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Skeleton castings dynamic load resistance

M. Cholewa, J. Szajnar, T. Szuter*
Foundry Department, Silesian University of Technology,
ul. Towarowa 7, 44-100 Gliwice, Poland
* Corresponding e-mail address: tomasz.szuter@polsl.pl

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ABSTRACT

Purpose: The article is to show selected results of research in a field of new type of cast spatial composite reinforcements. This article shows skeleton casting case as a particular approach to continuous, spatial composite reinforcement.

Design/methodology/approach: The research is concerning properties of cast spatial microlattice structures called skeleton castings. In this paper results of impact test of skeleton casting with octahedron elementary cell were shown. The selection of internal topology of skeleton casting was based on numerical simulations of stress distribution.

Findings: The possibility of manufacturing of geometrically complex skeleton castings without use of advanced techniques was confirmed.

Research limitations/implications: With use of computer tomography, analysis of deformation mechanisms was carried out. Different levels of impact energies were used

Practical implications: Spatial skeleton casting with octahedron elementary cell confirmed their usefulness as impact energy absorbers.

Originality/value: The overall aim of presented research was to determine the mechanisms of skeleton castings deformation processes. Thanks to CT data next step will be to create accurate numerical model for further simulation and design optimization.

Keywords: Casting; Composites; Mechanical; Skeleton casting; Materials design

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1. Introduction

Lattice truss structures, metal foams and honeycombs offer a number of practical advantages. If the relative density is low, they can be readily flexed into curved panels and then attached to curved face sheets. From economics and ecology point of view they should allow lowering the weight of constructions. This makes possible 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 [1,2]. Periodic truss structures (Fig. 1) show also features like good kinetic energy absorption, important for use in ballistic impact protection, acoustic damping or shock absorption. In several of these applications, the structures are loaded to their maximum strength [3–6]. Fleck and Deshpande [3] developed an approach to analyse the dynamic response of a sandwich beam. The structure of the core can consist of different topologies (Fig. 2), such as pyramidal, diamond cell, corrugated, hexagonal honeycomb and square honeycomb, depending on the types of loading anticipated. The dynamic response of monolithic and sandwich plates with different types of core (pyramidal, corrugated, metal foam, and square-honeycomb) was investigated by loading the plates. It is found that all sandwich plates have a higher shock resistance than monolithic plates of equal mass. It was also shown the outstanding impact resistance of square-honeycomb sandwich plates and the pyramidal core plates was the weakest of the sandwich beams.

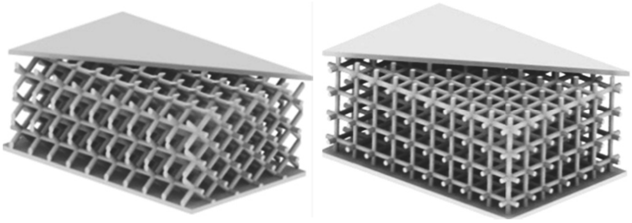

Fig. 1. Sandwich type periodic lattice cellular metals[7]

Xue and Hutchinson [7] showed that sandwich plates (Figs. 3, 4) with sufficiently strong cores can withstand a uniform impulsive load three times that of a solid plate with identical weight and material. The interconnected spaces within lattice truss core structures can also facilitate multifunctional applications such as cross flow heat exchange. Wei et al. introduced a Hybrid Sandwich Panel, which added hyper-elastic material between the face sheet and core to increase the blast resistance [8,9].

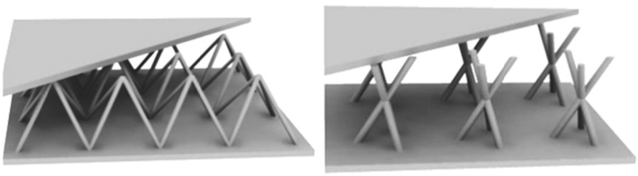

Fig. 2. Sandwich type periodic lattice cellular metals[10]

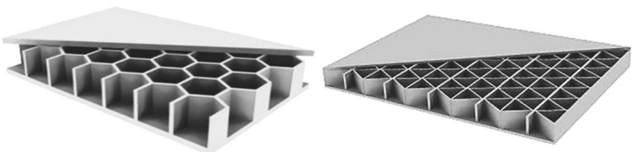

Fig. 3. Periodic cellular metal sandwich structures[11]

Application examples of periodic cellular metals as part of impact energy absorbing panels are deforming barriers used in automotive crash tests. Their ordered structure allows creating a precise numerical model to proceed simulations. The mechanical properties adaptation flexibility allows using them to tests at different speeds. The use of cellular materials in rail vehicles, in principle, subject to the same rules as for the automotive industry. In the past decades the travelling speed of railway trains significantly increased and reached the speed of 300-350 km/h [12] Some trains are equipped with bumpers made of aluminium foam in order to improve safety during impact [5,7,11].

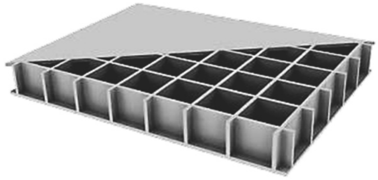

Fig. 4. Periodic cellular metal sandwich structures[13]

2. Skeleton castings

The conception of skeleton castings (Fig. 5, Fig. 6), as periodic truss, highly porous, cast construction, has been developed in the Foundry Department of Silesian University of Technology [14-20]. Very similar technology, with same assumptions, but with use of 3D printing was recently developed in Virginia Polytechnic [21]. Base alloy used for skeleton castings is aluminium alloy but also cast steel, cast iron and MMC.[22-25] Truss-type structures, which skeleton castings are similar to, are characterized by a different approach.

Production of components with complex shapes qualifies casting methods as the most suitable for this application. The possibilities of using particularly advantageous rheological properties of liquid alloys allow producing castings of almost any shape and in a wide range of characteristic dimensions. It is worth mentioning that the rheological properties of liquid alloys allow getting casting wall thickness of 0.5 mm by conventional, gravity casting methods. One limitation is the dimensional accuracy, resulting from the use of common mould materials [26] and lack of normative regulations in the design of similar technologies. Even special techniques of moulding and casting, as well as simulation approach [27,28] need appropriate adaptation.

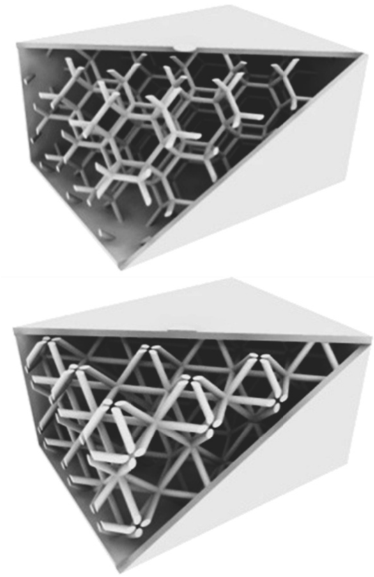

Fig. 5. Skeleton casting topology examples designed in Foundry Department of Silesian University of Technology

The key importance of this technology is the core manufacturing techniques. It assumes the use of production possibilities for a typical, small foundry, without the use of laboratory equipment and high precision technology. Important was the high symmetrical accuracy of cores and castings. On the one hand due to the isotropy of mechanical properties and, second, the use of modular design and flexibility to match the overall dimensions to the application needs. Another aspect that was taken into consideration was the degree of complexity. Also important is the relative density defined as the volume occupied by the metal in the volume of the whole element.

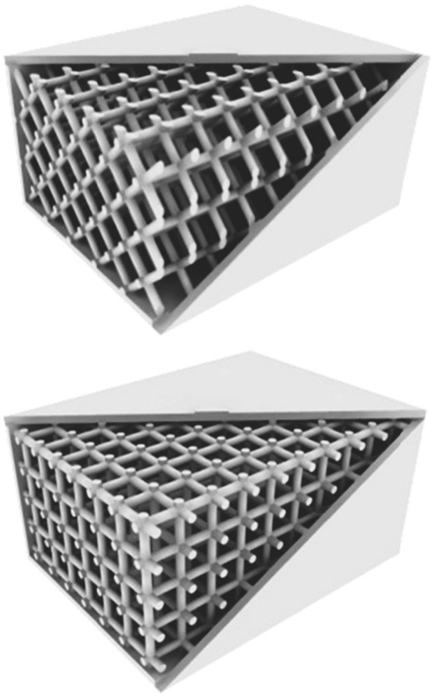

Fig. 6. Skeleton casting topology examples designed in Foundry Department of Silesian University of Technology

3. Description of the research

The paper presents the results of preliminary research of dynamic load resistance of new ceramic - metal composites, particularly focused on the ability of impact energy absorbing. Skeleton castings were cast from AlSi11 alloy. Selected geometrical parameters of investigated skeleton castings with octahedron elementary cell (Fig. 7) can be found in Table 1. As mentioned above interconnected spaces can be used by many ways. In presented conception internal spaces were filled with porous oxide ceramics, with open pores, to create composite construction. In assumption it should improve energy dissipation abilities. High porosity of ceramic filling is favourable for energy dissipation mechanisms. Compression of the pores significantly improves effectiveness on the construction but with maintaining low weight. Ceramic filling also allows for obtaining strong cores with complex geometry, which are at the same time the matrix of a composite, influencing on its mechanical properties. Internal topology of skeleton casting was chosen based on previous studies [14].

The impact response research was conducted on gas gun. Series of tests with different energy were performed. Parameters of each test are presented in Table 2. Change of velocity in time was measured by laser device. High speed camera was also used to record the deformation processes.

Table 1.
Selected geometrical parameters of skeleton casting with octahedron elementary cell

Weight	2.07 [kg]
Volume of block	3000 [cm^3]
Volume occupied by metal	762.6 [cm^3]
Volume without walls	176.6 [cm^3]
Relative density	25.42%
Relative density without walls	6.57%
Face sheets thickness	6 [mm]

Table 2.
Parameters of each shoot

	1st trial	2nd trial	3rd trial
Velocity [m/s]	7.23	15.12	17.17
Pressure [bar]	1.94	7.79	9.52
Energy [J]	499	2181	2813

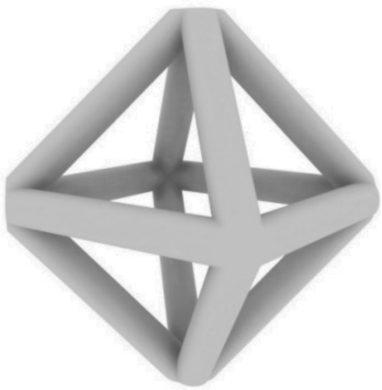

Fig. 7 Example of octahedron elementary cell

After each impact, series of CT scan was performed, to reveal results of impact on internal geometry of skeleton casting. Hemispherical head impactor was used for tests. Diameter of impactor was 92 mm and its weight 19.096 kg. The overall aim of presented research was to determine the mechanism of skeleton castings deformation processes. Next step will be to create accurate numerical model for further simulation and design optimization.

4. Results

In Fig. 8 experimental force - displacement and velocity - time curves were presented. At the start, the load increased with displacement nearly linearly up to an initial peak load.

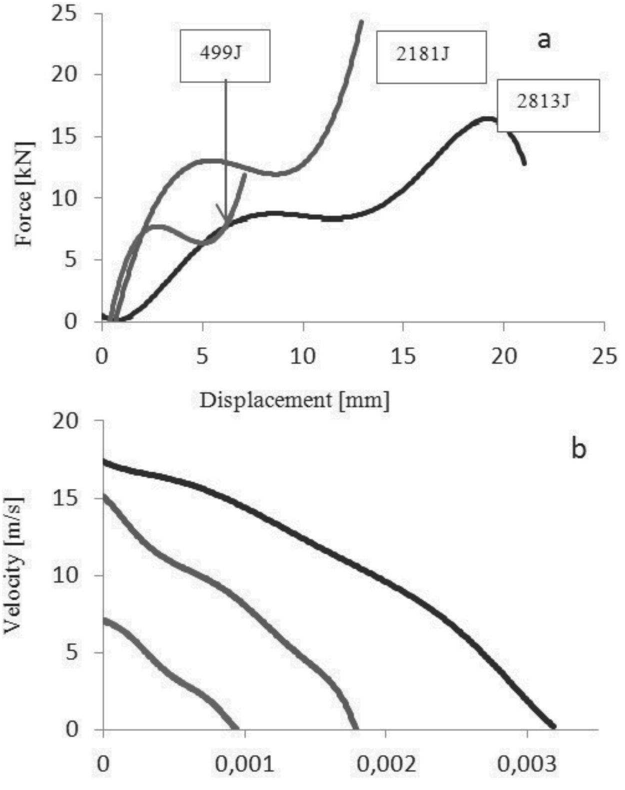

Fig. 8. (a) Experimental force - displacement curves (b) Experimental velocity - time curves

This represents deformation of face sheets without penetration due to stretching. In each trial after initial peak load, from 2.5 mm to 7.5 mm of displacement, the near plateau can be observed. After the initial peak, failure occurred due to the face sheet fracture and the load decreased with the displacement. The decrease in the load continued up to the point of complete fracture of the face sheet. After that it is clear from Fig. 8a that as the displacement increases, the resistance increases correspondingly. It is due to the next phase of the deformation - densification of the whole structure in connection with internal friction of the components. Pores compression in ceramic matrix and destruction of the interconnected struts are responsible for impact energy dissipation in whole volume of the composite. Destruction of internal struts was initiated by stress concentration in near nodes areas. Fractures appear in same locations in second and third specimen. Only the front face sheet was brittle destructed even in trial with highest energy (Fig. 9) [29]. It can be observed slight plastic deformation of other sheets. Energy of the shoots was dissipated in whole volume of composite, not only in axis parallel to the shoot.

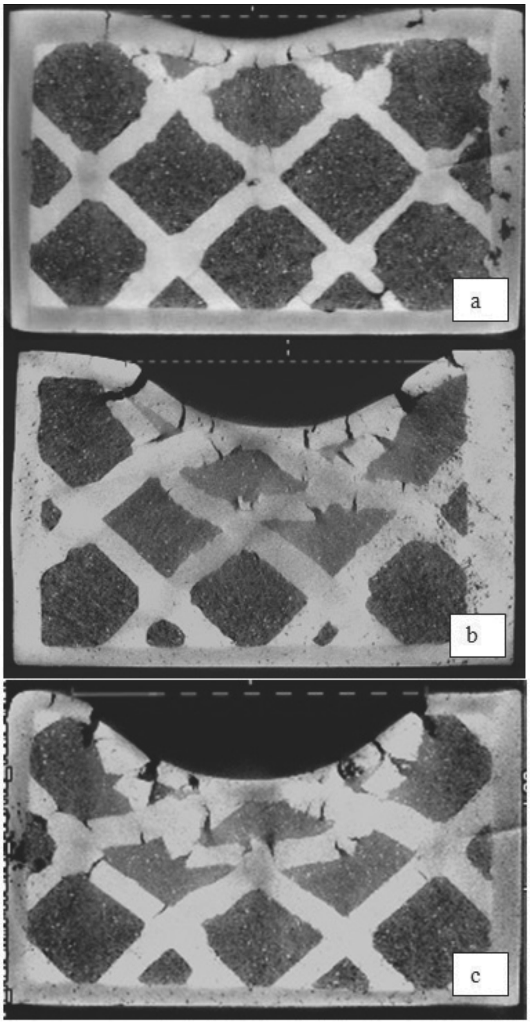

Fig. 9. Computer topography scans after impact: a) 499 J, b) 2181 J, c) 2813 J

5. Conclusions

Skeleton castings filled with open pores ceramics was tested under impact loading, with energies from about 500 J to about 2800 J and velocities accordingly 7.2 m/s to 17.1 m/s. Compared to the previous research[30,31], castings filled with ceramics matrix absorbed almost all the impact energy and proved to be good value in energy absorbing application. It was found that the energy absorption capacity depends on properties of filling material. Based on conducted research next step will be to make numerical model. Simulations are crucial for further developing of skeleton casting conception. Its mechanical behaviour depends on base material, geometrical features such as internal topology and face sheet thickness or filling material properties. All this factors will be taken into account in further design optimization and tailoring mechanical properties to final application of skeleton castings.

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