STRUCTURAL SUPERLIGHT POROUS METALS (Review)

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Porous metals, having many attractive technological properties, have aroused greater interest over the recent years. The paper gives the main technological advantages of porous metals opening up good prospects for their application. Porous metals, while preserving the main advantages of the initial material, have many times lower heat and electric conductivity, while their sound absorption and damping capability are higher. Adhesion bonding, brazing or diffusion welding can be used as methods of joining porous metals. Porous aluminium is capable of providing an unprecedented strength-to-weight ratio that can be actively applied in aerospace technologies, where mass minimizing is highly important. Porous aluminium properties, the most widely applied at present, are damping and maximum absorption of vibrations, waves and impact energy at collisions. In the near future porous alloys, depending on the degree of porosity and manifestation of new unique properties, will become the main structural and protective materials in development of military ammunition, in construction, instrument-making, as well as automotive, railway, aerospace engineering and in ship-building. Porous metals have been intensively manufactured since 2000 in Europe, USA and Japan. In Ukraine porous aluminium manufacturing has been mastered at the experimental level, and still is expensive and energy-consuming. 17 Ref., 12 Figures.

Keywords: *superlight materials, aluminium, magnesium, porous aluminium, foam aluminium, damping, specific strength, instrument-making, telecommunications satellite, aerospace industry, weldability*

Over the recent years porous metals, which have a lot of attractive technological properties, have aroused increased interest. Porous metal (PM) is metal foam, the cellular structure of which contains a large number of uniformly distributed pores and bridges. There exist several fundamentally different technologies of producing porous metals, one of which is sintering of granules-semi-finished products (Figure 1). Technological differences allow manufacturing PM with different pore configuration that changes their density and technological properties into opposite ones. For instance, PM with closed pores (Figure 2, *a*) has 50–80 % porosity, and ensures thermo-insulating properties, while material with open pores (Figure 2, *b*) and 35–95 % porosity enables heat exchange to be performed. PM has low hygroscopicity (1–3 %), that provides frost resistance and absence of cracks at temperature gradients. Metallic foams from aluminium, magnesium, steel, titanium or zinc are readily joined by adhesion bonding, welding, brazing with different materials, have higher corrosion resistance, and lend themselves easily to drilling, sawing and milling.

Porous aluminium (PA) is capable of providing an unprecedented strength-to-weight ratio, that can be actively applied in aerospace technologies, where mass minimizing is highly important. As aluminium fraction in aircraft structures is equal from 2/3 up to 3/4, and in rocket structures it is from 1/20 up to 1/2, the possi-

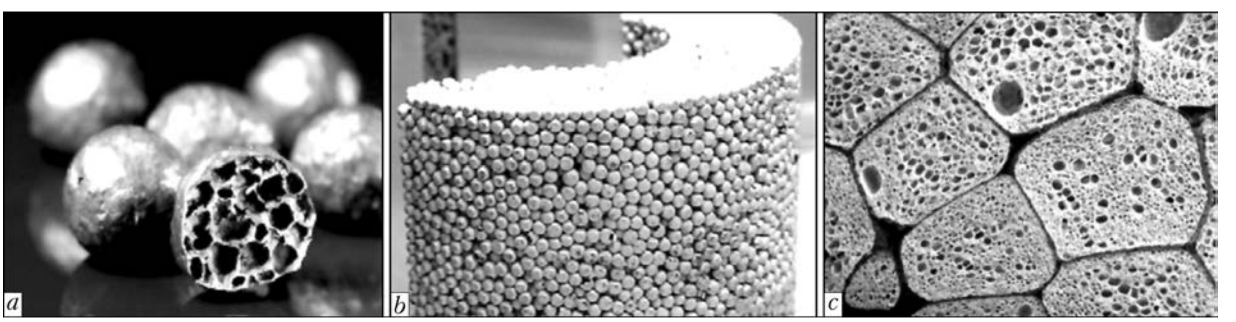

Figure 1. Granules-semi-finished product (*a*) are placed into a form for sintering (*b*) in production of porous aluminium (*c*)

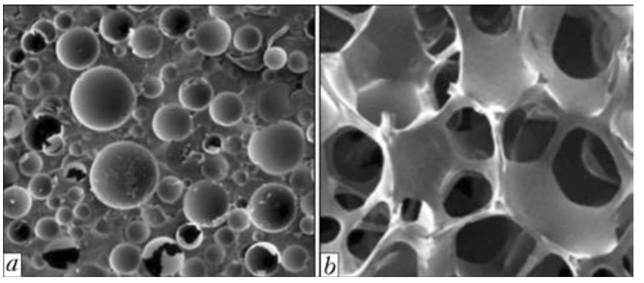

Figure 2. PA with closed (*a*) and open (*b*) type of porosity

bility of replacement of monolithic materials by porous ones in large-sized structural elements is an attractive goal (Figure 3).

Replacement of expensive honeycomb structures by PA panels [1–3] (Figures 4–6) can essentially reduce the manufacturing cost of telecommunications satellites and other space equipment, where there is a tendency of increase of the ratio of weight of payload (research equipment fastened on the satellite) to total weight of the launched space vehicle (platform) (Figure 7).

PMs, while preserving the main advantages of the initial material, have many times lower heat- and electric conductivity, and their sound absorption and damping capacity are higher than those of bridge metal. More over, they are not-toxic, heat- and bio-resistant, do not fail at the impact of combustive-lubricating materials, solvents, ultraviolet and radiation. Under the impact of open flame they gradually soften, if the temperature in the heating zone reaches 650–800 °C.

Mechanical properties of foam material are due to three-dimensional isotropic structure and are determined by behaviour of individual structural elements — bridges. Material compression proceeds in four stages. At the first stage, deformation of the frame weakest elements and edge inhomogeneities occurs at small loads, at the second stage, elastic deformation takes place, and at the third stage, the bridges lose their stability, plastic deformations develop and compressive diagram moves into a flat area (compression plateau). The process is of a cyclic chain nature: loss of stability of one of the bridges involves development of deformation in the adjacent ones and furtheron over the entire layer, material layers gradually collapse to the compactification limit, when the pores close completely and deformed material begins acquiring the properties of compact material. At the fourth stage, the

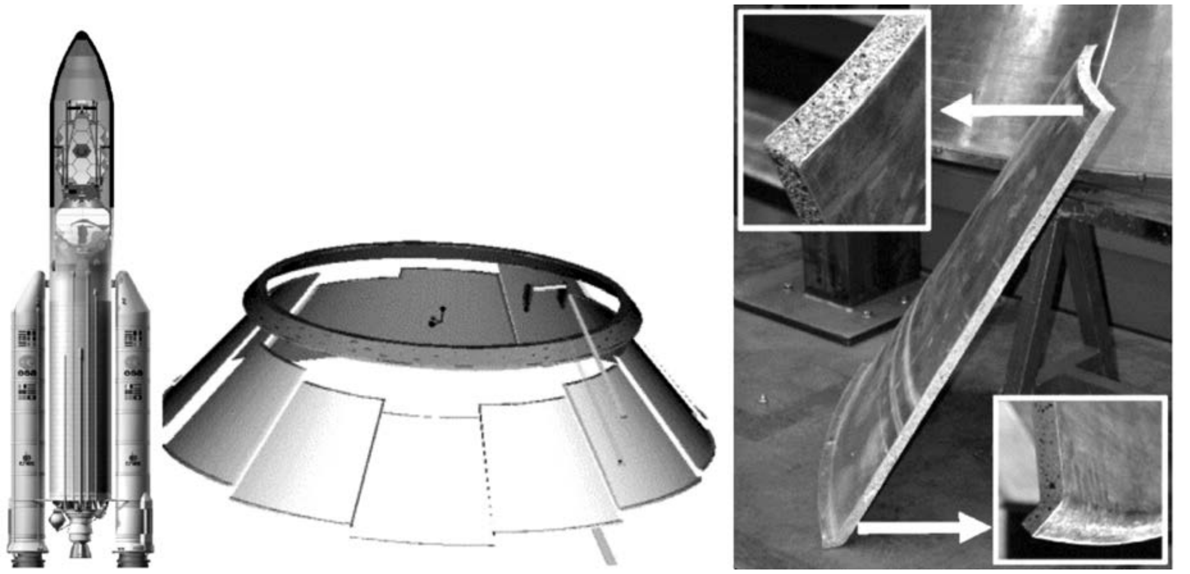

Figure 3. Segments of AFS cone of Arianne missile engines from PA

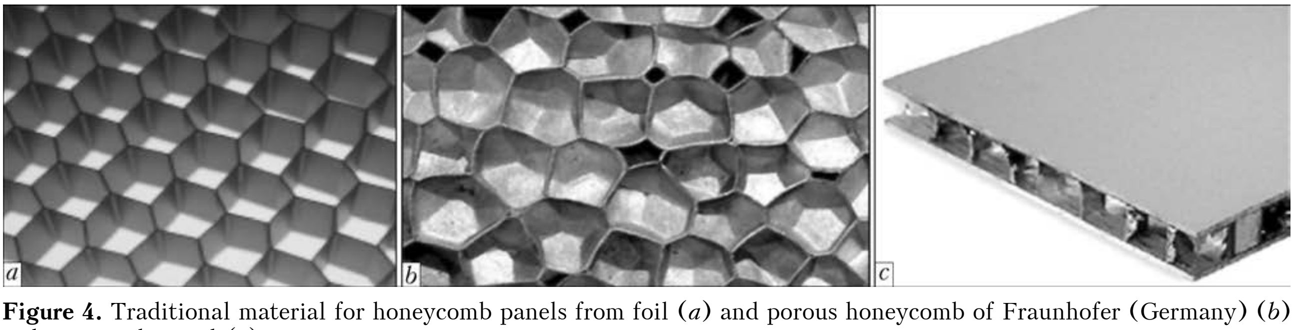

Figure 4. Traditional material for honeycomb panels from foil (*a*) and porous honeycomb of Fraunhofer (Germany) (*b*) in honeycomb panel (*c*)

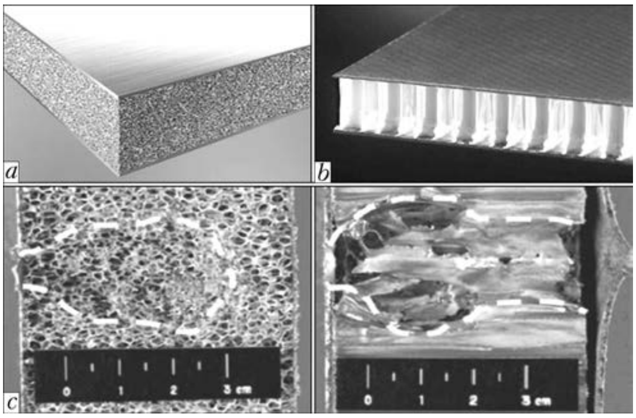

Figure 5. Comparative testing (*c*) of honeycomb panel from aluminium foil (*b*) and sandwich panel from highly-porous aluminium (*c*)

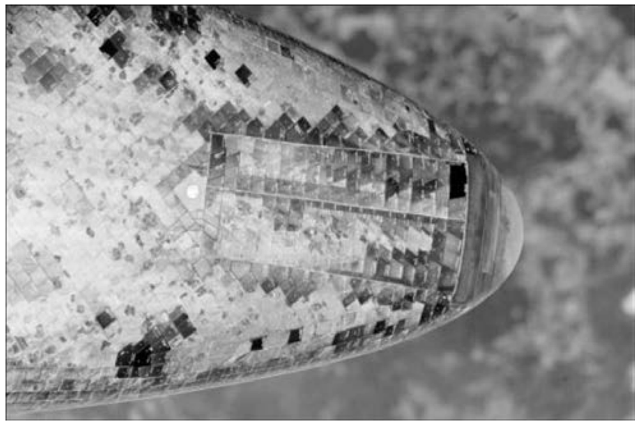

Figure 6. Damage of anti-meteor defense of Space Shuttle Discovery

stress in the material rises again, and it gradually becomes close to a compact material.

PMs demonstrate nonlinear behaviour at deformation, characteristic of cellular structures. Therefore, PMs are used not only for shock damping, but also for increasing the rigidity of hollow profiles (Figure 8), manufacturing incombustible light-weight flame- and heat-resistant damping materials, as well as reinforcing anchors in concrete walls. PA can be used as mould cores. After casting they remain in the finished shaped casting instead of cavities, which are envisaged to reduce the car weight that yields certain advantages in strength and reduces the expenses for removal of standard sand cores.

Strength of PA products is greatly increased at surface treatment — rolling, forging, stamping [4, 5]. PA does not melt at the temperature of melting of the initial alloy: at heating in the electric furnace up to 1400 °C it did not melt; after soaking for 100 h at 1482 °C it strongly oxidized, but strength and dimensions of the samples remained the same. Thus, PA can be heated many times up to high temperatures and rapidly cooled, here its properties change only slightly. To manufacture flexible PA sheets of large dimensions with adjusted values of porosity, air content is brought to 93–98 % by volume, and then the manufactured material is rolled into sheets.

Characteristics of PA structure influence the degree of deformation at its compression [6]. PM from AMg6 alloy of 0.5–0.6 g/cm^3 density is resistant to elastic relaxation before and after plastic deformation, right up to 27 % compression. At 4.5–5.0 % compression this material is elastically deformed; at 5.5–6.0 % elastic deformation in it develops into plastic deformation. Material strengthening after multiple compression in the elastic and elastic-plastic region for a specimen of 0.6 g/cm^3 density does not exceed $\Delta\sigma$ = 1 MPa, and for a specimen of lower density of 0.5 g/cm^2 it reaches $\Delta\sigma$ = 2.7 MPa, that may be related to the mechanism of frame evolution. During compression the structure of material of 0.5 g/cm^3 density evolves by the mechanism of pore closure and torsion.

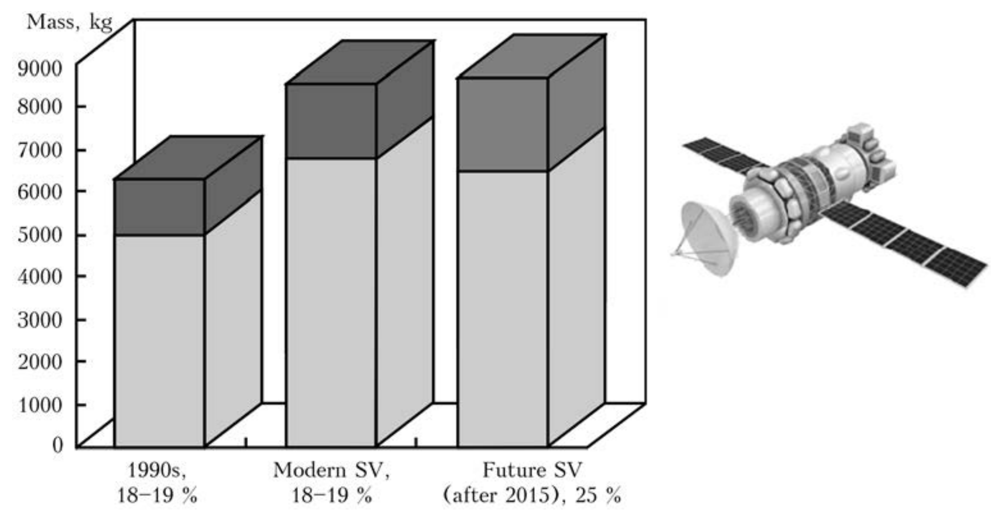

Figure 7. Prospects for increase of ratio of payload weight (*dark colour*) to the total weight of space vehicle (SV) (*light colour*)

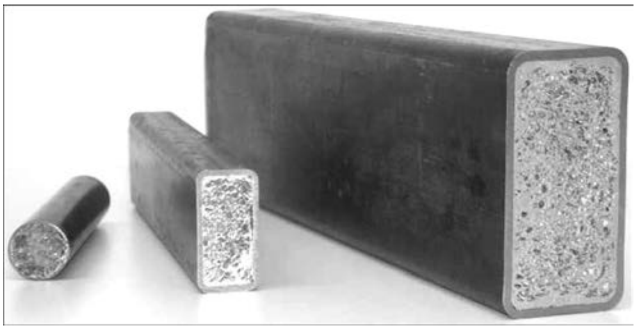

Figure 8. Types of panels with PA filler

«The strongest metal foam in the world» was produced at the University of North Carolina (USA) [7]. Material can be compressed to 80 % of its size under the impact of weight and can preserve its initial form after the load has been relieved. New metal foam is unique due to uniformity of the cells and their walls. This is exactly what gives it strength and elasticity, required for compression without deformation.

Automotive industry is showing the greatest interest to PA. Three-layered aluminium sheets with aluminium foam are used in body manufacture. The low weight of such a structure reduces petrol consumption. The body is by 50 % lighter than the respective steel one, but 10 times more stable. Three-dimensional multilayer structures enhance the frame rigidity. They can be used to make also the body parts — from the doors to a complex group of bottom elements. Such parts are very light and have the rigidity 15 times higher than the regular sheet structures.

PA of Cymat (Canada) in the form of rectangular-shaped profiles is used for car door shock-absorbers and emergency partitions. Unlike the honeycomb structure from aluminium material, PA is isotropic and can resist a shock at any angle.

Application of the technology of foamed magnesium production by filtration through granules of water-soluble salts allows producing items of the porosity of 55–75 %, density of 0.7–0.9 g/cm^3, with ultimate compression strength of 5–10 MPa. Foamed magnesium has high damping properties, and its coefficient of elastic and viscous deformation is 2–5 times smaller than that of PA [8].

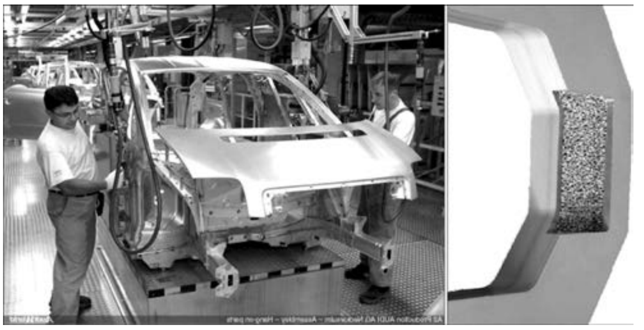

Figure 9. Car body parts from PA

Nickel alloys with manganese and hallium, developed by the staff of Boise State University (Idaho, USA) and Northwest University (Illinois, USA) feature a coarse-grained structure.

This makes them light-weight, while the materials preserve an exceptionally high strength. However, the new alloys also have a totally unusual property — they are elongated under the impact of an external magnetic field up to 10 % of their initial length. They also have shape-memory effect — they are preserved in the changed state for any length of time after field removal, but can return to the initial condition at magnetic field rotation through 90°. The new alloy was produced in the form of a polycrystalline material. Such materials are usually characterized by absence of pores, while their elastic properties and deformability, on the whole, are very insignificant.

The new material with the «magnetic shape memory» was produced by pouring the melt into a sample of sodium aluminate salt with inner pores. Then, the sodium aluminate is dissolved with acid, and large pores form in place of fragments filled with it. This material was subjected to various tests, in particular, by a rotating magnetic field. After 10 mnl revolutions in the magnetic field the material preserved its capacity for elastic deformation that makes it quite suitable for application in different magnetic drive systems. Developers believe that there is still room for further improvement of such systems. The porous structure of the material and low density, respectively, and reaction to magnetic fields, will allow it to be applied in the future in such industries as biomedical pumps without moving parts, various devices for slight displacement monitoring.

Neuman Alufoam (Austria) makes from PA unloaded car parts (Figure 9) and lateral shock absorbers, placed into the side doors. Density of parts from PA is 0.5–0.6 g/cm^3. It is noted that the closed external shell, surrounding the porous structure, provides a higher rigidity than that of the structure with open porosity. The company also produces parts of the body and chassis working in bending and torsion, to enhance their rigidity.

Alulight International GmbH (Germany, Austria) proposes PA of 300 up to 1000 kg/m^3 density for manufacturing basic shock-absorbing parts; electromagnetic shields in the form of wall and ceiling plates, protecting from penetration

Figure 10. Items with application of PA produced by ERG Aerospace Corporation (USA) [9]

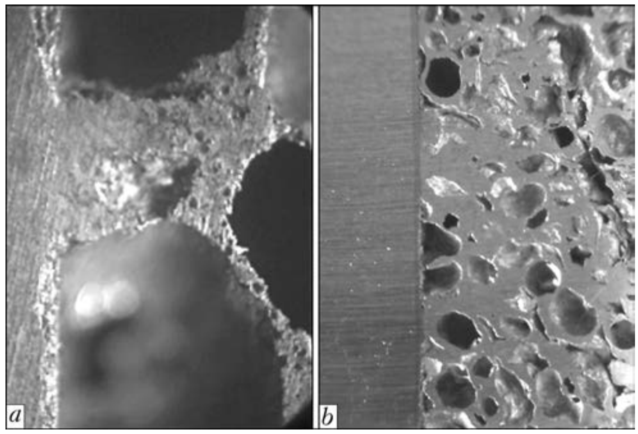

Figure 11. PA joints with monolithic aluminium (*a*) and magnesium (*b*) alloys

or radiation of electromagnetic waves of the frequency from 0.1 up to 1000 MHz, as well as electronic device cases; thermal shields; light construction materials as non-combustible alternative to wood and plastics (can be supplied in the form of plates with maximum dimensions of 625 × 625 mm, of thickness from 8 up to 25 mm); shock-absorbers for motor and rail transport; noise-killers operating under difficult conditions (high temperature, humidity, dust, vibration), in sterile or fire-risk premises.

Method to produce extended PA plates is interesting [10]. PA plates produced by hot rolling of a mixture of aluminium alloy powders with frothing agent into a blank with its subsequent foaming, are successively abutted. A powder interlayer of a mixture of aluminium granules of not less than 200 μm size and frothing agent in the quantity exceeding by 50 % the frothing agent quantity in the mixture for producing a blank, is placed between the plate end faces. The assembled plates are fixed to avoid relative displacements and the butt area is heated up to the temperature, ensuring foaming of the powder interlayer at the speed of 150–300 °C/min. The method allows increasing the strength and quality of the joining areas.

Thus, PM application is possible for the following items: filters; flame arresters; noise-killers (at increased frequencies higher than 800 Hz); catalyst carriers; dampers of mechanical, acoustic and electromagnetic pulses; structural elements; sandwich panels; fillers of cavities and tanks (Figure 10).

Brazing, diffusion or electron beam welding and adhesion bonding can be used as methods to join PM.

Department of Physico-Metallurgical Processes of Welding Light Metals and Alloys of the E.O. Paton Electric Welding Institute of the NAS of Ukraine made experimental bimetal joints of PA from V95 and AK7 alloys with monolithic aluminium (AD1, AK12, AMg6) and magnesium (ML4, MA2-1) alloys (Figure 11) by the method of activation of the surfaces being joined at 140–300 °C for fabrication of superlight blocks for encapsulation of microelectronics for aero-

Figure 12. Fastening PA granules (*a*) for fabrication of panel-insert (*b*) of combined arms assault bulletproof vest (*c*)

space applications [11–17]. Such joints can also be used for fastening the granules-semi-finished product in fabrication of composite armour plates of combined arms assault bulletproof vest (Figure 12), built by the modular principle that ensures all-round protection of the torso from fragments, cold and small arms.

The most widely applied at present PA property is damping and maximum absorption of vibrations, waves and shock energy at collisions. In the near future porous alloys, depending on the degree of porosity and manifestation of new unique properties, will become the main structural and protective materials at development of military ammunition, in construction, instrument-making, as well as automotive, railway and aerospace equipment and shipbuilding. PMs have been intensively manufactured in Europe, USA and Japan since 2000. In Ukraine PA manufacturing has been mastered on the experimental level and still is expensive and energy-consuming. Considering the military-political situation in the country, advance of PA manufacturing and fabrication of light and strong structures from it could significantly influence the defense potential of Ukraine.

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