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Modelling of the material destruction of vertically arranged honeycomb cellular structure

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ABSTRACT

The paper presents the results of the experimental and numerical analysis of material destruction of honeycomb cellular structure. Based on the experimental research, the results of numerical calculations regarding the compression process were verified along with the correctness of used constitutive numerical model. The destruction was analyzed for the casting with no structural defects and for the casting with detected porosities. The results were compared to the structural strength of the honeycomb structure manufactured on the CNC machine. The metallic honeycomb structure was manufactured as a casting of Al alloy in the investment casting technology. For manufacturing purposes the honeycomb model was obtained in additive manufacturing process. The castings and the CNC honeycomb were used in the compression test trials. The process was controlled by the displacement and the results were registered as the changes of the height and the force value. Based on the experimental results the numerical model of honeycombs was introduced for the numerical analysis of the energy absorption and compression process. The results showed good correlation between the experiment and FEM (*Finite Element Method*) analysis.

1. Introduction

The use of cellular structure materials in the various fields of technologies is the result of the research of the internal structure of i.e. plants, which shows the optimal combination of two parameters: high strength and low mass [1]. The use of available knowledge in the field of biomechanics has become the basis for designing of cellular structures of metallic, plastic, ceramic and composite materials. The main feature of cellular materials is the presence of internal air or gas filled spaces, voids that reduce their density compared to the solid material. Optimal shapes manufactured from various types of technologies, shows high properties for energy absorption capacity during static and dynamic loading, which makes it possible for the military, aerospace, automotive, and many more industrial applications. A wide range of such materials makes it necessary to systematize them and extract special types of the designing and the manufacturing processes. The basic division of cellular material is based on the void occurrence. The first type is the regular cellular structure with the voids evenly distributed and the second type, irregular cellular structures

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where the voids occur randomly. The research on the mechanical behaviour of cellular structure is a very wide issue. The research scope of many publications is to optimize the topology of a single cell in terms of strength to weight ratio, develop the analytical and numerical models, conduct laboratory experiments in order to define the model of destruction and internal coherency during the energy dissipation and perforation under the influence of external force along with the determination of critical values of compression velocities and energy absorption In the field of metal casting the cellular structures can be a part of the skeletal shape of the casting or be used as a component of the casting tooling. In the first case, research work related to manufacturing technology focuses on the use of traditional foundry techniques based on a geometrically complex core and gravity casting using the metallostatic pressure [2,3], or on the use of 3D printing methods to prepare a mould or a foundry model necessary to make a skeleton casting [4]. In the second case, the cellular structure is a part of the tooling used in casting process i.e. high pressure die casting as the element of die cooling system [5]. Cellular structures due to their application are usually subjected to static or dynamic compressive forces, and questions related to the course of their decohesion are the subject of numerous works and publications: [6–8]. The authors of the publication emphasize the importance of the impact of defects that may occur in the cellular structure on the destruction process [3]. In the case of casting structures, the defects are related with shrinkage or gas porosity, the influence of which on the process of decohesion of the structure is, among others, the subject of this work. The possibility to prepare a reliable numerical model based on the material properties allows for testing the cellular structure in various exploitation conditions. Due to that possibility the assumption was taken to conduct analysis of perpendicular loading of the cells on presented cellular structure shape.

2. Design and types of regular cellular structures

According to Ashby and Gibson [9] the cellular structures are described as an interconnected network of solid struts or plates which form the edges and faces of a cell. A typical example of such structure is the honeycomb shape, which is the subject of presented series of analysis. In that shape the plates are connected by the edges forming an elementary hexagonal cell shape. The shapes of the elementary cell could be a simple or very complicated geometries. When the geometries are connected to each other in the certain configuration, with additional connected panels on the bottom and top are creating sandwich type structures. The design of sandwich structure topology is based on the acting external and internal forces and the purpose of the structure. Cellular materials are characterized by a lower relative density Δ compared to the material from which they are made, defined as the density ratio of the porous material ρ_p to the solid ρ_s:

$$\Delta = \frac{\rho_p}{\rho_s} \quad (1)$$

In case of relative density, generally we can use the relationship as:

$\rho_p/\rho_s < 0.3$ – a density ratio where the material can be defined as a cellular structure,

$\rho_p/\rho_s > 0.8$ – a density ratio, where the material only has pores in the structure of the solid material.

Generally the metal in the cellular structure typically is less than 20% of its volume.

3. Manufacturing of the regular cellular structure in the casting methods

In general the manufacturing methods can be divided into [10,11]:

- Shaping in the meanings of plastic processing of prefabricated components and combining them with the laser welding, traditional welding or glueing,
- Methods of investment casting.

In the presented subject the investment casting method was used in the manufacturing process of cellular structures. The model was 3D-printed in the *FDM* technology as additive manufacturing process. An important advantage of *AM* technology is the possibility to obtain very complex geometries. Additionally the practical use of the results of the strength shaping and compression of cellular structure can be visualized. There are some limitations of the *AM* manufacturing technology, which are involved with the minimal wall thickness and the needs of removing of supporting material after printing process. For the casting method there are limitations also regarding the wall thickness of the mould, the flowability of the liquid metal and removal of residues of mould during cleaning of the casting [12]. In the ceramic shell making process as pattern a wax, ABS or different *AM* material can be used. Due to complicated shapes of the cellular structure the alloys with good flowability should be used, for example Al–Si, Cu–Be and some of the super alloys group. The advantage of using casting methods is the possibility to obtain casting structures with complicated internal and external geometries different from the sandwich type structure where the top and bottom closing plates are used. The use of special techniques of casting such as centrifugal or high pressure casting allows for obtaining casting with different amount of casting defects i.e. shrinkage porosity.

The cellular model was designed in the CAD software and exported to the native file to the *FDM* 3D printing machine. The dimensions of the model are 80 mm × 80 mm × 20 mm. In the 3D printing the geometry needs to be divided into layers along with the definition of nozzle path, size and speed. For the model manufacturing a thermoplastic ABS material was used.

Models presented in Fig. 1 were used for the manufacturing of the silicone mould. Specially designed core allows for easy wax patter removal. In Fig. 2 the silicone mould, wax patterns and tree assembly used for the ceramic shell preparation are presented.

The pattern tree was moulded in the plaster with the assist of vacuumed, which was used to obtain good surface quality. The plaster material was moulded in the special sleeve with the