ANALYSIS OF INFLUENCING THE MACROSTRUCTURE AND HARDNESS OF CASTING SURFACE LAYER BY CHANGING CONDITIONS OF CRYSTALLIZATION

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In manufacturing technology, we often encounter the demand for increasing surface hardness of the machinery components. Although there are new varied coating and surface hardening technologies, those are processes implying increasing costs, economic burden and time required for the manufacturing process including increase in production capacities, increased need for machinery and equipment, or possible dependence on external suppliers. The capability of increasing hardness of components starts in casting itself. By understanding and mastering the processes involved in the process of solidification of the melt it is possible to adjust technical parameters so that the hardness characteristics of the casting is increased by the crystallization process and thereby also by the formation of the internal structure morphology.

The article presented deals with assessing the changes in surface hardness of castings achieved by changing crystallization conditions. The issue of crystallization is addressed in terms of the processes accompanying the process of melt solidification in casting mould. The parameters observed are macrostructure and hardness of castings fabricated using high pressure die casting technology and changes of these parameters compared to the surface hardness of the castings produced using conventional foundry technologies. At the same time, the influence of structural design of the gate on the selected parameters is observed.

KEYWORDS

crystallization, hardness, macrostructure, high pressure die casting

1 INTRODUCTION

Increase in using casting in modern construction requires good knowledge of the principles of foundry processes and their targeted use. High pressure die casting of metals occupies the forefront among foundry technologies. This is due to the production of thin-walled products complicated in terms of shape with high-dimensional accuracy and strictly copied surface relief of the mould. The specificity of this technology is also reflected in the crystallization mechanism and the crystalline structure of the castings. The mechanism is determined especially by a high degree of sub-cooling of the melt in contact with the mould face and a high-pressure crystallization process. This is reflected in the fine of the surface layer on which the casting hardness depends. [Gaspar 2017] [Ruzbarsky 2014]

2 PHENOMENA OCCURRING DURING THE MELT SOLIDIFICATION IN THE MOULD

Crystallization of alloys is generally characterized by formation of crystal structure of solid phase during the melt solidification. According to the crystallization theory, crystallization nuclei may be created under specific thermodynamic conditions directly from the melt, which is referred to as homogeneous crystallization, or on active nucleation objects, that is, during forced heterogeneous crystallization. Research demonstrated that the homogeneous crystallization occurs during sub-cooling higher than $\Delta T = 0.2$ TL, where TL means the liquidus temperature [°C]. However, practice showed that crystallization occurs even with significantly lower sub-cooling temperatures. The main cause of crystallization is the physical contact of the melt with the mould face. By removing the heat from the overheated melt through the mould wall, the melt at the point of contact is cooled and the formation of crystallization nuclei starts. With increasing sub-cooling temperatures the critical nuclei size from which the crystallization process starts decreases, which results in increasing its number, and the casting structure consists of smaller crystals. The cooling intensity has a substantial impact on the growth of the crystals. Changing conditions and the speed of the solidification can be seen also in changes in the structure of the parts of the casting in the proximity of relatively cold mould wall and the heat axis of the casting. As a result of different cooling speed, the structure between the casting surface and its heat axis is formed by areas of grains with different morphology (see Fig. 1).

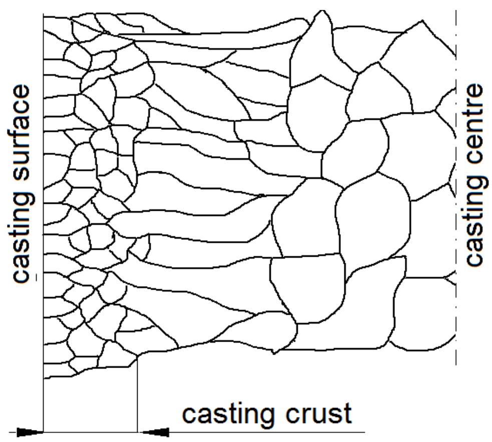

Figure 1. Morphology of parts of casting structure

The mechanism of the formation of diverse casting structure as a result of changing solidification conditions is showed in Fig. 2.

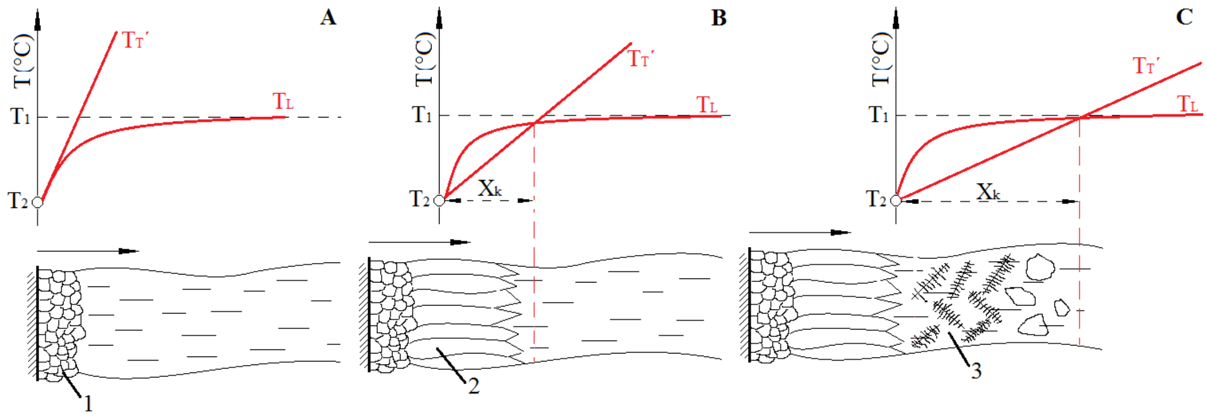

Figure 2. Changing solidification conditions during casting cooling process

After filling the mould with the superheated melt, as a result of the contact of the melt with the mould wall, the alloy starts to cool down. With sufficient sub-cooling temperature of the mould walls, the amount of emerging crystallization nuclei is high enough for beginning of the heterogeneous crystallization. On the crystallization nuclei the initial stage of solidification starts, which passes to stationary process of solidification. As a result of intense heat removal (see Fig. 2A), the grains are fine at the initial stage with high temperature gradient dT_T/dx (1) and grow fast. At the end of grow-finishing phase, a part of the grains serves as nuclei for further crystallization. With a continuing solidification the temperature of the mould surface rises and subsequently the heat removal gradually decreases together with the reduction of the temperature gradient (Fig. 2B). Under the fast solidified casting crust, the solidification progresses more slowly and other grains (2) grow on the casting crust crystals. Therefore, the grains are coarser and longer with oblong axis orthogonal to the casting heat axis. The axis orientation is a result of a dominant influence of the direction of heat transfer. In the proximity of the casting heat axis the oriented heat transfer is stopped due to high sub-cooling (Fig. 3C), and on the nuclei emerging in the melt in front of the solidus-liquidus interface, randomly-oriented (so-called equiaxed) polydendritic grains (3) with dendritic structure appear. [Murgas 2002] [Gaspar 2016]

3 EXPERIMENT MATERIAL, METHODS AND EQUIPMENT

The subject of macrostructure analysis were castings made of the EN AC 47100 – AlSi12Cu(Fe) alloy. The melt temperature in the melting and holding furnace was 708 °C, while the temperature of die casting mould was 220°C. Macroscopic evaluation of the samples taken from castings was carried out using OLYMPUS GX51 microscope. The samples hardness measurement was carried out by means of the Brinell hardness test method using HPO 250 hardness tester. The hardness measuring conditions were set in accordance with STN EN 6506-1 (STN 42 0371):

- Ball diameter D = 2.5 mm,
- Load force F = 613 N
- Dwell time t = 10s.

4 ANALYSIS OF MACROSTRUCTURE AND HARDNESS OF CONVENTIONALLY FABRICATED CASTS

Fig. 3 shows the macrostructure of the cast fabricated using gravity casting.

Figure 3. Macrostructure of sample edge (gravity casting) /250x/

Upon the contact of the melt with the mould face, in the casting subsurface fine-grain structure is seen which grades to the polydendritic, randomly oriented grains zone, thereby confirming the assumptions based on the theoretical findings in foundry.

Hardness values HB were measured at five points of selected evaluated castings. The values measured are showed in Tab. 1.

Casts surface hardness values *HB* according to Brinell – gravity casting							
Samples	Measured values					Arithmetic mean of individual measurements	Overall arithmetic mean
	No. 1	No. 2	No. 3	No. 4	No. 4		
1	75	76	75	76	74	75.2	75.28
2	76	76	75	77	76	76	
3	74	75	74	76	76	75	
4	73	74	75	76	75	74.6	
5	78	76	74	73	76	75.6	

Table 1. Surface hardness HB of casts made by gravity casting

According to the measured hardness values HB, the overall average value is 75.28 HB. This value is identical with the values given in material data sheet of the alloy provided by the supplier.

5 ANALYSIS OF MACROSTRUCTURE AND HARDNESS OF DIE CASTS

Fig. 4 shows the macrostructure of die cast. It demonstrates fine-grained structure at the point of contact of the melt with the mould cavity (the point is showed coloured red).

Figure 4. Macrostructure of sample edge (high pressure die casting) /250x/

The casts hardness test was conducted on five sets of casts fabricated with different gate length. Hardness HB was measured at five points of selected casts in each set. The objective was to determine the impact of the gate length on the degree of hardness. As in the gate the metal flow is regulated and its speed increases, subsequently changes in the flow and filling in the mould cavity occur. The results of the tests are given in Tab. 2.
As seen from the measured values, the hardness values of the castings fabricated using high pressure die casting were on average 106 HB and 107 HB. The changes in casting hardness influenced by changes in the gate length are showed in Fig. 5.

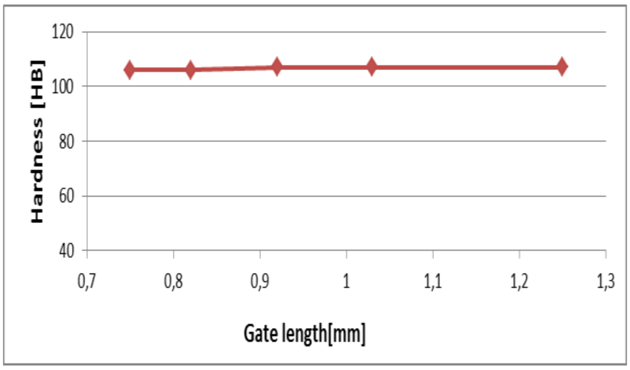

Figure 5. Dependence of casts surface hardness HB on gate lengt

Casts surface hardness values *HB* (Brinell) depending on gate length HPDC								
Sample	Gate length [mm]	Gate thickness [mm]	Measured values [HB]					Arithmetic mean
			No.1	No.2	No.3	No.4	No.5	
1	1.25	60.968	108	107	108	107	107	**107 HB**
2	1.03		109	107	106	108	106	**107 HB**
3	0.92		106	108	107	108	107	**107 HB**
4	0.82		106	104	107	107	107	**106 HB**
5	0.75		105	107	105	106	107	**106 HB**

Table 2. Surface hardness HB of casts made by hight pressure die casting

6 ANALYSIS OF THE RESULTS ACHIEVED

The objective of the paper was to identify and describe the impact of changing crystallization conditions on the casts surface macrostructure and hardness. The conditions under which the crystallization took place were influenced by changing foundry technology. The evaluated castings were fabricated using gravity casting and high pressure die casting. Diverse conditions of melt solidification in the mould enabled different crystallization processes influenced mainly by solidification time and by temperature gradient in the interface of melt – mould wall. In the high pressure die casting, crystallization occurs under the pressure.
Comparing the macrostructures (c.f. Fig. 3 and Fig. 4) it is obvious that the structure of casts fabricated using high pressure die casting is finer and is constituted of higher number of finer grains. This phenomenon is closely related with the surface hardness of the casts being evaluated. The hardness of gravity die casting fabricated castings was about 75 HB, which corresponds to the values given in the material data sheet of the alloy observed. Using high pressure die casting technology, the surface hardness increased to 106 HB–107 HB. This increased the surface hardness of the casts made of the same alloy by 24 %.
Comparing the macrostructures with the hardness values it may be stated that with finer structure it is possible to improve the casts surface hardness. The impact of gate length and change in the mould cavity filling on the hardness values was not confirmed. The insignificant difference in the values measured indicates that the casts surface hardness is not affected by changing the mould cavity filling regime, but is related to the degree of sub-cooling in the contact of the melt with the mould wall, casting solidification time and the pressure on the melt during the solidification. [Majernik 2017] [Majernik 2014]

7 CONCLUSION

Understanding the principles of the processes involved in the melt solidification in the mould enables engineers and designers of technological equipment better designing of technology nodes on the basis of crystallized alloys. One of the basic phenomena associated with solidification is crystallization. Choosing the right foundry technology and setting appropriate technical parameters can significantly influence mechanical properties of castings.

The article deals with the impact of crystallization conditions on the casts structure and hardness. As shown above, changing crystallization conditions allowed change in the structure of the material surface layer. Subsequently, it was confirmed that the casts surface layer structure directly influences the hardness values HB. The formation and morphology of the crystalline structure are thereby directly dependent on the degree of sub-cooling of the melt in the contact with the mould face and solidification time, and the effect of the pressure during crystallization process is also a key factor.

It may be concluded that by modification of crystallization and crystallization condition in order to achieve fine-grained structure of the subsurface layers it is possible to increase casting hardness.

The tests and findings described in the article were carried out under the initiative resulting from the TACR project solved in cooperation with Jihostroj. The conclusions reached when addressing the issue have been implemented in the design of the alloy used for thrust faces of gear-pump of T3 series.

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