation of the analysis of the porosity of the castings, it was necessary to carry out the preparation of the samples, consisting in the selection of a suitable place for the collection of the metallographic sample. Sampling locations for metallographic analysis were determined in the direction of the load force, Fig. 2 (the arrow indicates the direction of action of the loading force FL) at the attachment points. The procedure for obtaining samples for optical metallographic analysis consisted of splitting using a machine saw with cooling. Subsequent degreasing, casting of the sample in methyl methacrylate casting material, grinding and polishing.

Subsequently, the collected samples were processed in the laboratory and samples 1 to 4 were microscopically evaluated (Tab. 6). For the evaluation of individual samples, the ImageJ analysis software was used, working on the principle of comparing the colour spectrum of the structure of the scanned sample and its evaluation consisting in determining the ratio of non-defective areas to areas containing specific defects, the so-called pores. The method of creating groups was used in the implementation of experimental analysis of porosity. This method consists in creating a monitored area from several metallographic images in order to increase reliability in the overall evaluation of porosity for a given casting. Metallographic analysis was carried out using a light microscope Carl Zeiss NEOPHOT 21. For individual castings, values were processed at 100 times magnification.

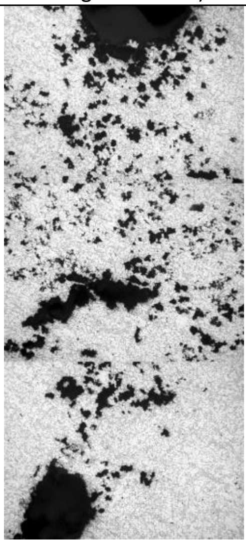	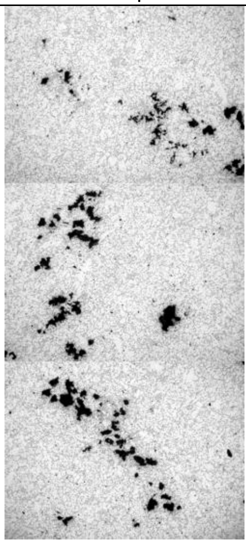	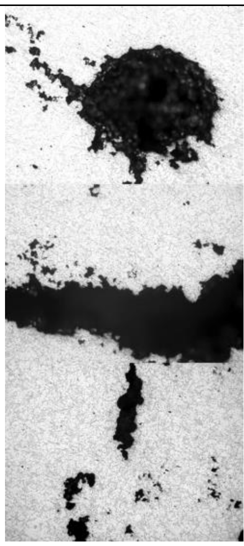	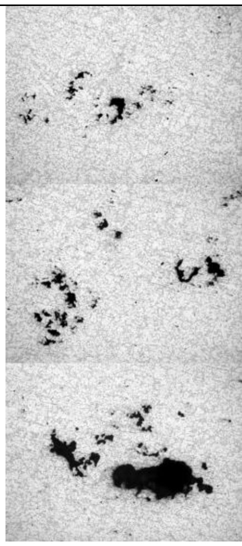
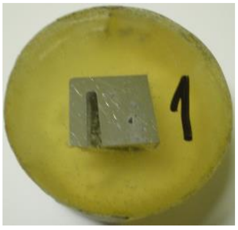	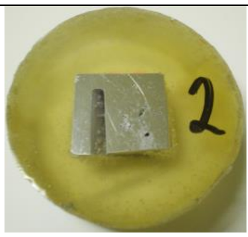	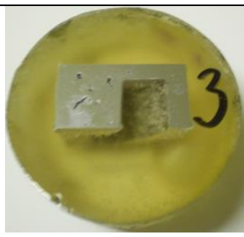	
1	**2**	**3**	**4**

Table 6. Microscopic evaluation of the samples

2.3 Residual deformation tests

The permanent, residual strain is the strain that is measured at incomplete unloading. The measurements were carried out on the TIRA test 28200 device. The measurement is carried out with a load force of F=65 kN at a load speed of 10 mm.min^{-1}. After reaching the maximum deformation, a partial relief occurs, during which permanent deformation is monitored under a load of F= 20kN during the specified time t=10s.

3 RESULTS AND DISCUSSION

In Figs. 1(b) and 3(b) a group of castings containing a large number of defects is shown. These defects occur in the entire volume of the casting body, are relatively extensive and can significantly affect the resulting mechanical properties. Their use in technical practice is inadmissible due to the high degree of possible damage. Errors are related to the effect of speed. In addition to excessive gasification, there was also an uneven decomposition of the liquid metal in the process of filling the mold. The reason is the formation of significant inhomogeneity in the entire volume of the casting. Figs. 2(b) and 4(b) show images of the casting, on which a smaller amount of internal defects can be observed. These defects occur in the entire volume of the casting body, but their occurrence is relatively small.

The results of the porosity analysis are processed as percentages of porosity for individual castings. The high occurrence of defects is in samples 1 and 3. The highest porosity of 61.55% is for sample 3. 48.96% represents the porosity of sample 1. For sample 2, the porosity value is 7.82% and for sample 4, the porosity value is 8.74%. It is possible to state that they have the so-called moderate number of failures.

It can be concluded that castings of series 1 and 3 do not meet the requirements for homogeneity. The described defects can significantly affect the structural properties. The speed of 1.5 $m.s^{-1}$ is insufficient and the castings are characterized by lack of casting.

The residual deformation value is the average of 5 measurements. Measurements were made for both mounting holes. The maximum residual deformation is 0.205 mm. The course of the residual deformation depending on the speed is shown in Fig. 3.

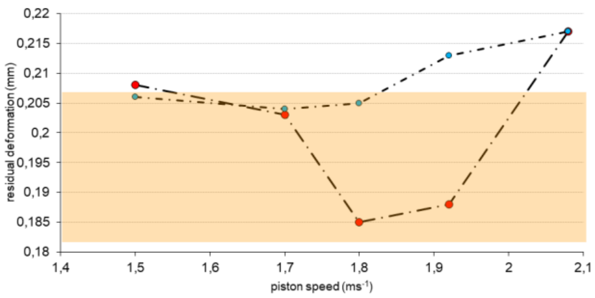

Figure 3. Course of residual deformation as a function of piston speed for casting holes

It follows from the course of residual deformation values that the piston speed of 1.7 $m.s^{-1}$ and 1.8 $m.s^{-1}$ meets the required value of residual deformation. Considering the X-ray and metallographic analysis performed at a speed of 1.8 $m.s^{-1}$, the occurrence of internal faults is critical.

4 CONCLUSIONS

In pressure casting, the filling of the mold is the result of the transformation of pressure energy into kinetic energy. During the filling of the mold cavity, high velocities of the liquid metal occur, and at the end of filling the mold cavity, the kinetic energy during filling changes to pressure energy. The melt flow is determined by the shape of the casting and the heat balance during filling. During the filling of the mold cavity, mainly turbulent flow to dispersed flow of air and melt occurs.

According to the experiments of the selected castings, it is possible to determine the influence of the speed of the pressing piston on the mechanical properties of the castings represented by permanent deformation and porosity. By measurement, it was confirmed that the value of permanent deformation is in relation with the value of porosity, which weakens the cross-section of the casting. The values of the residual deformation increase with increasing speed. At piston movement speeds of 1.9 $m.s^{-1}$ and higher, the residual deformation values are above the maximum allowed value of 0.205mm. At a speed below 1.5 $m.s^{-1}$, there is the formation of under-fills castings.

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