METAL FOAM AS A HEAT EXCHANGER

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Abstract

The paper deals with the optimization of manufacturing of cast metal foams and possibilities of using of this specific material. It is focused on castings from aluminum alloy with a regular arrangement of internal cells. The optimization relates to already used casting technologies - production of metal foams using sand cores. Casting of metal foams has a wide range of applications such as: automotive, aerospace, construction, energy. They have unique properties thanks to reduced weight with sufficient strength and they are used e.g. for: absorbing impact energy or heat conduction. In this article we deal with the usage of the metal foam as a heat exchanger. The shape and size of heat exchanger depending on its effectiveness by using a simulation program is solved.

Keywords: Metal foam, 3D modelling, heat exchanger, heat conduction, efficiency

1. INTRODUCTION

Metal foams are materials with ongoing research and we can say that they can be materials of the future. These unique materials contain artificially created pores in their structure and thanks to these pores metal foams have specific properties such as large rigidity at low density. There are many different ways to create metal foams. This article deals with metal foams manufactured with foundry technology - infiltration of molten metal into the mold cavity filled with preform. Thanks to this technology we can create casting of metal foams with regular structure with open interconnected pores so the gaseous or liquid medium can flow through them. Such types of castings can be used as heat exchangers. This paper presents a computer simulation that evaluates the efficiency of the proposed heat exchangers [1].

1.1. Procedure for solution

First we manufactured the prototype of heat exchanger - the real casting of metal foam with regular inner cells and with a solid wall separating two floors of cavities. On this basis, a geometric model of the heat exchanger (metal foam) and a classical pipe heat exchanger were created. Both variants were calculated by simulation software Ansys 16. It has been found that the heat exchanger in the form of a metal foam has better heat transfer efficiency [2]. Therefore, other variants of the internal geometry of the casting of metal foam in the newly acquired software Ansys R18.0 were created and calculated.

2. EXPERIMENTAL PART

This part is devoted to the design and testing of metal foam geometry with a regular internal arrangement for use as a heat exchanger.

2.1. Individually assessed geometry

The four different geometries of the co-flow heat exchangers have been designed, which are shown in **Figures 1 - 4**. It is about heat exchangers with the spherical cores which differ from each other. Change of the heat exchangers is either in a different cores arrangement during casting in their body or change of the input and output. The each mathematical model has contained a mesh with approx. 5 million cells. Heat exchangers were simulated with the same boundary conditions at the input, output and side for comparison of the results with each other. At the same time conventional tube heat exchanger was re-calculated and its outputs were chosen as a reference for a better comparison. The results are included in **Tables 2, 3**.

2.2. Boundary conditions

The calculation of both geometries was divided into a two main domains. The first domain was set up as a liquid representing flow water. The second domain was set up as a solid body representing a metal heat exchanger. The material properties of both domains are summarized in **Table 1**. Wall roughness is not included in the calculation [4]. A heat transfer coefficient of the value 5 W/(m^2·K) was applied to the outer walls of the heat exchangers, which representing free laid body in the space and is freely cooled by the external environment. [4]. Velocity condition of 1 m/s was applied at the input and an average static pressure of value 0 Pa was applied at output. **Table 2** summarizes the initial values of boundary conditions [4, 5].

Table 1 Material properties

Properties	Unit	Domain	
		Water	Aluminum
Thermal conductivity	W/(m·K)	0.6069	237
Specific heat capacity	kg/(J·K)	4181	903
Density at 20 °C	kg/m^3	997	2702
Dynamic viscosity	kg/(m·s)	$8.9 \cdot 10^{-4}$	-

Table 2 Boundary conditions

Inlet		Outlet	
The temperature of the upper floor (°C)	80	Average static pressure ([Pa)	0
The temperature of the bottom floor (°C)	20	Average static pressure (Pa)	0
The flow velocity in the upper floor (m/s)	1		
The velocity in the bottom floor (m/s)	1		

2.3. Results

The calculation was run on a workstation including 16 CPus, 64Gb Ram and SSD. The calculation was finished after approx. 6 days. Convergence was achieved under the required accuracy of 5E-5. The precision is adequate to compare each model. **Table 3** summarizes the average values of the output areas of the fourth heat exchangers.

Table 3 The average value of the output temperature (°C)

	Hot side	Cold side	Hot side outer + center average	Cold side outer + center average
Geometry 1	74.35	25.55		
Geometry 2	68.85	31.15		
Geometry 3	69.75	30.25		
Geometry 4			67.5	32.45
Geometry 5			68.35	31.6
Geometry 6	62.25	37.85		

The results of the thermal field in a plane located in the center of the spherical core are shown at **Figures 1-6**, In other words at the points of flowing water in all calculated variants. The heat exchanger number 6 was the best one of the all designed heat exchangers. This heat exchanger is characterized by the arrangement of the balls in four rows. Two rows are interconnected in a pair. The each pair is separated from each other pair by the wall. Its efficiency is numerically the highest, as **Table 3** demonstrates.

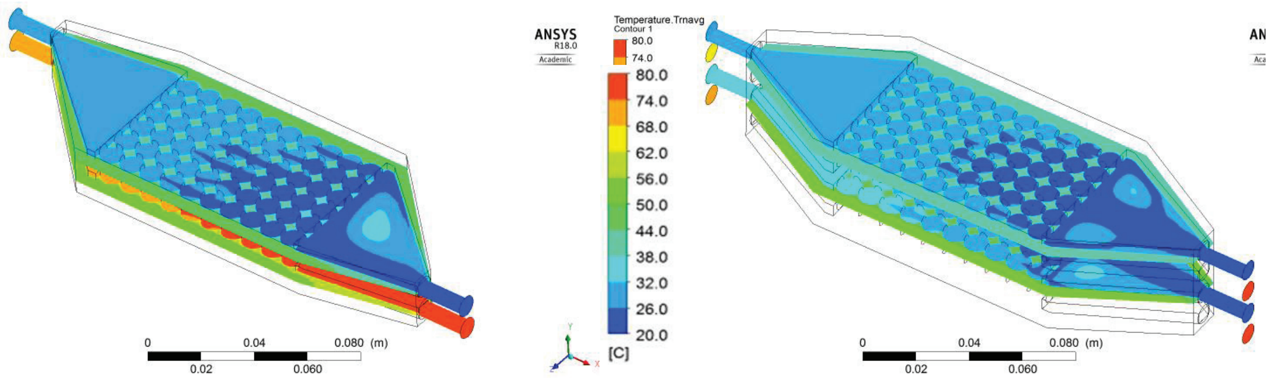

Figure 1 Cold side of the heat exchangers geometry 3, 4

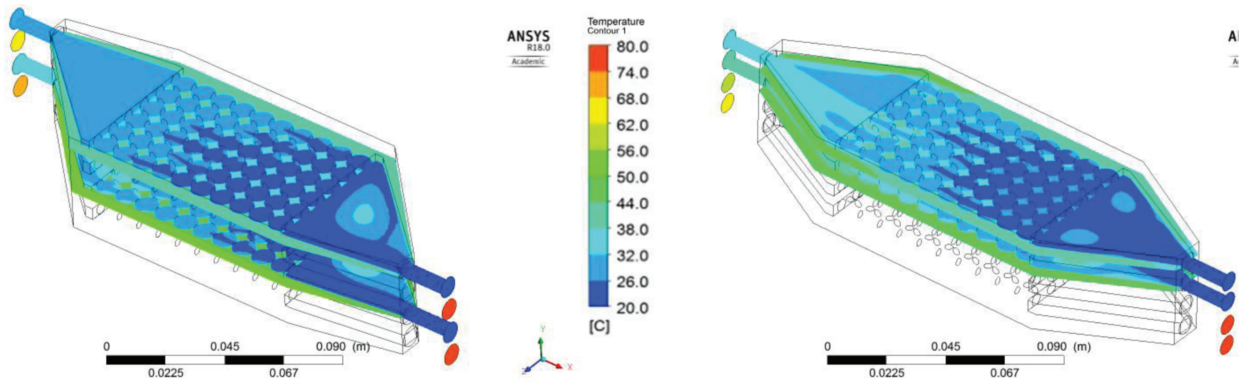

Figure 2 Cold side of the heat exchangers geometry 5, 6

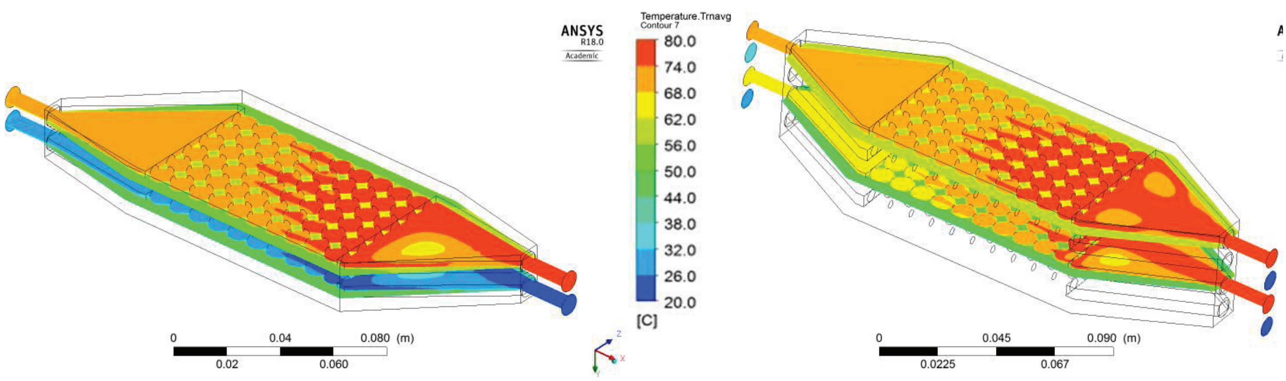

Figure 3 Heat side of the heat exchangers geometry 3, 4

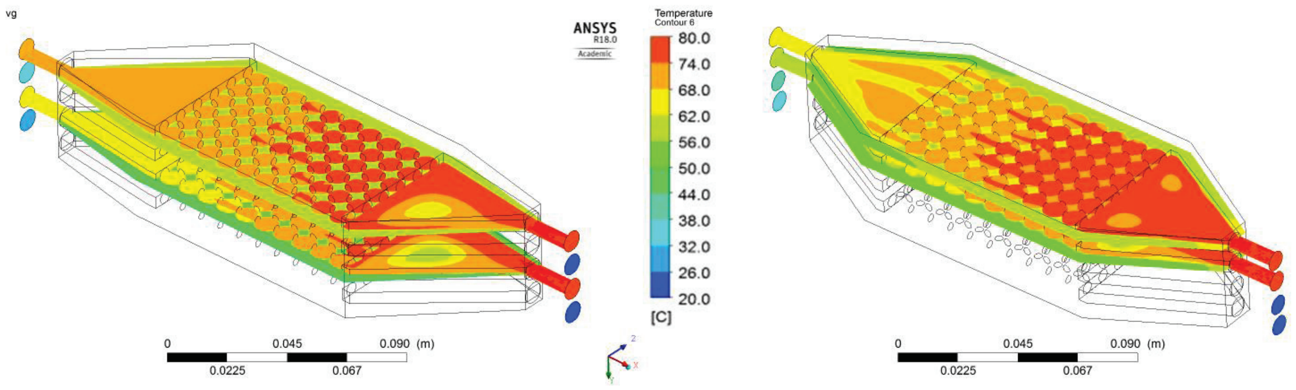

Figure 4 Heat side of the heat exchangers 5, 6

The thermal distribution on the surface of the heat exchangers (warm side) is shown at **Figures 5 and 6**. It can be seen that heat exchanger No. 5 has achieved a uniform distribution of heat from the center towards its outlet. While heat exchanger No. 6 has achieved a certain thermal gradient over the entire surface. The heat exchanger No. 6 seems to be the best. However, it depends on its application in an industry. For heat exchange purposes in order to achieve the most efficient heat exchange for secondary use, this would be suitable, but for the purpose of uniform heating of a heated bed for laboratory conditions etc., it would certainly be preferable the exchanger No. 5.

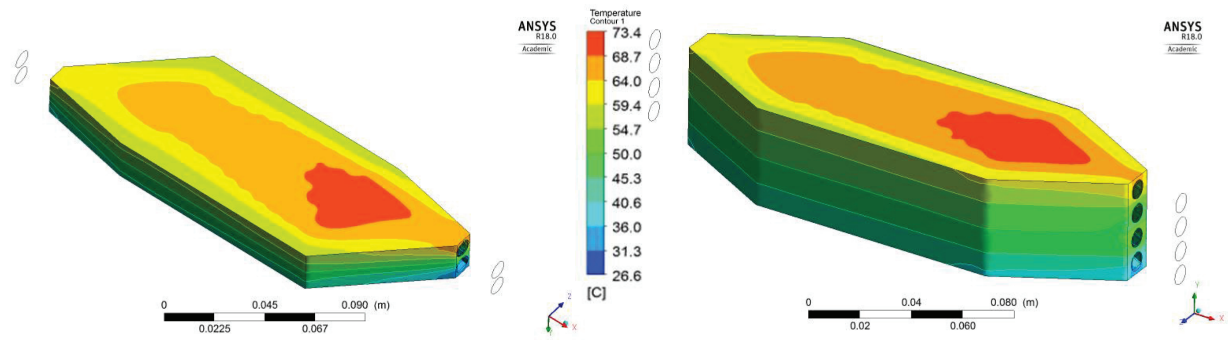

Figure 5 Thermal distribution on the surface geometry 3, 4

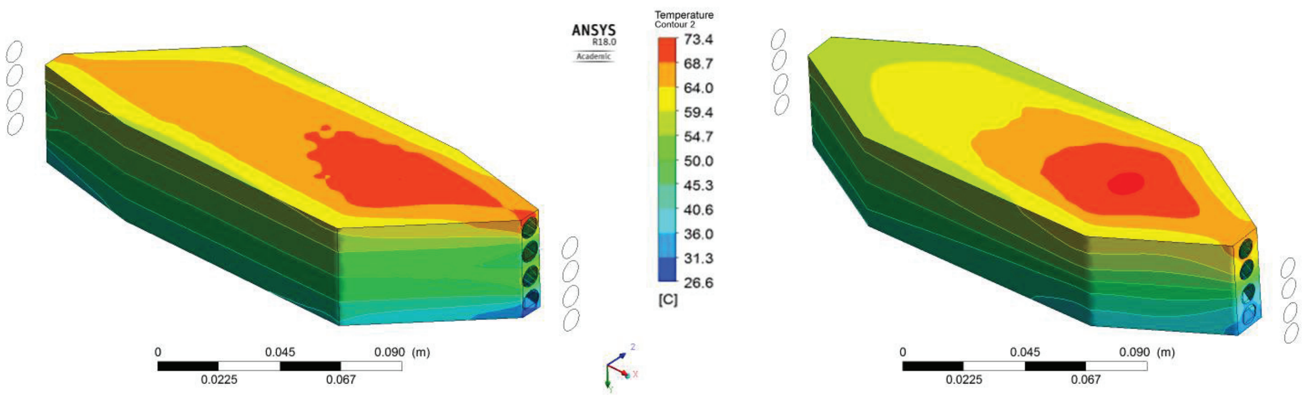

Figure 6 Thermal distribution on the surface geometry 5, 6

The pressure field within the individual heat exchangers is shown at **Figures 7** and **8**. All heat exchangers have a similar pressure distribution; the overpressure is in the range of about 0 to 10 kPa, except for the heat exchanger number 6. There is no higher pressure loss in this heat exchanger, the overpressure is about 0 - 6.5 kPa. Geometry designed in this way is particularly suited to applications where less efficient pumps are needed, with an emphasis on its size or energy consumption. To achieve the same mass flow would require a 40% more efficient pump.

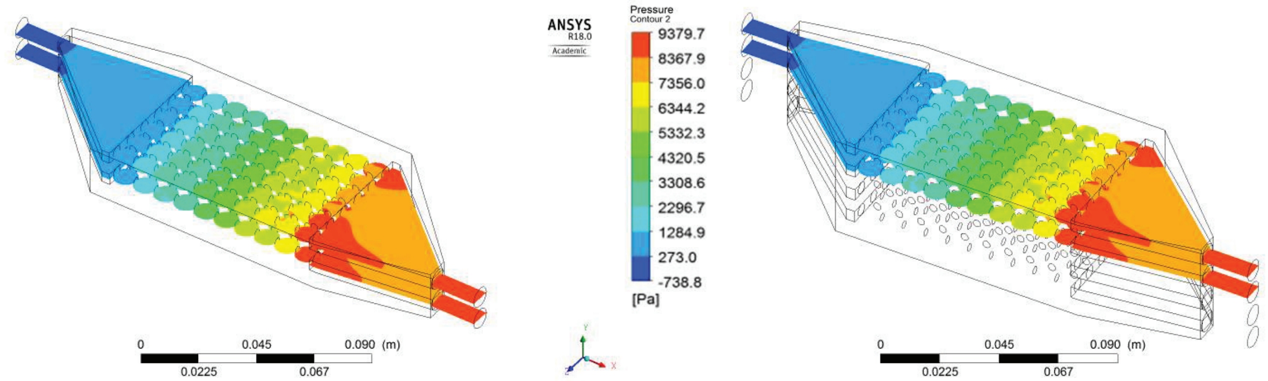

Figure 7 Internal pressure field

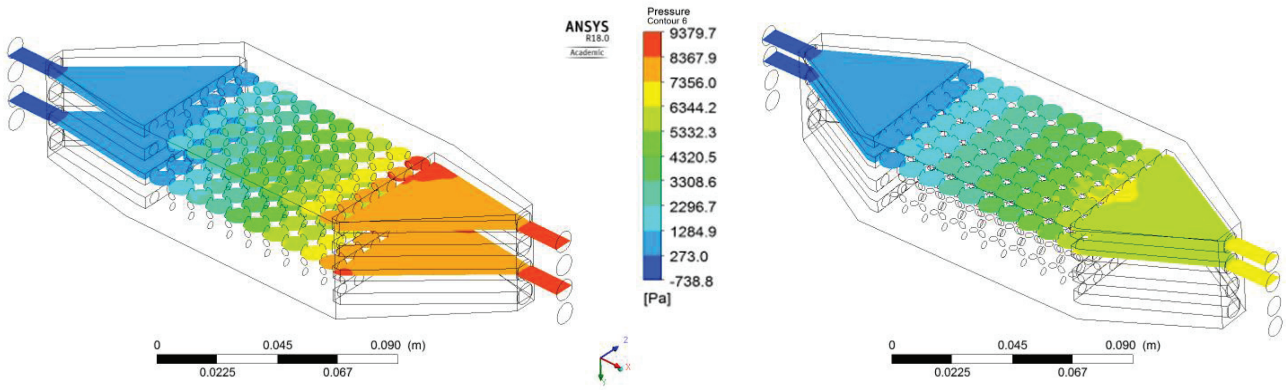

Figure 8 Internal pressure field

3. CONCLUSION

Due to the technology of infiltration of molten metal into the mold cavity, we can create a cast metal foam with a regular arrangement of internal cells. One possible application of castings with such a complicated inner cavity is a heat exchanger. For the purpose of verifying efficiency, variants were simulated to simulate flow of liquid media through a metal foam. Computational analysis showed that computational analysis has shown that such a designed heat exchanger could find its application in engineering practice. It achieves better results than a conventional tube heat exchanger, which is found, for example, in boilers for water heating. Its thermal efficiency is higher and even the pressure losses correspond to the results of heat exchanger No. 6. Such a heat exchanger with its design and robustness could also be used in nuclear power engineering, where production safety and material inclusions are strictly monitored. Advantageously, we can consider its modularity or usability as a deformation safety member and heat exchanger in synergy to heavy traffic.

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