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Study of Thermal Properties of Cast Metal-Ceramic Composite Foams

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Abstract

Owing to its properties, metallic foams can be used as insulation material. Thermal properties of cast metal-ceramic composite foams have applications in transport vehicles and can act as fire resistant and acoustic insulators of bulkheads. This paper presents basic thermal properties of cast and foamed aluminum, the values of thermal conductivity coefficient of selected gases used in foaming composites and thermal capabilities of composite foams (AlSi11/SiC). A certificate of non-combustibility test of cast aluminum-ceramic foam for marine applications was included inside the paper.
The composite foam was prepared by the gas injection method, consisting in direct injection of gas into liquid metal. Foams with closed and open cells were examined. The foams were foaming with foaming gas consisting of nitrogen or air.
This work is one of elements of researches connected with description of properties of composite foams. In author's other works acoustic properties of these materials will be presented.

Keywords: Materials and foundry technology, Casting, Metal-ceramic composite foams, Thermal properties

1. Introduction

According to the definition given in [1, 2] foams are porous materials, the microstructure of which can be described geometrically as disordered distribution of pores in the matrix or a material that in its volume has a large number of gas-filled pores. Thus, unlike monolithic materials, foams are characterized by the presence of designed discontinuities of the matter with repeated or different shape, size and arrangement across the whole volume of the product in a structured or unstructured manner, thus rendering a significant difference in properties, varying responses of the material to external factors, e.g. temperature or load. Besides porous cellular materials of natural origin (e.g. cork, sponges) other widely used materials are those artificially synthesized from polymer, ceramic or glass, such as polystyrene foam, pumice stone, foam concrete, etc., with such applications as insulation, shock absorption, packaging, etc.

These materials, however, demonstrate significant shortcomings. For instance, polymeric foams have poor resistance to elevated temperature, ultraviolet light, emit large amounts of smoke and toxic substances when burning and have poor mechanical properties. Ceramic foams demonstrate high brittleness and consequently poor impact resistance [3-7]. Metallic foams can be produced from virtually all metals (except mercury). The most common foams are made from aluminum, magnesium, titanium, zinc, nickel, copper and iron or their alloys [1-6].

Metallic foams have many unique properties making them applicable in machine construction. Their low density makes them excellent filler material for sandwich structures with high stiffness. Low thermal conductivity allows using these foams as insulating materials, and their ability to suppress vibrations suggests they can be used as damping coverings. In contrast, the tendency to significant deformation under load can be utilized in systems absorbing impact energy, mitigating explosion effects and in the manufacture of packaging materials. Cellular materials may exhibit both isotropy and anisotropy of their properties. Metallic foam is characterized by high porosity, typically in the 75–95% range. As a result, their density is 5–25% of the density of metal from which they are made.

Closed cell foams, in many cases, demonstrate the ability to float on water surface. The density of the most common foams produced from aluminum has the range 0.15–0.5 g/cm^3 [1-7]. The pores of metal foams, similar to ceramic and polymeric foams, may be open or closed [1, 4, 6-9]. It depends largely on the adopted method of production. There is a strong relation between the method of foam manufacture and their microstructure (distribution, size, type and shape of the pores, wall thickness between pores, etc.), which translates to the properties of these materials. Besides, the material used for making metallic foam often determines the choice of technology.

Production of metal foams using the appropriate processing of pure metals or alloys gives a certain, rather limited, scope of changing the parameters characterizing these foams. Extending the scope of functional properties of foam, and being able to control them, we can yield multiphase materials. These are composite materials, formed by joining together at least two chemically and physically different materials in such a way that - according to one definition - with good interconnection, there will be a clear boundary between them, and that the distribution of reinforcing phase will be possibly uniform over the entire matrix volume [6, 7, 9-12]. Metal-ceramic composites, with a wide range of different compositions, can make up a basis for the production of foams with specific properties, useful in shipbuilding. Composite metal-ceramic foams, developed in accordance with the principles of materials science, expand design capabilities. The paper presents the thermal properties of composite metal-ceramic foam (AlSi11/SiC) formed through injecting gas into liquid matrix.

Fig. 1. An example of metal-ceramic foam (values given in centimeters)

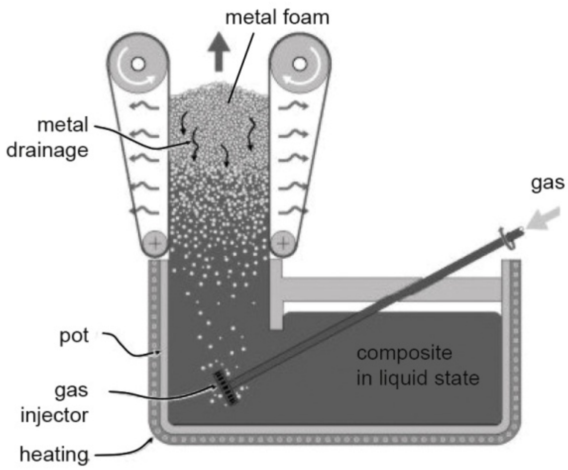


Fig. 2. Schematic illustration of gas injection into the liquid composite [6]

2. Research material

The material subjected to tests was metal-ceramic foam (Fig. 1) produced by the gas injection method at the Maritime University of Szczecin [4-7]. The method involves blowing the gas directly into the liquid composite: aluminum alloy (AlSi11) with SiC particles (Fig. 2).

The method is technologically difficult, but offers a lot of flexibility in the selection of materials and foaming gases, giving the possibility to create the microstructure and properties of the foam in a fairly wide range of [5-9]. For this reason the paper presents this method, using modern materials, i.e. aluminum-ceramic composites.

3. The thermal conductivity of cast aluminum-ceramic foams

Thermal conductivity is a characteristic of a substance in a specific state of aggregation and phase. For heterogeneous substances thermal conductivity depends on their internal microstructure and porosity. Metals are substances with best heat conductivity, while gases are worst heat conductors. Relationships of thermal properties of cast aluminum and aluminum foam are shown in Table 1.

Table 1.
Basic thermal properties of cast and foamed aluminum [3, 9, 13]

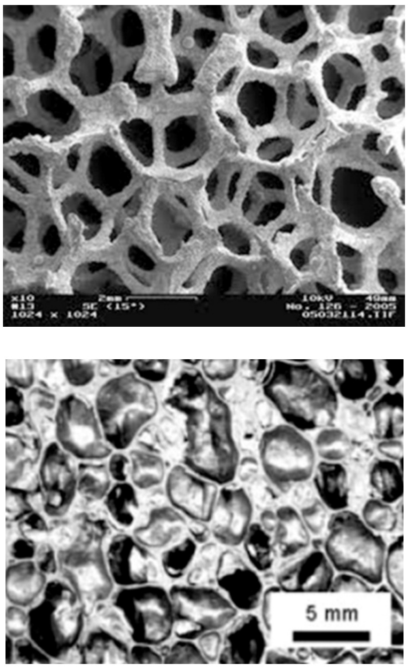
Property		Cast aluminum	Aluminum foam
Maximum operating temperature	°C	165	170
Melting Point	°C	570	560
Specific heat	J/kg·K	980	850
Thermal conductivity	W/m·K	160	12
Thermal expansion	1/°C	$22.9 \cdot 10^{-6}$	$23 \cdot 10^{-6}$

It follows from the above table that the thermal conductivity of aluminum foams is much lower than that of cast aluminum. Certain differences in the thermal conductivity of foams can occur depending on the gas used for foaming. The values of thermal conductivity λ [W/mK] of some gases are shown in Table 2.

The thermal conductivity varies considerably depending on the basic type of foam microstructure, one with closed or open cells. Figure 3 shows metal foams with open and closed pores.

Table 2.
The values of thermal conductivity coefficient of selected gases used in foaming composites [1-4, 9, 10]

Gas	Thermal conductivity coefficient λ [W/m·K]
Hydrogen	0.168
Helium	0.143
Air	0.024
Nitrogen	0.24
Argon	0.016



a) b)

Fig. 3. Example microstructure of foam: a) open pores, b) closed pores [9]

Foams can be used as a material (product) acting as heat insulation or facilitating heat transfer. The thermal insulation function is best performed by closed cell foam (Table 3).

Table 3.
Thermal conductivity coefficient – composite foams

Composite foams	Thermal conductivity coefficient λ [W/m·K]
AlSi11 / SiC. Foam with closed-cells. Foaming gas: air	8.74
AlSi11 / SiC. Open cell foam. Foaming gas: air	15.63
AlSi11 / SiC. Foam with closed-cells. Foaming gas: nitrogen	9.57
AlSi11 / SiC. Open cell foam Foaming gas: nitrogen	17.97

4. Conclusions

Metal foams, particularly cast aluminum-ceramic foams are characterized [8-12, 14-17] by low thermal conductivity coefficient compared to other materials (Fig. 4).

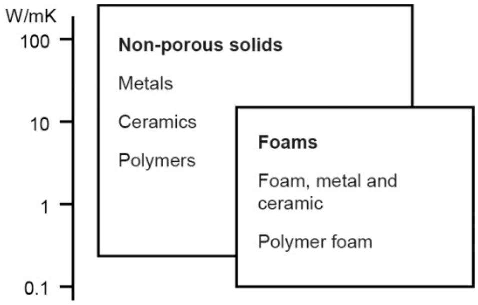
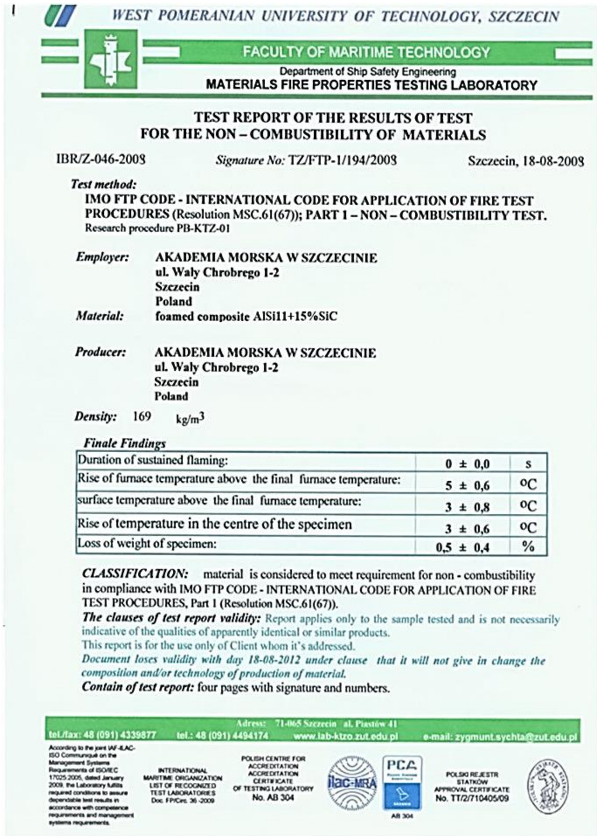


Fig. 4. The thermal conductivity of selected materials [13]

There are differences in the thermal conductivity of foams with different gases blown into composites and foam composites with different types of pores. Open pore foams filled with air have a slightly worse insulation ability than closed-cell foam, as insulation is related to gas circulation throughout the overall volume of the product. The microstructure characteristic of the foam with open pores, where a medium (gas or liquid) may flow across, makes these foams applicable in efficient heat exchangers. These solutions utilize a large surface area of metal-medium contact. Metal foams can also be used as safe, i.e. non-flammable heat-insulating material (particularly foams with closed cells filled with air (Table 3) as having the lowest thermal conductivity.

The foams herein discussed were also subjected to non-combustibility tests in accordance with procedures specified in the PN-EN ISO 1182:2010 standard [8-12]. Due to the projected use of developed cast aluminum-ceramic foams in the maritime industry the tests involved tougher procedures specified in the FTP Code Part 1 issued by the International Maritime Organization. The research procedure used was PB-OCT-01 – 7 the edition of 09.01.2009. The test results are shown in Figure 5, presenting the report No. TZ / FTP-1/194/2009 dated 18.08.2009.

It follows that the material (cast aluminum-ceramic foamed composite) is non-combustible according to the internationally accepted definition stating that materials referred to as non-combustible are materials that heated to a temperature of 750°C do not burn and do not emit flammable gases in quantity sufficient for ignition, and do not give off heat causing an increase in temperature of the furnace [12]. Such foam can be successfully used as insulation and fillers, e.g. in aircraft construction, transport, civil engineering and road infrastructure elements.



WEST POMERANIAN UNIVERSITY OF TECHNOLOGY, SZCZECIN

FACULTY OF MARITIME TECHNOLOGY

Department of Ship Safety Engineering

MATERIALS FIRE PROPERTIES TESTING LABORATORY

TEST REPORT OF THE RESULTS OF TEST FOR THE NON – COMBUSTIBILITY OF MATERIALS

IBR/Z-046-2008 *Signature No:* TZ/FTP-1/194/2008 Szczecin, 18-08-2008

Test method:
IMO FTP CODE - INTERNATIONAL CODE FOR APPLICATION OF FIRE TEST PROCEDURES (Resolution MSC.61(67)); PART 1 – NON – COMBUSTIBILITY TEST.
Research procedure PB-KTZ-01

Employer: AKADEMIA MORSKA W SZCZECINIE, ul. Wały Chrobrego 1-2, Szczecin, Poland

Material: foamed composite AlSi11+15%SiC

Producer: AKADEMIA MORSKA W SZCZECINIE, ul. Wały Chrobrego 1-2, Szczecin, Poland

Density: 169 kg/m³

Finale Findings

Duration of sustained flaming:	0 ± 0,0	s
Rise of furnace temperature above the final furnace temperature:	5 ± 0,6	°C
surface temperature above the final furnace temperature:	3 ± 0,8	°C
Rise of temperature in the centre of the specimen	3 ± 0,6	°C
Loss of weight of specimen:	0,5 ± 0,4	%

CLASSIFICATION: material is considered to meet requirement for non - combustibility in compliance with IMO FTP CODE - INTERNATIONAL CODE FOR APPLICATION OF FIRE TEST PROCEDURES, Part 1 (Resolution MSC.61(67)).
The clauses of test report validity: Report applies only to the sample tested and is not necessarily indicative of the qualities of apparently identical or similar products.
This report is for the use only of Client whom it's addressed.
Document loses validity with day 18-08-2012 under clause that it will not give in change the composition and/or technology of production of material.
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According to the joint IAF-ILAC-ISO Communiqué on the Management Systems Requirements of ISO/IEC 17025:2005, dated January 2009, the Laboratory fulfils required conditions to assure dependable test results in accordance with competence requirements and management systems requirements.

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Fig. 5. A certificate of non-combustibility test of cast aluminum-ceramic foam for marine applications

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