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Characteristics and Test Aspects of Metal-Based Foams

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Abstract

There is a continuous development in automotive body production to expand the use of metal foams. The use of aluminium foams in vehicles is made possible by the high strength/mass ratio, which means that mass reduction is not accompanied by a reduction in safety. Reducing mass (self-weight), on the other hand, is essential due to increasingly stringent environmental regulations. The present composition draws attention to the structural properties of metal-based foams and its testability.

Keywords: *metal foam, cavity, sandwich structure, non-destructive testing, computed tomography.*

1. Introduction

The group of „hybrids" included in a possible division scheme of structural materials (**Figure 1**) includes composites, sandwich structures - as a special subgroup of layered composites -, segmented (connected, bundled) structures and cellular materials of various designs, foams (**Figure 2**) **[1]**. Segmented (connected, bundled) material structures are built from discrete units that can absorb significant loads as a block unit, while being sufficiently resistant to damage.

Among the porous materials, plastic foams are the most well-known: polystyrene foams („hungarocell"), polyurethane (PUR) foams, artificial sponges, packaging materials, etc. However, their applicability is limited by, among other things,

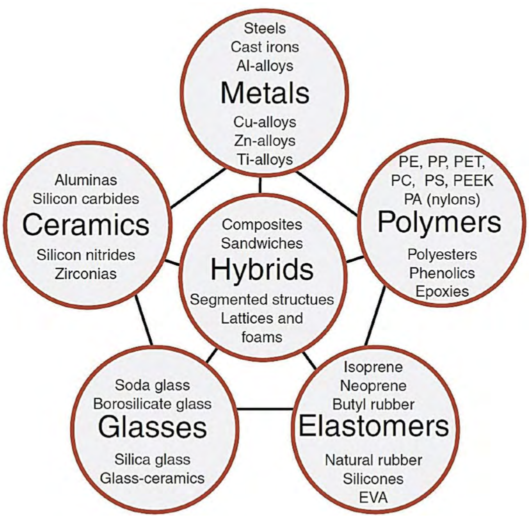

Figure 1. *A possible division of structural materials and typical examples.*

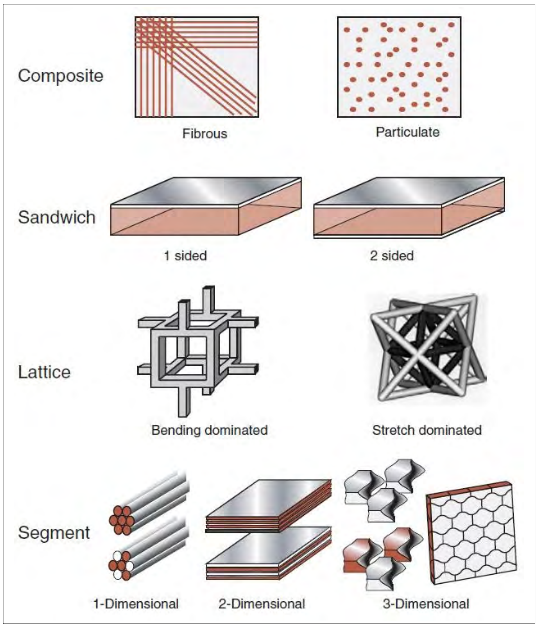

Figure 2. *Subgroups of hybrid structural materials.*

the strong temperature dependence of their properties and their inherently low strength [2]. In the case of metal foams, these disadvantages do not occur or occur to a lesser extent. Metal foams are lightweight cellular materials inspired by nature (biomimetics): e.g. cork, balsa wood, sponge, cancellous bone, coral, cuttle-bone and palm plant stalk also have a similar structure (Figure 3) [1].

2. Characteristics of metal-based foams

Based on their structure, metal foams can be divided into two groups (Figure 4) [3]:

– Open-cell metal foams, the cavities of which are connected to each other, and the framework of which is formed by interconnected cell edges;

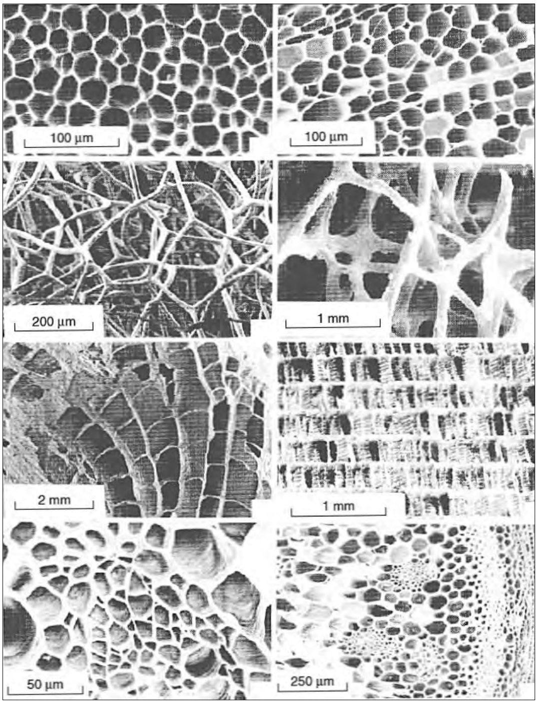

Figure 3. *Cellular biostructures.*

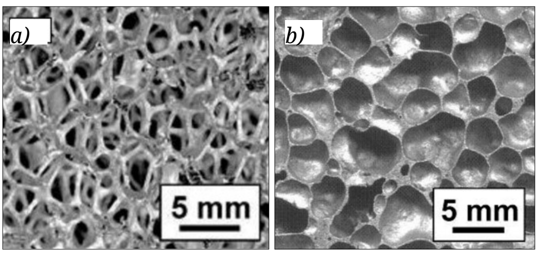

Figure 4. *Open and closed cell metal foam.*

– Closed-cell metal foams in which the cavities are separated by cell walls.

In order to (more) accurately identify metal foams, a distinction can be made between the materials (variants) commonly known as metal foam [4]:

– Cellular metals: the most general term that refers to a metal body in which cavities filled with gas can be found, i.e. the metal phase divides the material into cells, in which there is a gas phase.
– Porous metals: a special type of cellular metals, which are characterized by a kind of cavity, so the pores are usually round and separated from each other.
– Solid metal foams: A special class of cellular metals, which are formed from liquid metal foams and thus have a defined morphology. The cells are closed, round or polyhedral and separated by a thin layer of metal.
– Metal sponges: a morphological type of cellular metals in which there are open cells.

Figure 5 shows the division of cellular metals in terms of production technology [5].

Metal foams can contain cavities of a few micrometers or even centimeters in size, and the wall thickness of the cells in them can vary widely, while their structure is similar to plastic foams. The density of metal foams is significantly lower compared to that of solid metals, their average density can be up to one hundredth of the density of the metal. One of the most common characteristics of metal foams is the relative density, which is the ratio of the density of the metal foam to the density of the metal forming the metal foam, often given as a percentage. The relative density of currently produced metal foams varies between 0.1% and 50%. Solid metal foams are known for their combination of specific physical and mechanical properties, such properties are relatively high stiffness, low specific weight (density), relatively high compressive strength and good energy absorption [6].

Figure 6. summarizes the mixture states that can be formed from materials with characteristic states, including foam materials. In these heterogeneous (consisting of different parts) material mixtures, one material quality (or state of matter) is present in a larger (dominant) proportion, while the other - in a fine and uniform (dispersed) distribution - is present to a lesser extent [7].

The metal foams used are mostly aluminum-based and can be achieved with special production technology to create closed cavities in the

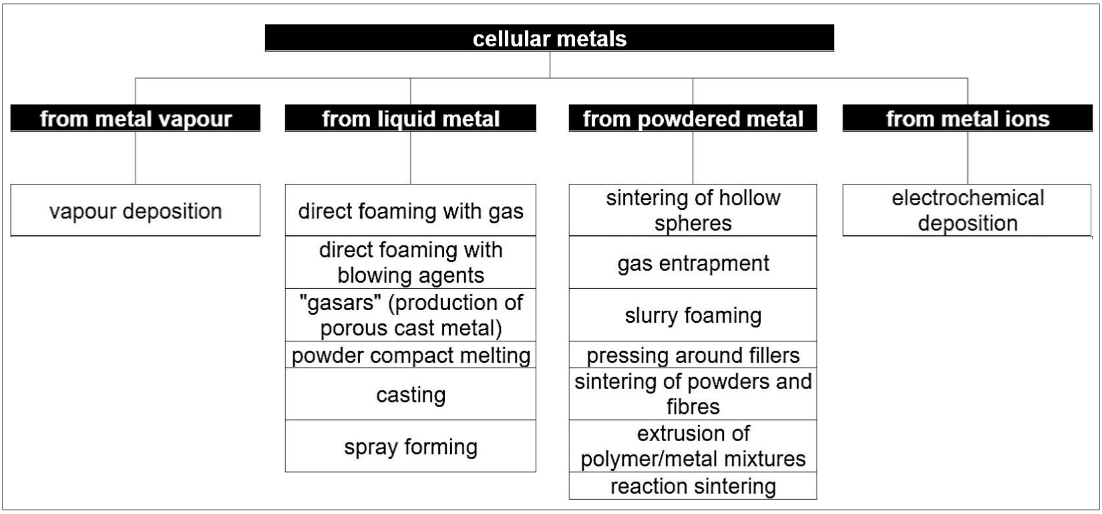

Figure 5. *Division of cellular metals based on production technology.*

Established mixture states, when		Material that we disperse		
		Gas	**Liquid**	**Solid**
Material in which we disperse	**Gas**	Gas mixture	Fog	Smoke
	Liquid	Foam	Emulsion	Suspension slurry
	Solid	Solid foam, cellular solid	Sludge Gel	Powder mixture Embedded particles

Figure 6. *Foam materials between mixing states.*

aluminum, thus giving the material a „spongy" structure. Components are produced in a closed mold, in which case the cavities of the foam are closed in contact with the surface of the mold, so the surface will be smooth and continuous. Another application is pouring thin-walled steel pipes with foamed metal. Since metal foams have good energy absorption and vibration damping capabilities, they are also excellent for stiffening pipes [8].

It is also possible to make sandwich structures using metal foams. Due to their advantageous properties, they can be used during body construction to stiffen support pillars, make floors and form bumpers. Due to their large specific surface area, they can also function as a support material for catalysts and as a large surface area electrode in batteries. Their electrical conductivity is lower than that of traditional metals.

When foaming with gas enclosed in pores, the high-pressure inert gas is trapped in the pores of the metal powder, so the metal powder is placed in a high-pressure gas space. Afterwards, this metal-gas mixture is rolled into a plate, while the wall of the sealed plate chamber forms solid side plates. The plate is heated so that the gas in the metal powder layer expands. With this method, a specific sandwich structure is obtained, i.e. a kind of composite, the core of which has a porosity of approximately 30%.

As an innovative material, aluminum foam has great potential for use as a composite component. It is a composite aluminum foam sandwich, which consists of aluminum plates as cover layers and aluminum foam as a core layer. Both the aluminum foam and the sandwich structure are completely recyclable and environmentally friendly, as they are made entirely of aluminum. These properties can be used very well for the bodywork of motor vehicles. In addition, the construction industry, the aerospace industry, marine and railway vehicle production also represent a great application potential.

3. Non-destructive material testing of metal-based foams

Continuity gaps must be detected using suitable test methods, with which they can either be recognized directly, or their presence can be inferred from some sign. The individual tests differ both in method and in the information content that can be obtained.

It is fundamentally important to keep in mind that there is no universal material testing method. Each method can only reliably detect discontinuities of a certain type and/or location, i.e. the individual non-destructive testing methods do not replace each other, but complement each other. Therefore, in some cases, a complex examination, i.e. the parallel execution of several methods, may be necessary.

The most important industrially applied non-destructive testing procedures:

- examination of density and physical (thermal, electrical, magnetic, optical, acoustic) properties,
- visual testing (VT),
- leak test (LT),
- penetrant testing (PT),
- magnetic particle testing (MT),
- eddy current testing (ET),
- ultrasonic testing (UT),
- radiographic testing (RT).

Various technical and economic requirements are imposed on the test methods, and the nature of the task is primarily decisive in selecting the appropriate method for the given task. There are also requirements that are partially contradictory and cannot be fulfilled in the same way:

- be as quick as possible, reliably detect the lack of continuity;
- it should be simple and can be done on site;
- preferably do not require special security measures;
- require minimal preparatory work;
- do not cause any changes in the condition of the workpiece;
- the equipment(s) should be simple and portable;
- the results can be permanently registered.

Aspects for choosing the test method:

- ability to reliably detect the desired discontinuity,
- the test site,
- size, shape, mobility of the product to be tested,
- size, design, surface fineness, accessibility of the area to be examined,
- the physical and chemical properties of the substance to be tested,
- requests related to the documentation (registry) of the examination,
- economy.

The CT examination is known as Computer Tomography, which is a branch of radiological diagnostics. The word tomography refers to slicing, because in tomographic images, the subject of the examination can be seen divided into imaginary slices. Computed tomography is a further development of the traditional X-ray screening technique (**Figure 7**) **[9]**.

CT machines therefore use X-ray radiation to create images, but the rays do not expose film, but detect them with the help of detectors, and then the reconstructed cross-sectional image is created from the electrical signals obtained from the detectors with the help of a computer. In the case of a tomographic scan, the examined object is illuminated with a thin, plane-like X-ray beam. The detector placed behind the object detects along a line where and how much of the beam has been absorbed.

With the beam, the body is illuminated from several directions in a given plane, and a drawing of the details located in the given plane (slice) unfolds from the measured intensity curves. The plane is then pushed away and rotated again. Once the procedure is completed, the spatial structure of the examined body can be mapped. By structure, we mean details that can be distinguished from the point of view of X-ray transmission, that is, the arrangement of material parts with different densities. **Figure 8** summarizes the factors influencing the CT examination **[10]**.

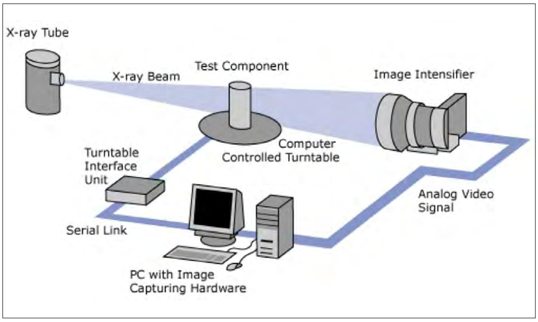

Figure 7. *Computed tomography equipment scheme.*

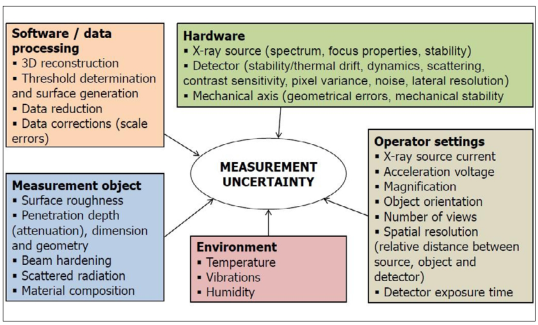

Figure 8. *Factors affecting for CT examination.*

4. Conclusions

AThe automotive industry is moving in a direction where it places great emphasis on reducing the weight of vehicles and thereby minimizing emissions. This weight reduction can be achieved mainly with new types of materials such as high-strength steels and aluminum alloys or cellular materials, including metal foams. Some of these non-destructive tests are essentially „quantitative", i.e. they indicate that there is a given number of (one or more) discontinuities, but provide information on their „quality" (type) and spatial extent, or only with limited validity, while the other part of the tests is a procedure with both quantitative and qualitative results.

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