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SHAPE COMPLICATED CASTING DEFECTS PREDICTION BASED ON COMPUTER SIMULATION

OCENA WAD ODLEWNICZYCH SKOMPLIKOWANYCH KSZTAŁTOWO ODLEWÓW NA PODSTAWIE SYMULACJI KOMPUTEROWYCH

The impact of mould filling parameters on casting defects in shape complicated skeleton casting was investigated. Skeleton castings are low weight cellular material mainly used for energy absorption in for example automotive industry. For prediction of defects such as porosities, the computer simulations of mould filling and solidification were used. In such shape complicated structures like skeleton castings it is very difficult to predict localization of the defects. This knowledge is very important to gain information about deformation mechanisms and for impact behaviour modelling. Series of the skeleton castings were investigated by computer tomography to validate simulations results.
Keywords: skeleton casting, spatial composite, lattice block structures, periodic metal

W pracy określono wpływ parametrów wypełniania wnęki formy na miejsca występowania wad odlewniczych w odlewach szkieletowych o rozwiniętej topologii wewnętrznej. Odlewy szkieletowe są produktami komórkowymi o niskiej masie, stosowanymi głównie do absorbowania energii kinetycznej, na przykład w przemyśle motoryzacyjnym. W celu wyznaczenia miejsc prawdopodobnego występowania wad odlewniczych, użyto symulacji komputerowych wypełniania wnęki formy oraz krzepnięcia. W odlewanych elementach szkieletowych, znacznie utrudnione jest precyzyjne określenie potencjalnych miejsc występowania wad. Wiedza ta jest niezbędna, w celu zdobycia informacji o mechanizmach deformacji odlewów szkieletowych. Istotna jest również z punktu widzenia modelowania numerycznego ich zachowania w przypadku odkształceń o dużej dynamice. W celu potwierdzenia wyników symulacji przeprowadzono serię badań z wykorzystaniem tomografii komputerowej.

1. Introduction

Cellular structures (CS) like metallic foams, lattice structures or sandwich panels are designed as multifunctional structural elements. Their main properties are high strength with low weight, good resistance to dynamic loads, acoustic insulation and possibility of heat flow control. Properties of CS depend on material which these are made of and their internal features – topology and microstructure. Lattice truss structures, metal foams and honeycombs offer a number of practical advantages. From economical and ecological point of view they should allow lowering the weight of constructions. This gives the possibility to save resources and sometimes energy used in manufacturing processes. Lower weight in aerospace and automotive industry also connects with lower energy consumption. Most challenging, while designing lightweight material is to achieve good proportion between strength/stiffness and weight.

Mechanical, thermal and electrical properties of CS are closely related to its application and manufacturing technique. Shape of internal cells, size of walls and ligaments are responsible for relative density. Basic information was shown in Ashby's studies [1].

Constructions close to skeleton castings can be made with different techniques. These constructions are manufactured with use of specific patterns, hollow tubes and rods. Another approach is with forging techniques. The core is formed from steel plates with use of press and bonded with outside walls with laser spot welding. Those panels are resistant to dynamic loads and mainly used in aeronautics [2-4]. Foundry technologies are also used for manufacturing of lattice and skeleton structures. Traditional casting methods are applied. Techniques of investment castings are useful. [5-11]. Together with the use of antigravity casting they provide possibility to obtain castings with ligaments of about 1.5 mm diameter [12-14]. This kind of castings are used by NASA for exhaust nozzle structures [15].

Casting techniques are used for manufacturing skeleton constructions where the core is made of cast AlSi tubes. It is less liable to buckling than skeleton castings, but manufacturing process is much more complicated. Each strut has to be mould and cast separately and then bonded together with welding technique.

Combination of electro-erosion and casting technology is also used.

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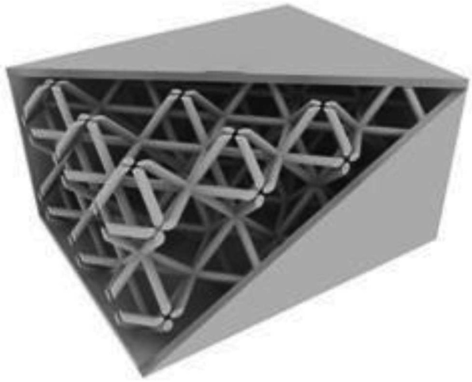


Fig. 1. Skeleton casting with octahedron internal topology

Foundry techniques (moulding, core making) put some limitation to the internal topology of skeleton castings (Fig. 1). There are a limited number of topologies possible to mould. This problem can be solved by using additive methods of production.

Moreover CS with open cells such as skeleton castings allows significant improvement of heat dissipation [16-18]. This makes possibility of using it as industrial power supplies heat radiators. Casings of power supplies made this way act also as part of heat dissipation system.

Potentially very wide possibilities of practical application of CS are a very important reason to its development also with the use of casting techniques [11], [19-22].

2. Range of research

This article shows results of mould filling parameters on location, size and character of internal defects of skeleton castings. Skeleton castings have in assumption complicated internal topology. It could be said that topology is non technological. Meeting points of internal ligaments are obvious hot spots (Fig. 2). Those locations are crucial from the casting technology point of view. The diameter of ligaments which in this situation acts as a channel for liquid metal mostly depends on desired mechanic properties of casting. Only at later stage, it may be subordinated to the technology.

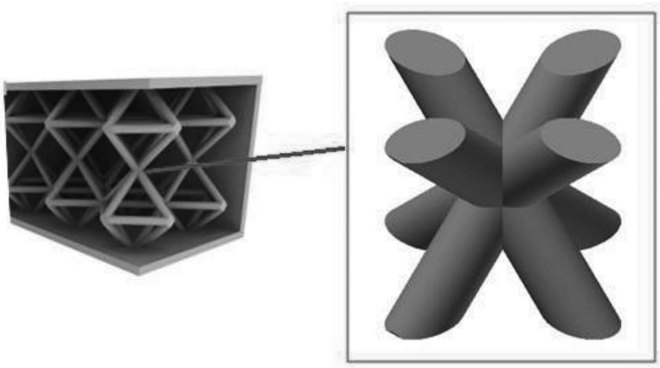


Fig. 2. Skeleton casting node with adjacent ligaments

Skeleton casting large surface of active heat dissipation can be problem at stage of creating defect free casting. It requires mould filling parameters to be precisely set.

2.1. Simulations

To describe preliminary mould filling parameters, FEM analysis of mould filling and solidification processes were carried out. As a base the skeleton casting with the octahedron elementary cell was used [5] The results were analysed in aspect of searching location of probable shrinkage porosities. According to the authors, the most important to assure correct internal structure of skeleton castings are following parameters:

- pouring temperature
- thermo physical properties of the alloy
- thermo physical properties of the mould material
- thermo physical properties of the core

The influence of gating system geometric features was skipped because conventional compression gating system with higher metallostatic pressure was used. As the optimal parameters of carried out simulations following values were used:

temperature of the alloy – 963K

temperature of the alloy – 373K

As the base an AlSi11 alloy was used. The mould was made from green sand with thermal conductivity at 373K – 0.742 W/mK. An insulating with thermal conductivity coefficient 0.25 W/mK in 373K was adopted as a core material.

2.2. The skeleton casting manufacturing

According to experimental plan three model castings were made. Dimensions of the castings are 120×120×80 mm. Thickness of the outside walls and diameter of ligaments is 6 mm. Used alloy as well as moulding materials are the same like in FEM experiment. For mould conventional green sand, and as core Al2O3 ceramic bricks were used. Mould with fixed core was dried and heated to required temperature. Each casting is characterized by different temperature of an alloy and mould. Parameters of each trial are shown in Table 1.

TABLE 1

Selected manufacturing parameters of each casting

	Casting 1	Casting 2	Casting 3
Temperature of an alloy [K]	690	820	690
Temperature of the mould and core	100	100	200

2.3. Shrinkage investigation

In purpose to describe shrinkage in skeleton castings V|tome|x L 450 computer tomography system was used. Bipolar minifocus X-ray tube – specially optimized for CT applications – in metal with maximum voltage of450 kV and power of 1500 W was used. Reconstruction and further analysis were provided by VGL Studio software.

Skeleton castings internal topology (without walls) was analyzed in three planes. In XY and XZ plane three sections and in ZY plane two sections were analyzed. Each sample in selected cross-sections the cutting plane passes exactly through the geometric center of the octahedron (Fig. 3).

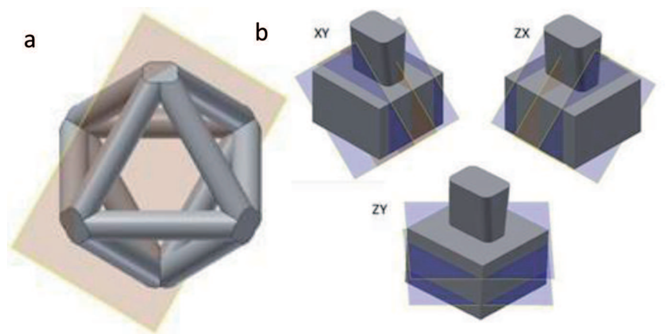


Fig. 3. Cross- section selection of shrinkage investigation; a) elementary cell; b) casting shape with feeder

That made possible to analyze shrinkage in axis of ligament and in center area of the node. Investigation was carried out in 20 mm area in nodes and ligaments (Fig. 4).

Shrinkage was also analyzed by NIS Elements computer image analysis system.

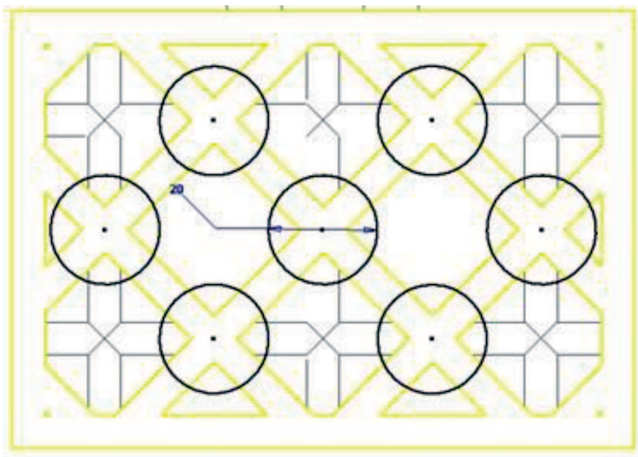


Fig. 4. Areas of shrinkage defects analysis

3. Results and discussion

The mean area of porosity and total surface pore area for each plane and castings were evaluated. Then the results were compared with the results of the simulation. Figure 5 and Figure 6 shows examples of the analysed areas, respectively, in the simulation and actual casting.

Distribution of porosity presented by the simulation program shows the percentage of shrinkage defects in marked area. It is impossible to say in what form this hollow is present: either in the form of one solid pore or many small pores. In the present case the limit value of porosity below which the results were not taken into account is 5%. This value is represented by the green contour line in Figure 5. The simulation shows that the most likely place for the formation of shrinkage defects are nodes and areas next to the nodes.

Defects locate almost symmetrically in relation to the axis through the centre of the node. Average porosity surface area in the XY plane is 0.25 cm^2, and in the ZX plane is 0.29 cm^2, while analysed cross-sectional area is 42.84 cm^2. The simulation results suggest that, in the plane ZY shrinkage cavities will not occur. ZY plane is perpendicular to the direction of filling the mould cavity.

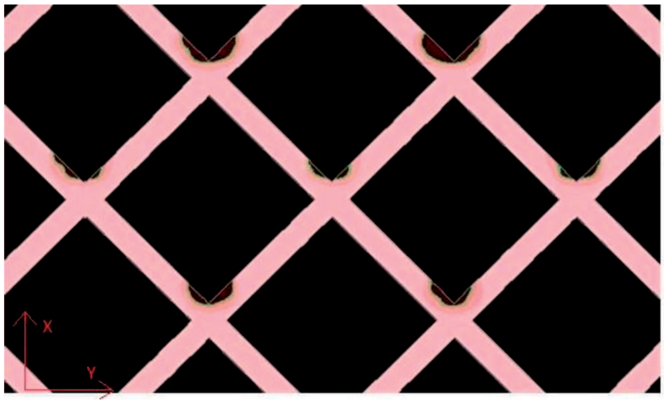


Fig. 5. Selected result of computer simulation with areas of probable shrinkage defects

Figure 6 shows an example of analyzed cross section of skeleton casting. There are shrinkage defects in places other than those provided on the basis of the simulation. Additionally, in most of the analyzed images coldshuts defects can be observed in the top layer cells. Their occurrence may be due to rapid filling of the mold cavity. Coldshuts and misruns were not observed in the casting 2, where pouring temperature was 1093K.

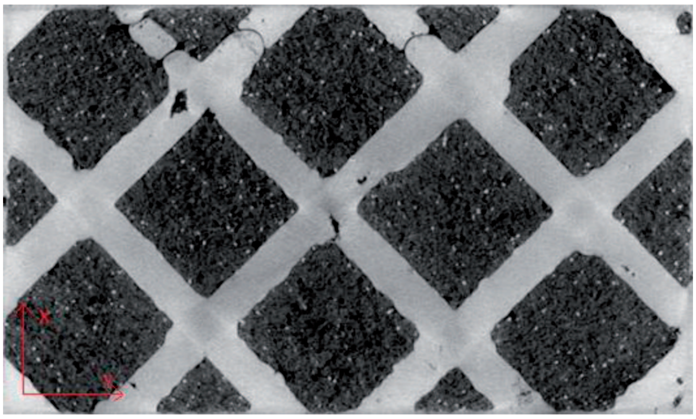


Fig. 6. Selected CT result image with defects in skeleton casting

In all of the sections in each plane the quantitative data were aggregated and are presented for each casting. The results of analysis of the mean area of porosity are shown in Figure 7.

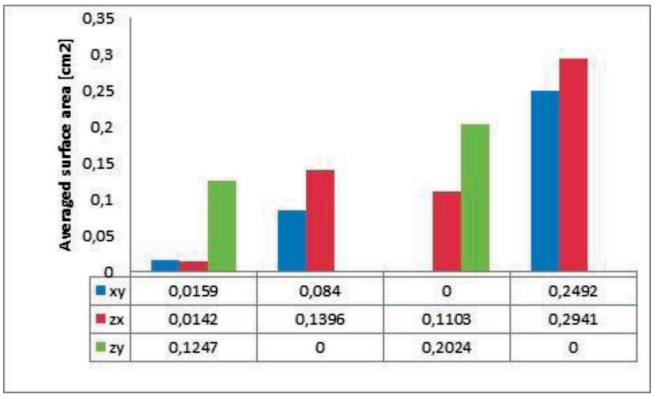
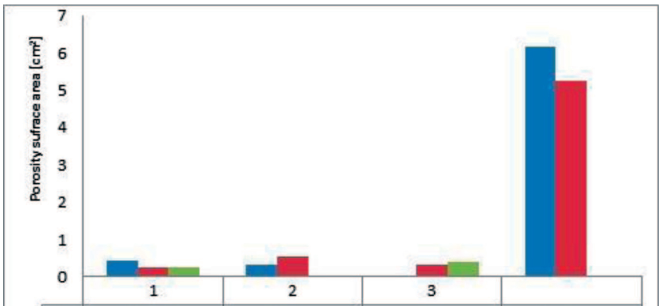


Fig. 7. The mean area of porosity for each casting and simulation result



	1	2	3	
xy	0,4392	0,308	0	6,1767
zx	0,2351	0,5586	0,3308	5,2585
zy	0,2494	0	0,4049	0

Fig. 8. The porosity surface area of each skeleton casting summed for all the sections in a given plane

There are no shrinkage defects in castings 3 in the XY plane and cast two ZY plane. Figure 8 shows the porosity surface area of each skeleton casting summed for all the sections in a given plane. Based on the Figure 8 it can be stated unequivocally that the simulations give significantly overestimated results on the assessment of the shrinkage defects in such geometrically complex components which the skeleton castings are.

4. Conclusion

In Figure 8 it is shown that shrinkage porosity are insignificantly small. It is also obvious that other defects need to be optimized. The results indicate the specific analysis of the filling of the mould cavity and uselessness of simulation in the design of similar technologies. It is advisable to develop an algorithm, maybe using reverse tasks in relation to the use of traditional simulation programs. It is crucial to develop correction factors or tailored module to simulate the skeleton castings – thin-walled castings with developed cooling surface area. Skeleton At this stage of research there is not enough data to formulate hypothetical rules solidification of skeleton castings which are an example of the need to individual development of casting technologies for special purposes.

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