Specific Pressure and Mechanical Properties of the Alternator Flange from EN AC 47100 Alloy in HPDC Technology

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Abstract – **The technology HPDC (High Pressure Die Casting) of metals represents accurate casting which approximates the most ideal effort of direct change of basic material to finished product. The die casting itself is characterized by mechanical method of casting with the molten metal being forced-in under high pressure (specific pressure) into the divided metal mould by a plunger acting upon the melt in the filling chamber. The HPDC technology has in recent years achieved an expansive growth in the volume as well as the range of production and that is particularly in aviation and automobile industry. The presented paper deals with the experimental assessment of the impact of specific pressure on the mechanical properties of the alternator flange from EN AC 47100 in HPDC technology.**

Keywords – **Die casting, specific pressure, casting, mechanical properties.**

1. Introduction

High Pressure Die Casting (HPDC) is characterized by replacement of gravitation metalostatic pressure by a plunger force acting upon the melt in the filling chamber of the die casting machine. The aforementioned refers to a mechanical mode of casting in case of which the liquid metal is pressed under pressure into split metal mold by the plunger acting upon the melt in the filling chamber [1]. By means of plunger speed in the order of meter units per second the melt is transferred by the gating system from the filling chamber through the ingate into the mold cavity. The total period of mold cavity filling is very short - ones and tens of milliseconds. This method of mold cavity filling allows production of thin-walled shape-demanding castings with high dimensional accuracy and with an exact surface relief profiling of a mold cavity [2, 3].

The quality of castings cast under pressure is influenced by a number of factors. One of them is a proper structure of the casting mold which includes mainly gating and venting and cooling systems of the mold. The quality of castings is also affected by other factors such as a die casting machine, a type of cast alloy and its metallurgical processing, the quality itself of the produced mold, the set technological parameters, and last but not least, attendance of die casting machine [4]. Optimal structural design of the mold and setting of all technological and metallurgical parameters presuppose production of high quality casting. Therefore, in production of castings it is necessary to utilize high-quality production equipment including melting, the melt treatment, and die casting machine with properly selected gating system [5, 6].

Basic technological factors in case of metal die casting include the following [2]:

- pressing speed in the course of casting cycle,
- specific pressure acting upon the melt and increase pressure,
- period of mold cavity filing,
- cast alloy temperature, filling chamber temperature and mold temperature.

These factors influence each other and that represents a complex of reciprocal bonds among alloy character, mold structure, filling period, and efficiency of die casting machine, i.e. comprehending of relations within the entire casting process from the commencement of the mold cavity filling up to the casting solidification in the mold [1, 7].

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2. Specific pressure on alloy during the casting cycle

Specific pressure which presses metal into a mold is given by the pressing force intensity and the internal chamber diameter. It ranges from 10 to 100 MPa and in rare cases up to 250 MPa, especially in cold horizontal chamber machines. The interval from 20 to 80 MPa is most used which assures the effective casting of standard castings just as it does not overstress the pressing plungers holders. Increase pressure should replace the gravity melt feeding into empty spaces of the casting and suppress the agglutination and expansion of gas bubbles during crystallization of the casting (sufficient hydraulic connection of a mold and the gating system is conditional). The multiplier is used for achieving the higher increase pressure and it is part of the casting machine [8].

Hydrodynamic pressure acts in the liquid metal flow in the process of the die casting mold filling. It arises as a result of resistance during the metal motion passing through the thin mold cavities and during the cores bypass, reversals, the flow reduction and expansion. In the absence of such resistances the value of the hydrodynamic pressure in the flow is determined by air and gases back pressure the removal of which is obstructed due to venting system [9]. Accuracy of the relief molding and the casting surface roughness depend on kinetic energy of the flow. At the moment of motion termination, there is a hydrodynamic pressure p_H.

$$p_H = \frac{S_f}{S_F}.\rho.v_f^2 \tag{1}$$

with p_H - hydrodynamic pressure [Pa],
S_f - cross section area of the ingate [m^2],
S_F - cross section area of a mold cavity [m^2],
v_f -metal flow speed in the ingate [m.s^{-1}],
ρ -specific weight of alloy [kg.m^{-3}].

To overcome the resistance of solidifying metal mass in thin cross sections of a molded cavity and also the resistance of gases remaining in the casting a large hydrostatic pressure is inevitable. It is transmitted from a pressing plunger through a sprue. The longer the sprue solidifies the more extended is the action of pressure. The process of transferring the hydrostatic pressure into a mold cavity is called a specific (increase) pressure. Using thicker sprues allows implementing of the increase pressure and the feeding of the casting with molten metal during crystallization which eliminates the contractions [12, 13]. For most castings it is necessary for the delay between the cavity filling and the maximum pressure achievement to be as short as possible during the tens of milliseconds (20-30 ms), at the time when the casting is not yet solidified and should favorably reflect on its quality. To obtain the high-quality casting the possibility of time control starting from increase pressure start-up time until it achieves its final value is inevitable [3, 10].

3. Influence of specific pressure upon crystallization parameters

The structure and properties of cast metals and alloys are in a high degree influenced by crystallization conditions. By the technological interventions into the crystallization process the mechanical properties and structural parameters of castings can be enhanced. Crystallization is commenced by formation of crystallization nuclei and by their consequent growth into the solute melt [7, 11]. The area of structure formed out of a single nucleus is called primary grain. Amount and size of grains depends on number of crystallization nuclei. If during the solidification only a small number of nuclei is activated, the result is a coarse-grained structure and vice versa. The outcome of these conditions is difference in morphology of the same alloy when solidifying at diverse speed.

Kinetics of a phase change is consequently characterized by a number of crystallization nuclei n being formed in volume unit per unit of time and at linear speed of crystal growth. At higher speed of nuclei nucleation and at lower speed of crystal growth smaller grains are formed. Dependence of amount of grains on crystallization parameters is determined by the relation as follows:

$$N = a.\sqrt{\frac{n^3}{v_k^3}.V_0} \tag{2}$$

with N - amount of grains [-],
a - diffusional coefficient of proportionality[m^2.s^{-1}],
n - number of nuclei [-],
v_k - linear speed of crystal growth [m.s^{-1}],
V_0 - primary volume of liquid phase [m^3].

Crystallization centres are formed in the volume of liquid phase spontaneously as well as in inclusions occurring in the melt. In compliance with the kinetic molecular theory of crystallization by Frenkel and Volmer Danilov's spontaneous nucleation occurs with the existence of heterophase fluctuations in the melt small areas which possess atom distribution similar to that of a crystal. To form the nucleus of critical dimension the following operation is necessary: [12]

$$A_k = \frac{1}{3}\sum_i S_i.\sigma_i \qquad (3)$$

with A_k - operation for nucleus formation [J],
S_i - surface of i-way of nucleus surface [m^2],
σ_i - surface tension of the melt on i-way edge [N.m^{-1}].

In homogenous nucleation the following is applicable for critical dimension of nucleus:

$$r_k = \frac{2.\sigma.T_t}{\rho.L_t.\Delta T} \qquad (4)$$

with r_k - critical dimension of nucleus [m],
T_t - melting temperature [K],
ρ - specific weight of the melt [kg.m^{-3}],
L_t -specific internal latent heat of melting [J.kg^{-1}],
ΔT-subcooling [K].

In practice the crystallization process is influenced by the cooling speed change, by the nucleation condition change, and by the change of structure components growth.

The castings cast under pressure during solidification are characterized by better mechanical properties and by increased airtightness. In case of die casting the specific pressure acts upon the alloy in the last phase of die casting cycle, and the so-called increase pressure affects the casting for the entire period of its solidification.[13] In die casting the critical size of nuclei is according to relation (4) influenced by the melt subcooling by the effect of high accumulation power of the metal mold and athermical subcooling caused by the pressure acting upon the crystallizing melt. The influence of pressure upon the temperature of liquid or solid of the metal and its alloys is expressed by the Clausius – Clapeyron equation: [12, 13]

$$T_t = \frac{dT}{dp}.\frac{L_t}{(V_l - V_s)} \qquad (5)$$

with T_t - melting temperature [K],
L_t - specific state of mater of melting [J.kg^{-1}],
V_l - volume in the liquid phase [m^3],
V_s - volume in the solid phase [m^3],
σ - surface tension on the boundary between the melt – nucleus [N.m^{-1}],
$\frac{dT}{dp}$ - the change of temperature of pressure.

After inserting the relation (5) into the relation (4) the modified relation for the critical size of nucleus is derived:

$$r_k = \frac{2.\sigma.dT}{\rho.\Delta T.(V_l - V_s).dp} \qquad (6)$$

with r_k - critical size of nucleus [m],
ρ - specific weight of the melt [kg.m^{-3}],
ΔT - subcooling [K].

The relation analysis (6) proves that the decrease of sizes of critical nucleus is possible to be achieved not only by decrease of surface interphase tension σ on the boundary between the melt – crystal and by increase of subcoolingΔT , but by the increase of the pressure *dp* as well. All these factors act upon the increase of speed of formation of crystallization nuclei and cause formation of fine-grained structure of metals and alloys [12, 14].

4. Influence of specific upon the values of mechanical properties

Influence of specific pressure changes on mechanical properties study was performed on experimental samples (Fig. 1. - alternator flange casting). A die casting machine with a type designation of Müller Weingarten 600 designed for casting of non-ferrous metals with a horizontal filling chamber was used to perform the experiments.

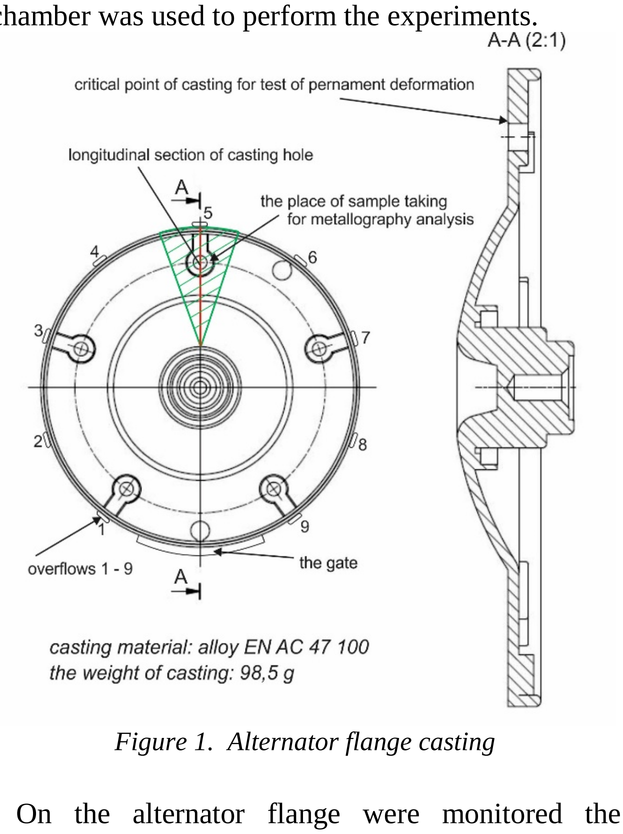

Figure 1. Alternator flange casting

On the alternator flange were monitored the mechanical properties:permanent deformation "*s*" (device TIRAtest 28200),hardness "*HB*" according to Brinell (device HPO 250) and porosity "*f*" (PC software ImageJ).A term of permanent deformation means deformation measured with incomplete unloading. Permanent deformation tests were performed on a critical casting point (Fig. 1.) and performed in accordance with GME 06 007 and GME 60 156 standards. Measuring of the hardness of cast samples was performed according to Brinell. Conditions of hardness measurements complied with EN 6506-1 standard: (a ball diameter D = 25mm, loading force F = 613N and loading period t = 10 s). In the macroscopic analysis, longitudinal cuts of the cast opening at load point have been evaluated observing the values of permanent deformation. The analysis of porosity *f* of metallographic cuts from obtained samples has been carried out using the OLYMPUS GX51 microscope at 100x zoom and processed by the ImageJ computer program, which evaluates the percentage of porosity from the observed point on the cut. When the experiment has been carried out constanttechnological factors: plunger pressing speed (2.6 $m.s^{-1}$), liquid alloy temperature (705°C), mold temperature (200°C) and variable technological factors: specific pressure (13; 22; 25 MPa), must be taken into consideration.

5. Achieved Results

The measured mechanical properties values of the alternator flange in dependence on the specific pressure are given in Table 1. and graphically presented in Fig. 2.

Table 1. The measured mechanical properties values in dependence on the specific pressure

Sample No.	Specific pressure [MPa]	Plunger pressing speed [$m.s^{-1}$]	Sample No. a	b	c	d	e	Arithmetic average
Permanent deformation „*s*“ [mm]								
A. 1	**13**		0.056	0.060	0.071	0.068	0.065	**0.064**
A. 2	**22**	**2.6**	0.055	0.062	0.057	0.053	0.059	**0.057**
A. 3	**25**		0.043	0.041	0.042	0.049	0.046	**0.044**
Hardness „*HB*“								
A.1	**13**		107 HB	104 HB	105 HB	104 HB	105 HB	**105 HB**
A.2	**22**	**2.6**	104 HB	105 HB	107 HB	107 HB	105 HB	**106 HB**
A.3	**25**		104 HB	107 HB	105 HB	105 HB	104 HB	**105 HB**
Porosity „*f*“ [%]								
A.1	**13**		3.82	3.58	3.63	3.92	3.68	**3.73**
A.2	**22**	**2.6**	0.86	0.93	0.98	0.89	0.93	**0.92**
A.3	**25**		0.72	0.86	0.85	0.72	0.78	**0.79**

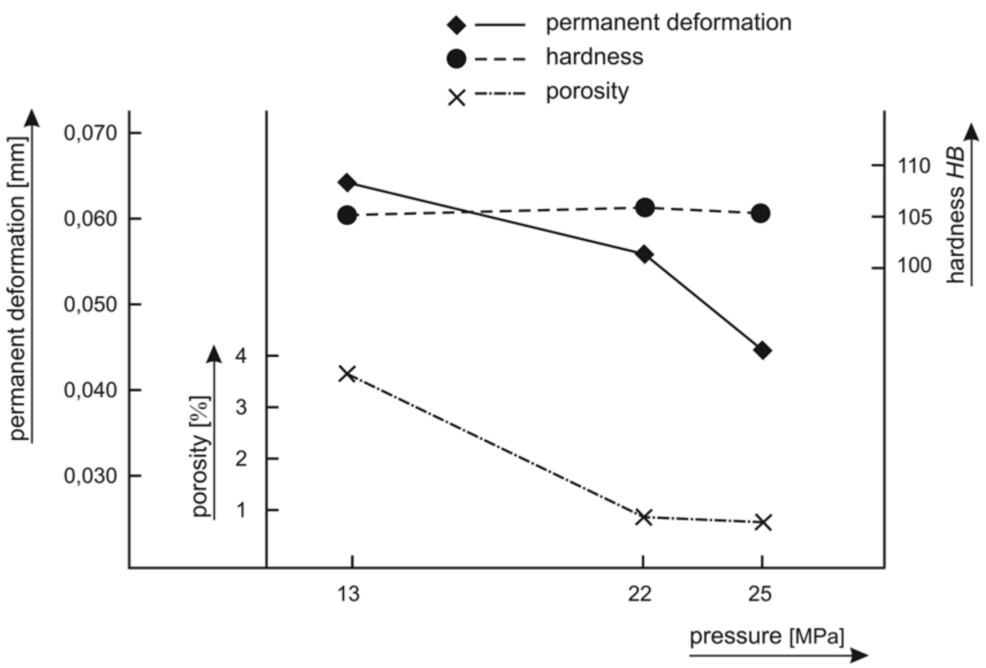

Figure 2. Dependence of specific pressure

6. Analysis of Achieved Results

From the perspective of the impact of specific pressure on the alloy inside a pressing mold in the last phase of the casting cycle on the value of permanent deformation and porosity, it is clear - that the highest values of permanent deformation and porosity have been recorded at the lowest value of increase pressure, i.e. 13 MPa. The higher the increase pressure has been, the lower the values of permanent deformation have been observed. As can be seen in Fig. 2., regarding the values of permanent deformation and porosity, the highest quality of the casts has been reached at the highest values of increase pressure of 25 MPa which are s = 0.044 mm and f = 0.79%. Based on the above mentioned, positive impact of rising values of increase pressure on metal inside a mold cavity on the values of mechanical properties by reduction and strong compression of the volume of pores in the walls of a cast can be clearly seen.

Significant difference among the hardness values of the casting surface from the perspective of the increase pressure change has not been proved.

7. Conclusion

Increase pressure is currently one of the most discussed factors of die casting. Its high value on one hand reduces service time of molds and increases idle time of die casting machines, on the other hand, increases the castings refill, reduces the volume of air that is entrapped in the solidified castings (porosity) and thus enhances their quality (strength, tightness, etc.). The size of the increase pressure value (specific pressure in a mold cavity) is practically determined individually according to a cast type of the casting and the alloy. For the castings with high strength and tightness requirements, the increase pressure of approx. 60 to 100 MPa is used.

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