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PRODUCTION AND APPLICATION OF METAL FOAMS IN CASTING TECHNOLOGY

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Subject review

Problems in the production of metal foams arise from the lack of knowledge in the control of process parameters. The results are frequently uneven and unpredictable variations in the structure and properties of semi products and final products. This paper comprises all production processes for metal foams and the most commonly used processes are described. Production of metal foams is continuously developing and in parallel are being developed the utilization methods of metal foams due to their specific properties. All the positive characteristics of metal foams, which make them suitable for the use in a variety of designs and products, are described in this paper. Benefits of using metal foams as a casting core material are clarified. Technologies for producing metal foam cores, positioning of cores and mould designs are presented. Casting technologies with metal foam cores and applications are described along with samples of aluminium foam cores.

Keywords: *casting core, die casting, impact energy, metal foam*

Proizvodnja i primjena metalnih pjena u ljevarstvu

Pregledni članak

Problemi u proizvodnji metalnih pjena proizlaze iz još nepotpunog ovladavanja parametrima procesa. Često se dobivaju neujednačene i nepredvidive strukture i varijacije u vrijednostima svojstava krajnjeg proizvoda ili poluproizvoda. U ovom radu navedeni su svi do danas poznati postupci proizvodnje metalnih pjena i detaljno opisani oni komercijalizirani. Proizvodnja metalnih pjena i dalje se razvija, a usporedno se razvijaju i metode korištenja metalnih pjena zbog njihovih specifičnih svojstava. Opisane su sve dobre karakteristike metalnih pjena koje ih čine iznimno zanimljivim materijalom za primjenu u različitim konstrukcijama i proizvodima. Razjašnjene su prednosti korištenja metalnih pjena za jezgre u ljevarstvu. Opisane su metode proizvodnje jezgri, te način pozicioniranja jezgre i oblikovanja kalupa u kojem se jezgra od metalne pjene koristi. Opisane su do sada primjenjene tehnologije lijevanja odljevaka s trajnim jezgrama od metalnih pjena i prikazani su primjeri odljevaka s jezgrama od aluminijskih pjena.

Ključne riječi: *energija udara, ljevačka jezgra, metalne pjene, tlačni lijev*

1 Introduction

Modern research in engineering is focused on developing new materials and composites for the purpose of producing structural elements of lower density and equal performances. Lighter elements are used in structures for the purpose of weight reduction and saving of energy. In order to achieve this goal, metal foams have been developed. Metal foams are simulating with their structure naturally porous, cellular and spongy materials like wood, sponges, bones, corals, etc. Structure of the metal foams is porous in the range from 40 % to 90 %. Till today metal foams have been produced on the basis of aluminium (Al), nickel (Ni), zinc (Zn), magnesium (Mg) and titanium (Ti) alloys [1].

Significant research in production technology, properties and area of the use of metal foams has been conducted for the last 20 years. The structure, size of the cells and the chemical composition are the most important factors that determine the properties, and thus the possible areas of usage. Metal foams with open cells or closed cells can be produced. Favourable properties of metal foams are: extremely low density, high specific stiffness, very good impact energy and electromagnetic waves, good heat insulation, very good sound absorption, fire resistance, recyclability, etc. [2].

A possible implementation of metal foams in new products has been researched in parallel to the improvement of production methods. One possible application of metal foams is the production of metal foam casting cores that remain permanently in the casting product and with their unique properties improve the overall product.

2 Structure of metal foams

Metal foam can be defined as a mixture of gas and metal with significantly higher volume percent of gas in the mixture. Internal local arrangement of metal foam is a result of liquid surface tension which was investigated by Joseph Plateau in the 19th century. According to his laws when two bubbles merge, they adopt a shape which makes the sum of their surface areas as small as possible. At a point where bubbles meet, they sort themselves out so that only three bubble walls meet tangentially, and only four bubble walls can meet at one point. Tangential line is called the Plateau border (marked in Fig. 1). The structure described by Plateau's laws is common to the solid foams that result from the freezing of liquid foams. These laws are only valid for the stable foams with predominant volume percent of a gas in the volume of mixture [3]. If gas bubbles tend to leave the molten metal structure becomes unstable. Metal foams consist primarily of a network of thin, frozen Plateau borders meeting at junctions that usually have the prescribed tetrahedrally symmetric form [4].

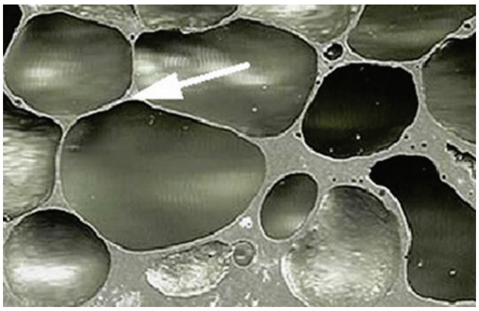

Figure 1 Cross section of metal foam with the closed cells structure [5]

3 Properties of metal foams

The properties of metal foams depend upon the properties of the base material, the relative density, cell topology and the production process. When defining the properties it is important to distinguish the difference between the properties of the metal foam and the properties of the base material. Beyond this, foam properties are influenced by structure, particularly by anisotropy and by defects of the cells. Cells can be of irregular shape, with differences in size. Cell walls are often broken, which considerably reduces the mechanical properties of the foam and porosity varies ten or more percent.

3.1 Mechanical and thermal properties of metal foams

When qualifying metal foams it is necessary to precisely determine their mechanical properties such as: compressive and tensile strength, Young's modulus, shear modulus, hardness, creep resistance etc., to be able to select a suitable material for a certain structure or after the selection of material to design the structure. An overview of ranges of mechanical and thermal properties of commercially available aluminium foams is given in Tab. 1. As can be seen from the data aluminium foams with closed cells structure have several times higher compressive and tensile strength comparing with the open cells foams.

The melting point, specific heat and expansion coefficient of aluminium foams should be the same as those of the basic aluminium alloys. The melting point of aluminium foams is slightly higher than the melting point of the basic alloy because the cells are covered with a thin film of Al_2O_3 with a higher melting point and thus increasing the melting point of aluminium foam to 780 °C.

3.2 Sound absorption in metal foams

Metal foams can be used for sound absorption because their specific cellular structure can absorb high quantities of various forms of mechanical energy. An efficient structure for sound absorption can be produced by drilling holes of sizes 1 to 2 mm in diameter within the aluminium foam. Holes are drilled to allow the entry of sound in the aluminium foam. Sound propagation through the foam is gradually decreasing depending on the structure of the cells. According to the research about sound absorption of ALPORAS foam conducted at the University of Cambridge [7] metal foams with lower relative density (till ρ/ρ_S = 0,09) show better results. For complete sound absorption it is efficient to have 10 mm thick ALPORAS foam as an insulator.

3.3 Vibration damping in metal foams

Vibration damping in metal foams is based on the conversion of mechanical energy of vibrations into heat by internal friction in material. Internal friction increases with increase of strain amplitude [8, 9]. Behaviour of metal foams under a vibration load also depends on the percent of porosity, size and shape of the cells, treatment of the test sample, etc. [1]. Metal foams are characterized by an asymmetric resonance curve and the resonant frequency is approximately proportional to the square of the strain amplitude. These nonlinear properties are enhanced with increase in porosity and decrease in pore size [8]. Dissipation of energy is best described with the dimensionless loss coefficient, η^C.

Dissipation of vibrations is a result of friction between the surfaces of cells and the formation of cracks. Damping may be increased by reducing the thickness of cells walls, adding structural irregularities – e.g. by adding insoluble ceramic particles (SiC, Al_2O_3 or graphite).

Table 1 Ranges for mechanical and thermal properties for commercially available aluminium foams [6]

PROPERTY, SYMBOL, UNIT	MATERIAL			
	CYMAT Al-SiC	ALULIGHT Al	ALPORAS Al	ERG Al
Relative density, ρ/ρ_S	0,02 ÷ 0,2	0,1 ÷ 0,35	0,08 ÷ 0,1	0,05 ÷ 0,1
Structure	Closed cells			Open cells
Density, ρ / Mg/m^3	0,07 ÷ 0,56	0,3 ÷ 1,0	0,2 ÷ 0,25	0,16 ÷ 0,25
Young's modulus, E / GPa	0,02 ÷ 2,0	1,7 ÷ 12	0,4 ÷ 1,0	0,06 ÷ 0,3
Shear modulus, G / GPa	0,001 ÷ 1,0	0,6 ÷ 5,2	0,3 ÷ 0,35	0,02 ÷ 0,1
Flexural modulus, E_f / GPa	0,03 ÷ 3,3	1,7 ÷ 12	0,9 ÷ 1,2	0,06 ÷ 0,3
Poisson's ratio, v / -	0,31 ÷ 0,34	0,31 ÷ 0,34	0,31 ÷ 0,34	0,31 ÷ 0,34
Comp. strength, R_{mt} / MPa	0,04 ÷ 7,0	1,9 ÷ 14	1,3 ÷ 1,7	0,9 ÷ 3,0
Tensile elastic limit, R_e / MPa	0,04 ÷ 7,0	2,0 ÷ 20	1,6 ÷ 1,8	0,9 ÷ 2,7
Tensile strength, R_m / MPa	0,05 ÷ 8,5	2,2 ÷ 30	1,6 ÷ 1,9	1,9 ÷ 3,5
Densification strain, ε_D / -	0,6 ÷ 0,9	0,4 ÷ 0,8	0,7 ÷ 0,82	0,8 ÷ 0,9
Tensile ductility, ε_f / -	0,01 ÷ 0,02	0,002 ÷ 0,04	0,01 ÷ 0,06	0,1 ÷ 0,2
Loss coefficient, η^C / %	0,4 ÷ 1,2	0,3 ÷ 0,5	0,9 ÷ 1,0	0,3 ÷ 0,5
Hardness, *HRC*	0,05 ÷ 10	2,4 ÷ 35	2,0 ÷ 22	2,0 ÷ 3,5
Fracture. toughness., K_{IC} / MPa·m$^{1/2}$	0,03 ÷ 0,5	0,3 ÷ 1,6	0,1 ÷ 0,9	0,1 ÷ 0,28
Melting point, T_m / K	830 ÷ 910	840 ÷ 850	910 ÷ 920	830 ÷ 920
Max. Service temperature, T_{max} / K	500 ÷ 530	400 ÷ 430	400 ÷ 420	380 ÷ 420
Min service temperature, T_{min} / K	1 ÷ 2	1 ÷ 2	1 ÷ 2	1 ÷ 2
Specific heat, C_p / J/kgK	830 ÷ 870	910 ÷ 920	830 ÷ 870	850 ÷ 950
Thermal conductivity, λ / W/mK	0,3 ÷ 10	3,0 ÷ 35	3,5 ÷ 4,5	6,0 ÷ 11

3.4 Impact energy absorption

Due to their specific behaviour under compressive stress metal foams have the ability to absorb high quantities of impact energy, which is one of the most useful properties of such materials. The average values of impact energy absorption per unit volume for ALPORAS foam during deformation of 55 % for the static load is 1,0 MJ/m^3, and for the dynamic load is 1,51 MJ/m^3 [1]. As can be seen absorption is 50 % higher for dynamic loading compared with the static load. The ability to absorb high quantities of impact energy is correlated with relative density and opened or closed cells structure. Plastic collapse of cells occurs when torque created by the compressive load exceeds the plastic limit of the cells nodes [6].

Aluminium foams have a long and almost horizontal stress – strain curve for compressive load which makes them almost an ideal material for absorption of impact energy [6]. Automobile industry is particularly interested for application of aluminium foams in producing many parts of the vehicles.

4 Production methods for metal foams

Metal foams are produced by melting of metal powder, foaming of molten metal and solidification of mixture. Gas necessary for foaming may be injected into molten metal or added to the metal powder in the form of a dispersing agent that allows foaming when it is heated. Till today metal foams have been produced on the basis of aluminium (Al), nickel (Ni) zinc (Zn), magnesium (Mg), copper (Cu), bronze, lead (Pb) and titanium (Ti) alloys [2].

Pure liquid metals cannot easily be foamed without additives – stabilizers that increase the viscosity of the molten metal during solidification. Drainage of liquid down the walls of the bubbles usually occurs too quickly to create a foam that remains stable long enough to solidify. However, small, insoluble, or slowly dissolving particles raise the viscosity of the molten metal and impede drainage in the bubble membrane, stabilizing the foam. Depending on the type of the metal and the production method there are different types of additives. In the Hydro-Alcan process additives are SiC particles, while in the ALPORAS process additives are aluminium, calcium or mixed oxides. Metal oxide fibres are used as stabilizing additives in the Alulight-Foaminal production process.

Nine distinct process-routes have been developed to make metal foams, of which five are now established commercially. Each of these nine processes may somehow influence the structure, size and regularity of the cells and relative density of the foam. Some produce open-cell foams, other produce foams in which the majority of the cells are closed. Production processes can be divided into four classes:

- the foam is formed from the vapour state of metal
- the foam is formed from the liquid state of metal
- the foam is formed from the solid state of metal
- the foam is electrodeposited from an aqueous solutions.

Metal foams are made by one of nine processes listed below. Metals which have been foamed by a given process (or a variant of it) are listed in brackets.

1) Bubbling gas through the molten Al-SiC or Al-Al_2O_3 alloys (Al, Mg).
2) By stirring a foaming agent (typically TiH_2) into a molten alloy (typically an aluminium alloy) and controlling the pressure while cooling (Al).
3) Consolidation of a metal powder (aluminium alloys are the most common) with a particulate foaming agent (TiH_2) following by heating into the mushy state when the foaming agent releases hydrogen, expanding the material (Al, Zn, Fe, Pb, Au).
4) Manufacture of a ceramic mould from a wax or polymer-foam precursor, followed by burning-out of the precursor and pressure infiltration with a molten metal or metal powder slurry which is then sintered (Al, Mg, Ni-Cr, stainless steel, Cu).
5) Vapour phase deposition or electrodepositing of metal onto a polymer foam which is subsequently burned out, leaving cell edges with hollow cores (Ni, Ti).
6) The trapping of high-pressure inert gas in pores by powder hot isostatic pressing (HIPing), followed by expansion of the gas at elevated temperature (Ti).
7) Sintering of hollow spheres, made by a modified automatisation process, or from metal-oxide or hydride spheres followed by reduction or dehydration, or by vapour-deposition of metal onto polymer spheres (Ni, Co, Ni-Cr alloys).
8) Co-pressing of a metal powder with leachable powder, or pressure-infiltration of a bed of leachable particles by a liquid metal, followed by leaching to leave a metal-foam skeleton (Al with salt).
9) Dissolution of a gas in liquid metal under pressure, allowing it to be released in a controlled way during subsequent solidification (Cu, Ni, Al).

4.1 Gas-releasing particle decomposition in the molten metal

In this process aluminium alloys are foamed by mixing into them a foaming agent that releases gas when heated. In the year 1986 the Shinko Wire Company developed aluminium foam with closed cells named ALPORAS using this approach [10]. The foaming agent, titanium hydride (TiH_2), begins to decompose into Ti and gaseous H_2 when heated above 465 °C. It takes about 10 minutes to totally decompose the titanium hydride [10]. Large volumes of hydrogen gas are produced, creating bubbles that can lead to a closed cell foam, provided that the foam drainage is sufficiently slow, which requires a high melting viscosity. The process begins by melting aluminium and stabilizing the melt temperature between 670 °C and 690 °C. Its viscosity is then raised by adding 1,5 % of calcium which rapidly oxidizes and forms finely dispersed CaO and $CaAl_2O_4$ particles or intermetallic Al_4Ca [1]. The melt is then aggressively stirred and 1 ÷ 2 % of TiH_2 is added in the form of 5 ÷ 20 μm in diameter particles. As soon as these are dispersed in the melt, the stirring system is withdrawn, and foam is allowed to form above the melt.

The cell size can be varied by changing the TiH_2 content, and the foaming and cooling conditions [1]. Aluminium foam with densities from 180 kg/m^3 to 240 kg/m^3 can be manufactured. Two types of ALPORAS foams can be produced, one with cells in the range from 1 to 13 mm (mean cell size 4,5 mm) and the other with cells in the range from 1 to 7 mm (mean cell size 3,0 mm) [10].

4.2 Gas-releasing particle decomposition in semi-solids

This process of manufacturing aluminium foams, also known as FOAMINAL-ALULIGHT process, begins by combining particles of a foaming agent (typically TiH_2) with an aluminium alloy powder. The resulting mixture is cold compacted and then extruded into a bar or plate of near theoretical density. This material called "precursor" can be cut into small pieces, placed inside a sealed split mold, and heated to a little above the solidus temperature of the alloy. The titanium hydride begins to decompose at about 465 °C, which is well below the melting point of pure aluminium 660 °C and of its alloys. These expand by semi-solid flow and the aluminium swells, creating foam that fills the mold, cooling then stabilizes the foam. The process results in components with the same shape as the mold and relative densities as low as 0,08. The foam has closed cells with diameters that range from 1 to 5 mm in diameter. Fig. 2 presents the sequences of gas-releasing particle decomposition in semi-solids manufacturing process for aluminium foams. IFAM Bremen, have developed a variation of the process, which has considerable potential for innovative structural use.

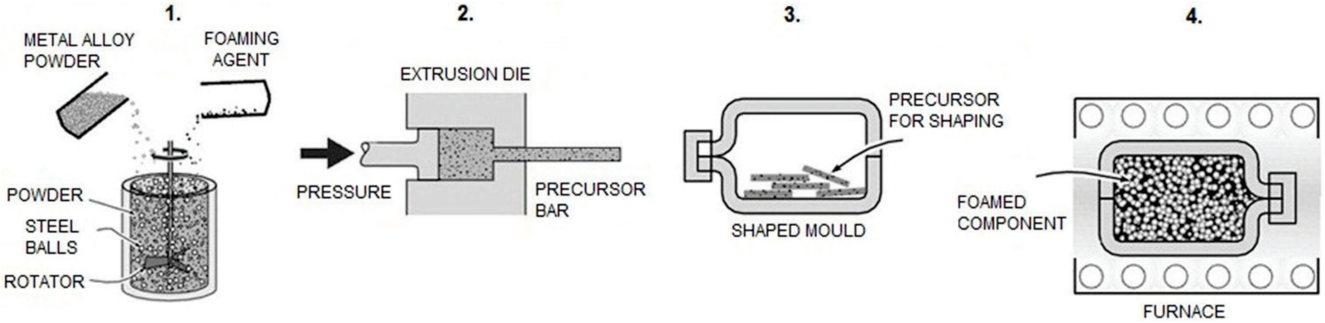

Figure 2 The sequence of powder metallurgy process used for gas-releasing particles decomposition in semi-solids: 1. Selecting and mixing of the ingredients; 2. Consolidation and extrusion of precursor bars; 3. Mould preparation; 4. Foaming in furnace

5 Application of metal foams in casting technology

In the casting technology sand cores or solid cores are often utilized for the production of cavities in casting products. Cavities can be of simple or complex shape. Standard casting cores can be replaced with metal foam cores that can be removed or permanently remain in the casting product. If the metal foam core remains in the casting product it increases the strength of the product. Weight increase can be ignored due to excellent strength-to-weight ratio. Metal foam cores also improve impact energy absorption and sound and vibration damping of the casting product. Good heat transfer insulation is also advantage of foam cores.

Casting aluminium around an aluminium foam core can create components where low density of core is completely surrounded by a massive outer shell (Fig. 3). The shell can be designed in such a way that additional functions beside its load carrying ability can be fulfilled. Metal foam cores can be used in different casting products such as housings, covers, gears, space frame nodes, linkages, legs, steering knuckles, control arms, cross-members and other parts of the car suspension, engine mounting brackets (see Fig. 3), etc.

High level of impact energy and vibration absorption, and high sound attenuation, favour the use of aluminium foam cores in manufacturing various castings used in the automotive industry [12]. Fig. 4 presents a prototype of automobile engine mounting bracket manufactured by LKR Ranshofen, Austria and produced for BMW. This composite part consists of an aluminium foam core and a cast shell. Engine mounting bracket is 25 cm long and can be loaded with the full weight of the automobile engine [13]. When the engine is running the mounting bracket absorbs mechanical vibrations converting them into heat by internal friction in the material. The heat dissipates into atmosphere and vibrations from the engine are not transferred further. Since the stiffness of the parts has increased, these products also increase safety in case of an automobile crash.

Figure 3 Casting products with aluminium foam cores [11]

Figure 4 Prototype of a BMW engine mounting bracket [13]

In manufacturing of modern machine tools the tendency is for achieving higher speeds of headstock with spindle or table with workpiece. High feed rates of heavy workpieces are difficult to achieve because of increased acceleration and deceleration of heavy weights. The usage of castings with aluminium foam cores results in the same stiffness of machine elements with significantly lower mass. Aluminium foam cores also provide good absorption of vibrations produced by the motion of parts which is also reflected in the increased accuracy of such machine tools. Figure 5 shows the machine tool crossbeam with the ALPORAS aluminium foam core and the outer shell of AlZn10Si8Mg. Shinko Wire Company has already produced 700 of these products for a machine tool manufacturer. Absorption of vibration is achieved up to 370 Hz frequency [13].

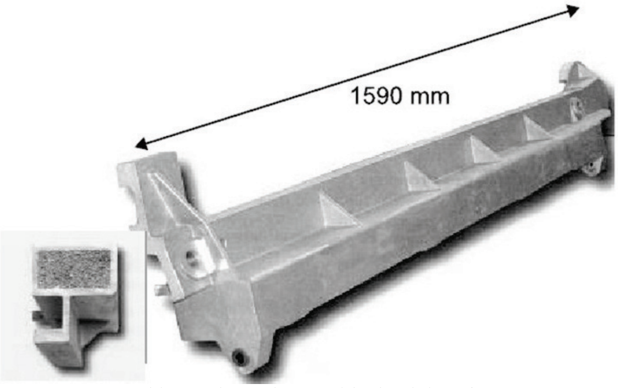

Figure 5 Machine tool crossbeam with aluminium foam core [13]

In the Ph.D. dissertation of Balázs Kovács [14] for the purpose of an experiment one car crossmember was produced containing a permanent casting core of aluminium foam. The aim of this experiment was to demonstrate that the usage of the aluminium foam core for casting crossmember provides better sound attenuation with superior mechanical properties. Earlier type of crossmember was produced with ribs. According to the dimensions of the previous model a new crossmember casting mold with aluminium foam core was designed (Fig. 6).

The casting mold is manufactured from silica casting sand consolidated with a furan resin. The mold cavity for the shell around the core is 5 mm wide for the purpose of simpler pouring and flowing of molten metal. The casting product has dimensions: length 410 mm, width 148 mm and height 75 mm [14]. The weight of the casting product with metal foam core is 2,05 kg and it is 32 % heavier than the previous version without the core. The increase of dynamic stiffness, which occurs on the basis of the weight increase, must also be observed. Fig. 7 shows the cross section of the casting with an aluminium foam core.

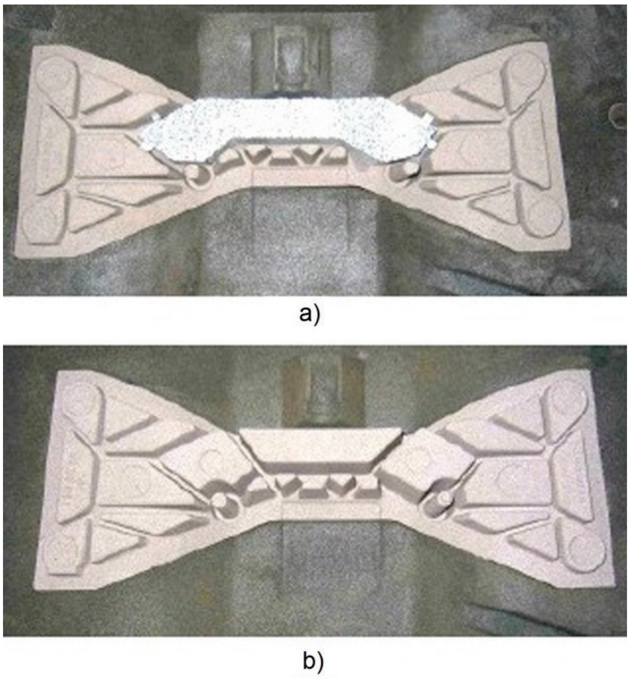

Figure 6 Comparison of two different molds: a) casting mold with a permanent foam core AlMgSi7; b) casting mold with rib reinforcements on the casting product [14]

5.1 Production of casting products with metal foam core

Metal foam cores produced by foaming in mold have a dense homogenous surface. Thickness of the surface can partially be just 0,2 mm or the same as the thickness of the cell walls in the structure [9]. By casting of homogeneous aluminium around aluminium foam core composite structural elements can be produced. Casting products have very light core and few millimetres thin homogenous shell. The thickness of the shell depends upon the structure and production parameters and can vary a few times in different places of the casting product.

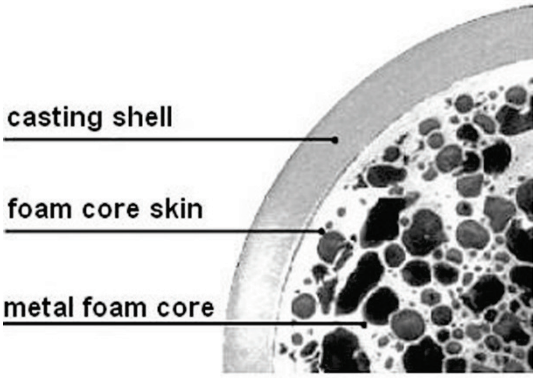

Figure 7 Cross-section of segment of casting product with the aluminium foam core

The various casting methods differ by the acting metallostatic pressure, the mold filling time, and the solidification time which is mainly determined by the temperature of the mold. Main prerequisite for using metal foam cores as cores in casting products is that a metal foam core must have homogeneous surface. Casting metal shells around metal foam cores is not completely a straightforward process because pressure of the molten metal is restricted with compression strength of the metal foam core surface. Additional difficulties can arise during positioning and fixing of the core in the mold.

5.1.1 Production of the aluminium foam cores

Aluminium foam core can be produced by heating in a furnace or by the injection of aluminium foam into the mold. The choice of method depends mainly on the geometry of the product. In both cases the core is basically produced by gas-releasing particles decomposition in semi-solid state of metal in the core mold [9]. Figure 4 presents the sequence of operations in the production of aluminium foam core by this technology. Precursor can be produced by a FOAMINAL or a FORMGRIP process. For complex shapes of the core it is preferable to use injection of the metal foam into the mold. The thickness of the homogenous surface obtained by injection into the mold is also higher than the thickness obtained by heating the precursor in a furnace. That can also be an advantage in the later usage of the aluminium foam core during the casting process.

5.1.2 Attaching the metal foam core in the mould cavity

If the aluminium foam core is an additional component in a casting mold it must be carefully attached in the mold cavity. A suitable core attachment system has to perform two functions: it must preserve the position of the core during the casting process and also maintain the desired distance between the core and the inner wall of the mold cavity. The specified distance determines the thickness of the shell around the casting core. One possible solution is to design a foam core with elongated wedge-shaped spacers placed on the edges of the core. These spacers enable the foam core to be permanently positioned in the centre of the mold cavity. Spacers have to be long enough to transfer the acting forces from the core to the mold cavity during casting. Arrangement and location of the spacers is also important for the transfer of forces to the mold cavity and for the smooth flow of the melt around the core without attenuation or barriers [9].

5.2 Casting of the molten metal around metal foam core

Depending on the used casting process, different requirements have to be fulfilled by the foam core and the processing conditions. Production of casting products without defects in the form of inclusions, misruns, folds or deformation is still a complicated process. It is necessary to avoid local melting of the core's homogeneous surface when the melt flows and fills the mold cavity. In previous research, conducted on sand molds and permanent molds, it has been observed that penetration of the molten metal into the foam core commonly occurs at the gate area where molten metal transfers the heat to the foam core and further erodes the surface [9]. This phenomenon can be avoided by surface coatings on the foam core that can increase the thickness and resistance to erosion.

Casting processes that utilize aluminium foam cores can be divided into low-pressure and high-pressure processes. Strength of the aluminium foam core surface must be increased for high-pressure casting process. This can be achieved by plasma spraying of the coating layer. Coating layer can be made of Al 99,5 or special ceramic [9]. Coating material must satisfy two conditions: it must be suitable for spraying on complex geometries of the foam core and must be suitable for achieving desired thickness. Applying thick coating layers on foam cores surface can become homogeneous without pores and with higher compression strength. By increasing the thickness of the coating the local compression strength is increased until the global compression strength is reached.

Experimentally it was found that with coating layers thicker than 350 μm local damage is completely suppressed and foam damage is defined by global compression strength. Since both, the local and the global strength show the same dependence on the foam density the critical thickness of the coating is supposed to be independent of the foam density [9].

Deformations of the foam core can be avoided by controlling solidification and pressure during casting. If the solidification of the molten metal occurs in contact with aluminium foam core, and if the solidification of the casting shell begins during the maximal pressure of the molten metal, then the core remains protected from the damage and deformations [9].

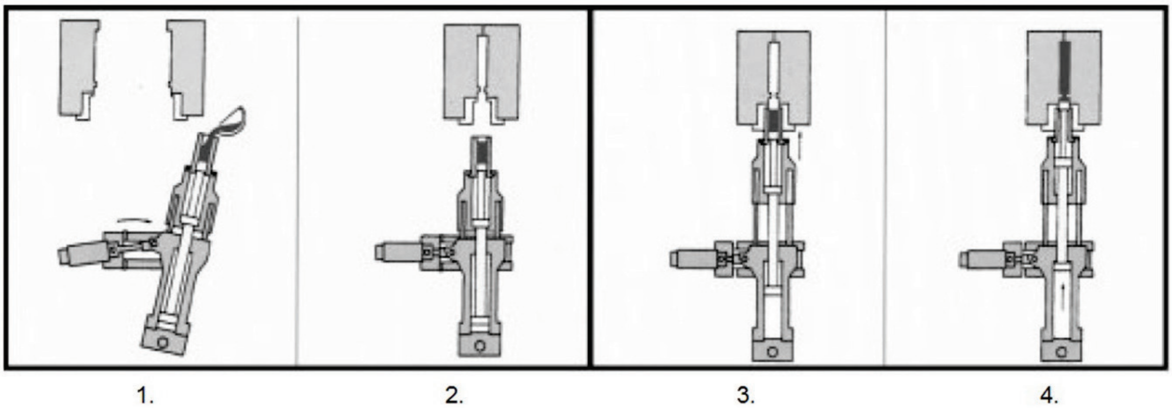

Figure 8 Metal casting in the semi-solid state: 1. Charging of the cylinder with the semi-solid metal; 2. Positioning of the injection unit and closing of the die; 3. Cylinder docking to the die; 4. Melt injection by piston movement [9]

5.2.1 Metal casting in the semi-solid state

Metal casting in the semi-solid state (also known as the squeeze-casting process) is characterized by slow, high-pressure bottom-up filling of the die. As the result the properties of casting product are similar to the properties obtained in low-pressure permanent mould casting process. Mould closing system in this process is similar to the conventional high-pressure casting process closing systems. An injection unit is positioned below the mould and fills the mould vertically (Fig. 8).

The injection process is relatively slow compared to the conventional high-pressure die casting process. Metallostatic pressure can be set between 300 and 1200 bar [9]. This controlled filling is specially suitable for moulds with complex core forms. In different experiments foam cores Al 99,5, AlMgSi1 and AlSi10 were used with casting molten AZ91 or AlSiCu3 [9]. Pouring velocity at the gate was 0,5 m/s, metallostatic pressure was reduced to minimum in order to avoid damage of the core. Casting products with shell thickness from 3 to 23 mm have been produced [9]. Process parameters cannot be significantly changed which results in the poor quality of casting products.

5.2.2 Die casting

Essential for die casting is controlling dwell pressure with the help of a real-time control system. In the first phase of the conventional die-casting process the die is filled with melts as fast as possible. In the second phase very high dwell pressures are applied to balance the shrinkage and to minimize porosity of the castings by compressing the entrapped gases. Because of the high velocity of the casting piston a high pressure peak appears at the end of the first phase when the die is completely filled resulting in massive foam infiltration and collapse of the casting product. In order to avoid this peak, a real-time controlled die-casting machine is indispensable. With real-time control it is possible to control the casting velocity and the casting pressure at every step of the casting process. The piston can be decelerated at the end of the filling phase to prevent the peak pressure.

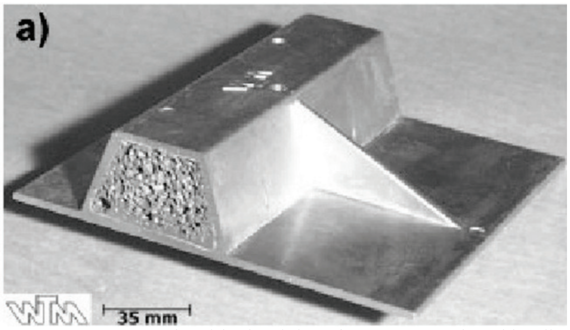

Figure 9 Test sample with aluminium foam core produced by die casting [9]

Casting experiments on coated and uncoated foam cores with different specific casting pressures have shown that a significant reduction of core infiltration is possible by using coated foam cores.

The porosity of the shell can be reduced even to less than 5 % without infiltration of the core. The minimum thickness of the shell can be about 2 mm for die geometries evaluated so far.

5.2.3 Gravity casting

In contrast to die or squeeze casting the acting pressures during gravity casting are insignificant and much smaller than the local compressive strength of the foam core. That is, as long as there are no large cracks in the foam surface infiltration or compression due to high pressures is not observed during gravity casting. Pouring liquid metal around the foam core results in heating up and consequent expansion of the gas inside the pores. In contrast to the high-pressure casting methods the gas is not prevented from diffusing from the core into the melt where it forms bubbles. That is, the expanding gas can cause porosity in the shell or even destroy the integrity of the casting because of gas bubble formation. This expansion of the gas and the deterioration of the shell can be minimized by preheating the core before insertion. Another advantage of preheating the core is that cold shuts, which appear in regions of the castings with the lowest thickness of the shell, can be avoided. The preheating of the core leads to a lower heat flow from the melt into the core, thus enabling reduction of the wall thickness in comparison to usual sand cores, which cannot be preheated. With preheating temperatures of 400 °C the minimum shell thickness is found to be about 1,5 mm.

5.3 Mechanical and metallurgical bonding between the core and the shell

Generally, no bonding develops between the core and the shell during casting because of the continuous aluminium oxide layer that prevents the core surface from reaction with the molten metal. The same effect occurs when using aluminium cores in magnesium squeeze castings [9]. The contact time appears to be too short for significant reactions between the aluminium oxide skin and the magnesium melt. There are two possible ways to improve the bonding:

1) Mechanical bonding by flow of liquid metal into the outer foam structure supported by intentional weakening of the surface skin, e. g., by sand-blasting. Disadvantage is that the weight of the casting increases and the bonding occurs only locally and is difficult to control.
2) Metallurgical bonding by coating the cores with various agents supporting diffusion through the aluminium oxide layer. With a suitable metallic coating a metallurgical bonding can be achieved. On this point, however, further research is necessary.

The shrinkage of the cast shell during solidification leads to a pressure fit of the inserted core. For most applications metallurgical bonding will not be necessary to achieve the required component properties such as improved energy absorption behaviour or improved damping properties. The absence of bonding may sometimes even improve structural damping of the part due to additional energy dissipation at the shell/core interface.

6 Conclusion

Metal foams are extraordinary forms of material applicable in production of products and structural elements. Number of researches about production and joining technologies that has been conducted is boosted by needs for lighter products with better strength-to-weight ratio, better thermal, acoustic and sound insulation and better absorption of impact energy. Production of metal foam cores for casting is a simple and reliable process that requires making the mould for core and heating the precursor for producing metal foam core. It is necessary to carefully select the casting technology for the foam core and to define process parameters because of high sensitivity of the foam core's surface. Homogenous surface of the core can be deformed or destroyed locally during pouring of the molten metal. Because of the oxide layer on the surface of aluminium foam cores metallurgical bonding is only possible by applying suitable metallic coatings. By spraying the cores with various agents diffusion through the aluminium oxide layer can be achieved. Mechanical bonding between the core and the casting shell is possible if entrance of the molten metal through the core's surface is enabled with a few holes.

Using permanent metal foam cores reduces the costs of cleaning and removing of the core from the casting product. Most commonly used permanent foam cores are aluminium foam cores just because aluminium foams are the most explored among the metal foams and producing them is the most developed process. Application of metal foams for permanent cores in foundry is one of the newer technologies that provides castings with different properties precisely according to current requirements for a reduced mass, with the same strength and quality of the casting product.

7 References

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