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Fatigue of Cellular Structures – a Review

Branko Nečemer* – Matej Vesenjak – Srečko Glodež
University of Maribor, Faculty of Mechanical Engineering, Slovenia

A review of the fatigue and fracture behaviour of cellular structures with consideration of their fabrication and characterization is presented in this paper. The review is focused on some typical and often used cellular structures, which are divided into three main groups: (1) pre designed regular cellular structures, (2) irregular cellular structures, (3) composites with cellular cores. For each group, the current manufacturing technique is presented for producing the particular cellular structure belonging this group. Furthermore, the state-of-the-art of the fatigue behaviour is explained for the analysed cellular structures. Based on the findings in this review, it can be concluded that cellular structures show a huge potential to become important light-weight structural materials of the future with further development of additive manufacturing technologies, or with introduction of some new, more cost effective manufacturing techniques. However, the knowledge of the fatigue behaviour of these structures is poor, and should be the subject of the further investigations.

Keywords: cellular structures, porous materials, foam, fatigue behaviour, dynamic strength, crack growth

Highlights

- *General characteristics of cellular structures are explained.*
- *Fatigue and fracture behaviour of different cellular structures is presented.*
- *Fabrication techniques of different cellular structures are briefly introduced.*
- *The guideline's for the further work are exposed.*

0 INTRODUCTION

Cellular structures are a relatively new class of materials in modern engineering. They represent a unique opportunity for adoption in lightweight structures, which are useful in advanced structural and thermal applications. Therefore, the research of their behavior under quasi-static and dynamic loading is of extreme importance for various engineering applications. Although cellular structures have a favourable combination of physical properties, mainly the mechanical and thermal properties have been the subject of thorough research so far. In general, the most important structural feature of the cellular structure is the relatively high stiffness in respect to the high porosity (low density) of the structure [1] and [2]. Besides their light weight, cellular structures offer additional advantages, such as sound insulation and damping, mechanical energy absorption, floatability, durability at dynamic load, and recycling [3]. Often, several advantageous properties can be extracted simultaneously, making cellular structures important as multifunctional materials in modern engineering applications.

The main parameters that define the mechanical and thermal properties of a cellular structure are the relative density (porosity), base material, morphology and topology. The relative density is defined as the ratio of the density of the cellular structure (ρ^*) and the density of the solid base material (ρ_s), while the porosity (p) is defined as the ratio between the total pore volume (V_p) and the total volume of the solid base material including pores ($V_s + V_p$) [1] and [4]. The cellular structures show a specific compressive response, which is different from the conventional solid materials. Fig. 1 shows the characteristic mechanical response during compression loading of a cellular structure, which can be divided into four main areas: I.) Elastic part ($0-\varepsilon_a$), where the structure deforms quasi-linearly; II.) The transition in the plastic region ($\varepsilon_a-\varepsilon_b$), where the base material starts to yield, thus, the intercellular walls and connections in local areas are subjected to plastic deformation; III.) Plateau stress (σ_{pl}) ($\varepsilon_b-\varepsilon_c$), where the cellular material reaches almost a constant stress level in a very wide range of

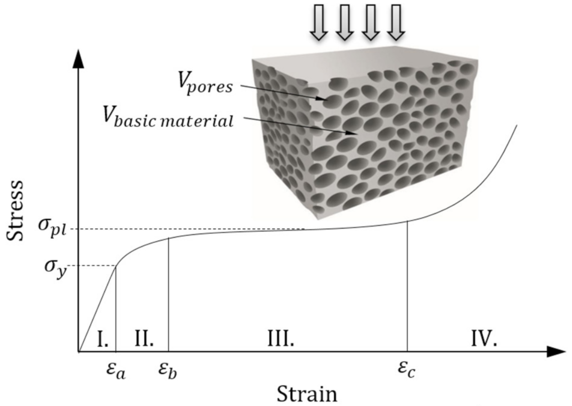

Fig. 1. *Characteristic response of the cellular structure under compression loading* [5]

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*Corr. Author's Address: Branko Neèemer, University of Maribor, Faculty of Mechanical Engineering, Smetanova 17, 2000 Maribor, Slovenia, branko.necemer@um.si specific deformations (massive plastic deformation of the cell walls and struts), and IV.) Densification ($>\varepsilon_c$), where the intercellular walls and struts collapse, resulting in a decrease of the global porosity and an increase in the global stiffness [1] and [4].

So far, extensive research has been performed in terms of characterization of the mechanical properties of various types of cellular structures, in order to study the compression [6] and [7], tension, torsion and shear under uniaxial and multiaxial loading conditions at quasi-static and dynamic loading rates, using experimental methods [8] and numerical simulations [9] and [10]. The response of cellular structures can be adopted by a combination of production processes and production parameters. In the last few decades, a number of distinct process-routes have been developed to fabricate metal and ceramic cellular structures, in order to decrease the manufacturing costs and increase the production capabilities. Thus, extensive research has been performed regarding the optimal manufacturing methods for cellular metals. These methods can be classified according to the state the metal is processed in [11]. Generally, we can define several groups of manufacturing methods, which are summarised in Fig. 2.

From Fig. 2 it can be observed that there are several ways to fabricate cellular structures, which are specially designed by taking advantage of the characteristic properties of the base materials [11]. Current manufacturing methods, especially additive manufacturing technologies, enable the creation of various cellular structures, either open-cell or closed-cell foams, with a varying regularity, isotropy and density. The most common methods for producing the three-dimensional (3D) cellular structures is by sintering of dusts, foaming and casting [2], [3] and [10]. The most common method for production of two-dimensional (2D) cellular structures is by laser or water jet cutting. Further details on fabrication of different types of cellular structures are given in [10].

To date, a lot of researches regarding static and crash performance of cellular structures have been performed and then published in the professional literature. However, a very few researches were focused on the fatigue problems of the cellular structures. In that respect, this paper provides a review of the fatigue behaviour of cellular structures, according to the different production methods and type of cellular structure. In general, the cellular structures can be classified by the cell connectivity (morphology: Closed- and open-cell structures, [1]) or by the cell regularity (topology: Regular and irregular structures [12]). Herein, the cellular structures presented are classified and discussed in two groups: i) regular (ordered) and ii) irregular (stochastic) cellular structures.

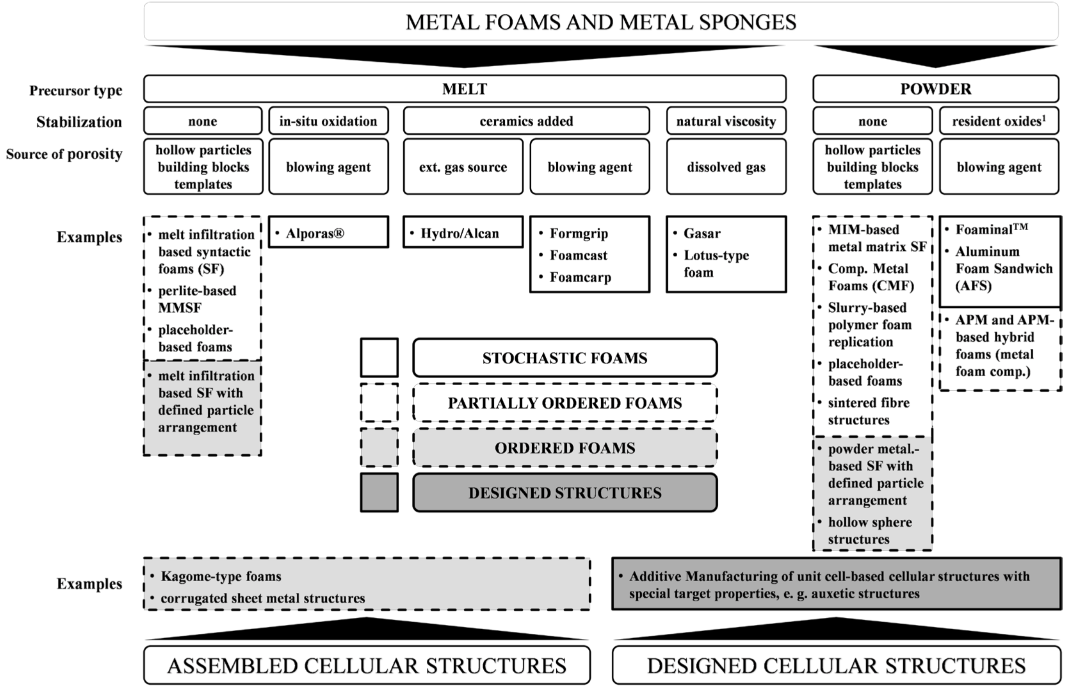


Fig. 2. *Overview of manufacturing processes and cellular metals* [12]

1 PRE DESIGNED REGULAR CELL STRUCTURES

The additive manufacturing technique is the most common method for production pre-design of cellular structures by using metal powder and an energy source to build up the geometry. Additive manufacturing techniques can be, according to the applied energy, divided roughly into two groups: i) selective laser melting (SLM) method, and ii) electron beam melting (EBM) method. Both can be used for the manufacturing of complex and customised 3D geometries of open-cell structures [13]. In general engineering praxis, titanium alloy powders are used most often. Therefore, porous titanium alloys have also been studied extensively for biomedical applications, e.g. bone implants [14] to [16]. Porous titanium implants, in addition to preserving the excellent biocompatible mechanical properties of titanium, have very low stiffness values, which are comparable to those of natural bones [17]. Some typical regular cellular structures are shown in Fig. 3.

Most of the research works in this field have been focused on experimental testing [15], [16], [19] to [24] or numerical simulations [25] and [26]. In [20], [27] and [28], the authors investigated the influence of the cell's shape (see Fig. 4) on the fatigue and mechanical properties of several pre designed cellular structures. In articles [15] to [17] and [20] to [24], the authors continued this work with the additional investigation of the influence of the material types which were used for experimental testing.

Table 1 shows the static mechanical properties of some typical regular cellular structures which were tested under quasi-static compressive loading. It is evident that both the fabrication method and the shape of the base cell have a significant influence on the observed mechanical properties, i.e. yield stress (σ_y),

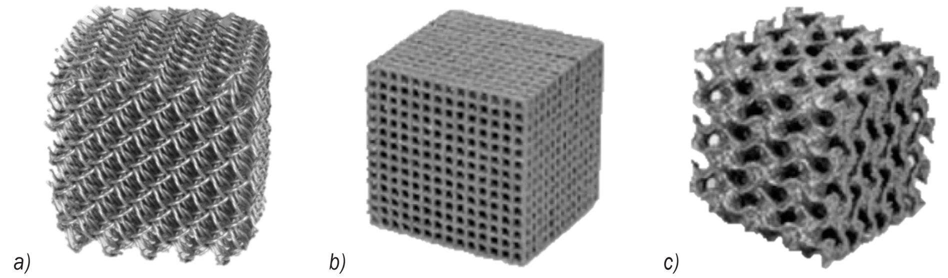


Fig. 3. *Regular cellular structures; a) Kagome wire structure [12], b) Cube cellular structure and c) Gyroid cellular structure [18]*

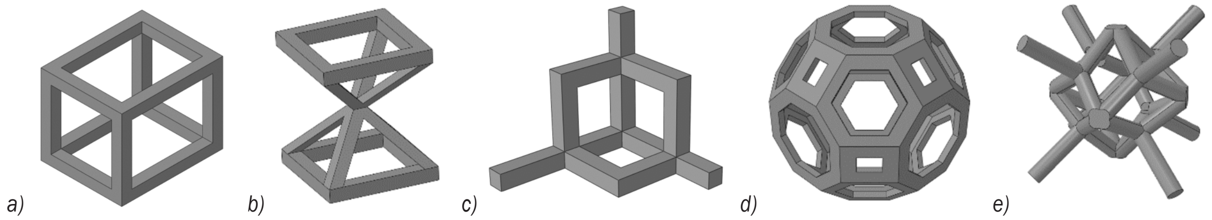


Fig. 4. *Shapes of the basic cells of regular cellular structures;*
a) cube, b) G7, c) diamond, d) truncated cuboctahedron and e) rhombic dodecahedron

Table 1. *Mechanical properties of typical regular cellular structures by quasi-static compressive loading*

Fabrication method	Shape of the base cell	Material	Porosity [%]	σ_y [MPa]	$\sigma_{\max}$ [MPa]	σ_{pl} [MPa]	E [GPa]	Ref.
SLM	Cubic	Ti6Al4V ELI	77	67.9	100.5	59.4	/	[16]
EBM	Cubic	Ti6Al4V	63.2	/	196.0	155.9	14.9	[20]
EBM	G7	Ti6Al4V	64.5	/	61.0	59.6	2.4	[20]
SLM	Diamond	Ti6Al4V ELI	77.3 to 80.1	34.5 to 43	55.6 to 57.9	35.3 to 36.5	1.36	[16] and [22]
EBM	Diamond	Ti6Al4V	70	62.87	/	/	/	[29]
SLM	Truncated cuboctahedron	Ti6Al4V ELI	74.5	66.9	89.9	59.6	/	[16]
SLM	Rhombic dodecahedron	Ti6Al4V ELI	≈75	≈46	64.5	52.6	/	[16], [24] and [30]
EBM	Rhombic dodecahedron	Ti6Al4V	62.1	/	112.0	77.2	6.3	[20]
EBM	Rhombic dodecahedron	Ti-24Nb-4Zr-8Sn	72.5 to 77.4	29.8 to 45.5	/	28.5 to 42	≈1.44	[15] and [30]

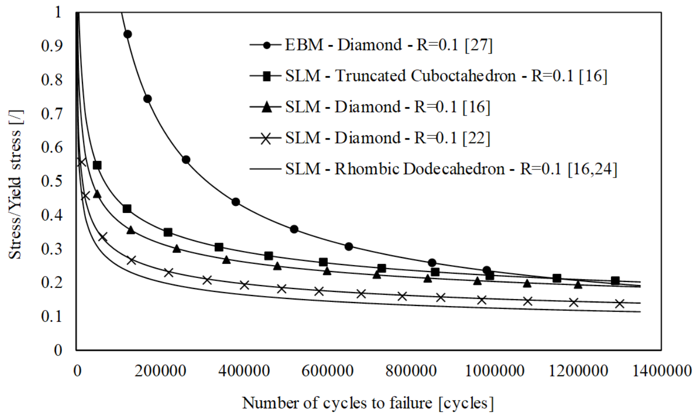


Fig. 5. *S-N curves of typical regular cellular structures*

maximum compressive stress (σ_{max}), the plateau stress (σ_{pl}) and modulus of elasticity (E).

Fig. 5 shows the fatigue behaviour (S-N curves) of typical regular cellular structures by dynamic loading. Here, the experimental tests were performed at the load ratio $R=\sigma_{min}/\sigma_{max}=0.1$ (in compression) and frequency of 10 Hz to 15 Hz. The maximum loading σ_{max} within the loading cycle was determined based on the previous static tests, and varied between $0.2\,\sigma_y$ and $0.8\,\sigma_y$. It follows that all experiments corresponded to the elastic area of stress-strain relationship, and the stress-life approach was used to determine the material fatigue properties. The fatigue limit was established by plotting the normalised values of stress (σ_{max}/σ_y) versus the number of cycles to failure N. It is evident from Fig. 5, that the EBM-cellular structure with diamond basic cells has the highest fatigue strength, while the lowest fatigue strength corresponds to the SLM-cellular structure with Rhombic dodecahedron basic cells.

2 IREGULAR CELL STRUCTURES

2.1 Closed- and Open-Cell Foams

Closed- and open-cell cellular structures (see Fig. 6) exhibit a stochastic pore distribution with a highly irregularity, which is a consequence of the production methods **[1]**. Production of open-cell structure is usually based on the method of replicating the polymer foam structure, which can serve as a core in the case of the investment casting, or be coated by electrolysis with metals steam **[2]**. The final product is an open-cell cellular structure of struts and interconnected cell architecture (high connectivity between the adjoining cells). The production of closed-cell foams is based mainly on powder metallurgy (using precursors), or gas injection, resulting in cellular structures with cells that are almost completely separated from each other with intercellular wall surfaces. These types of foams are used in applications mostly as energy absorbers or structural parts **[3]**. Different metals (e.g. aluminium) can be used for fabrication of open- and closed cellular structures, achieving porosities above 90 %.

Numerous studies have been performed for the characterization of the mechanical properties of the metal foams, but the available information on fracture and fatigue is rather limited. Some work on the standard fatigue properties of closed-cell aluminium alloy foams was performed by Zettl et al. **[33]** and **[34]**. They used an ultrasonic test method to investigate the tension–compression fatigue properties. Their work was continued by Zettl et al. **[34]** and McCullough et al. **[35]**, who investigated the tension/tension and compression/compression fatigue behaviour of closed-cell aluminium alloy foam experimentally. Kashef et al. **[36]** performed the experimental and numerical investigation to observe the fracture toughness and fatigue crack growth in open-cell stainless steel foam, while a similar procedure for titanium foam at two different load ratios ($R=K_{min}/K_{max}=0.5$ and $R=0.1$) was performed by Kashef et al. **[37]**. Zhao et al. **[38]** investigated the damage evolution and damage mechanism in closed-cell aluminium alloy foam under tension/tension fatigue loading experimentally, while the failure mechanisms of closed-cell aluminium foam under monotonic and cyclic loading was investigated by Amsterdam et al. **[39]**. Fatigue crack propagation in closed-cell aluminium alloy foam was investigated experimentally by Fan et al. **[40]** and Taherishargh et al. **[41]**. In **[42]**, the authors performed an experimental investigation of the low cycle fatigue behaviour of

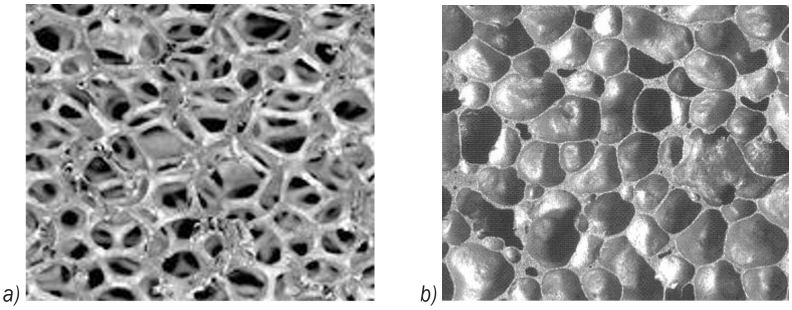


Fig. 6. *Stochastic cellular structures: a) open-cell foam [31], b) closed-cell foam* **[32]**

closed-cell aluminium foam with consideration of the multiple strain amplitude. Their results confirmed fatigue behaviour which corresponds to the Coffin–Manson relationship. Similar investigation was performed by Linul et al. **[43]**, where researchers investigated the low-cycle fatigue behaviour of ductile closed-cell aluminium alloy foam. The fatigue tests were performed in uniaxial compression with a stress ratio of $R=0.1$ at a loading frequency of 10 Hz. Furthermore, the effect of the structure irregularity, number and the size of the cell were investigated. The experimental results have shown the significant influence of structural irregularities on the fatigue behaviour of the analysed aluminium foam. Based on the experimental results, researchers concluded that the scatter of fatigue life increases as the higher irregularity of cell structure and that the fatigue life decreases as the number and the size of large cells increases **[43]**. Motz et al. **[44]** investigated the fatigue crack propagation of two types of cellular materials: (i) closed-cell aluminium foam with two different densities, and (ii) hollow sphere structures made of stainless steel (316L). Based on the fatigue tests and the microstructural analysis of the fracture surface, a significant difference was observed in the fatigue crack propagation mechanisms between these two types of cellular metals. A similar investigation was performed by Olurin et al. **[45]**, where the influence was investigated of the relative density of the porous structure (Alporas and Alulight aluminium alloy foams) on the fatigue crack growth. Here, the influence was also considered of the mean stress effect and the single peak overload on the fatigue crack propagation. The authors concluded that the Paris exponent m increases more than twice with an increase of load ratio R from 0.1 to 0.5. The comprehensive study of the fatigue crack propagation of closed- and open-cell foams made of different materials was presented by Kashef et al. **[36]** and **[37]**, Fan et al. **[40]**, Motz et al. **[44]** and Olurin et al. **[45]**. Their experimental results were presented by the crack propagation curves as shown in Fig. 7, which correspond to the Paris equation:

$$\frac{\mathrm{d}a}{\mathrm{d}N} = C \cdot \Delta K^{m}, \tag{1}$$

where $\mathrm{d}a/\mathrm{d}N$ is the fatigue crack growth rate, C and m are the experimentally determined material parameters and ΔK is the stress intensity factor range. It is evident that the shape of a cell and the microstructure of the base material of treated foam, have a significant influence on the crack growth rate. Here, the open-cell foams made of titanium and stainless steel have a higher Paris exponent than the foams made of aluminium alloys. The authors explained this fact as a consequence of the crack closure effect and crack bridging, which reduce the crack growth rate and, consequently, extend the fatigue life.

In everyday engineering praxis, open- and closed-cell foams made of several polymers are often used for different engineering applications **[46]**. The polymer foams have excellent characteristics, such as strength to weight ratio, superior acoustic absorption, and manufacturing possibilities to produce different shapes of final products. In **[47]**, the researchers analysed tension, compression and shear fatigue behaviour of closed-cell polymer foams. They concluded that foam porosity is an important factor influencing the fatigue behaviour of polymer foams.

2.2 Unidirectional Porous Structures

Lotus or Gasar porous structures can be recognised by their elongated cylindrical pores (Fig. 8) and, therefore, exhibit closed-cell morphology with the uni-directional elongated parallel pores. They are fabricated by unidirectional solidification in a pressurised gas atmosphere **[48]**. Further details on the fabrication method are given in **[49]**. The fabrication procedure results in metal structures (e.g. copper, steel), etc. with a high level of anisotropy, which

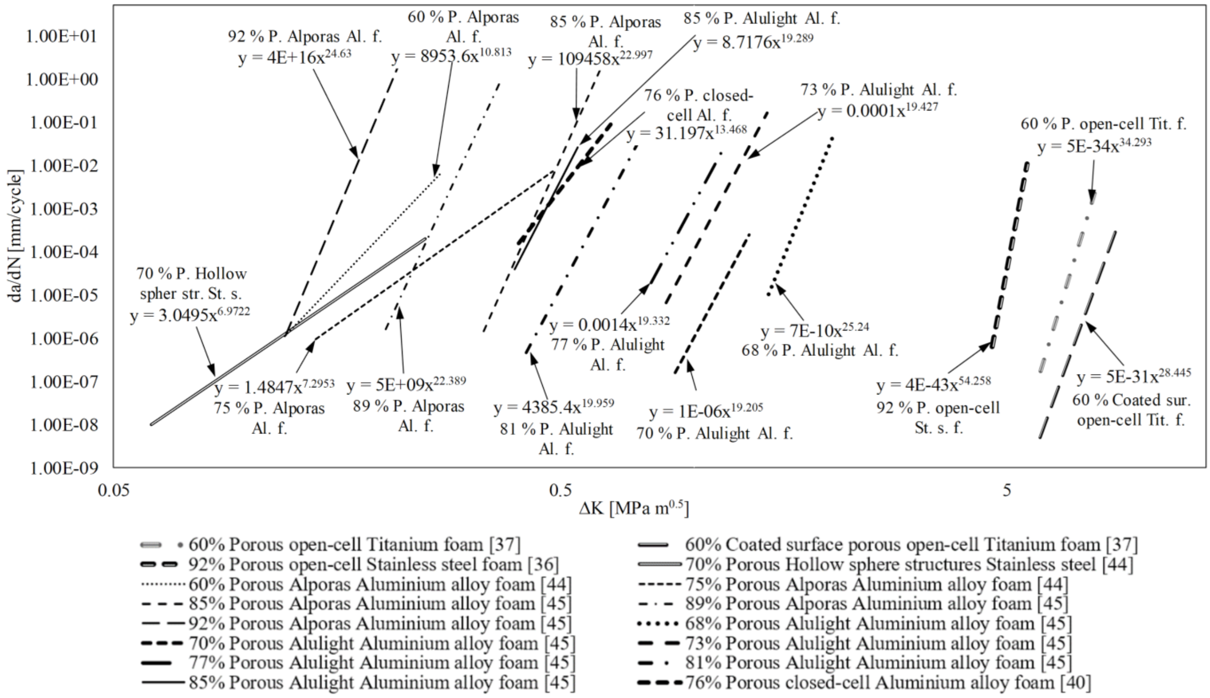
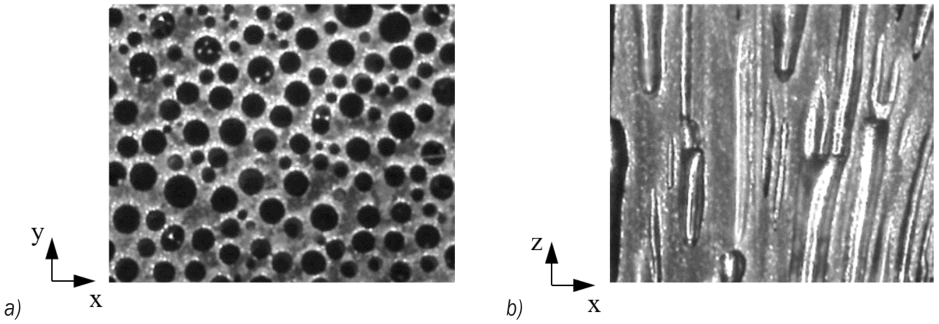


Fig. 7. *Log (da/dN – log ΔK) curves of different porous materials*

depends on the distribution of pores. The porosity is usually lower than 70 % [50], which is lower in comparison to the conventional open- and closed cell cellular metals. The pore size and distance between the pores affect the mechanical properties strongly, which are presented in [51] and [52]. They can be applied in structural and thermal applications.

There are some studies where researchers investigated the fatigue behaviour of lotus porous material experimentally and numerically. Seki et al. [54] investigated experimentally the effects of anisotropic pore structure and fibre texture on the fatigue properties of lotus-type porous magnesium. The experimental results showed that the fatigue strength in the direction parallel to the longitudinal axis of pores (z-axis) is higher than the fatigue strength in the perpendicular direction (x-axis and y-axis). Based on the experimental results, they concluded that the fatigue strength at the finite life of a magnesium lotus structure is closely related and proportional to the ultimate tensile strength for both loading directions (parallel and perpendicular to the pores). The experimental investigation of the fatigue crack initiation and propagation in lotus-type porous copper was performed in [55]. In this research work, the authors used two types of specimen: (i) a specimen with a notch, and (ii) a specimen without a notch. Based on the experimental results, the authors concluded that the high stress is concentrated around large pores which affect the direction of the crack propagation. In the case of parallel loading, the fatigue crack was propagated along a straight line, while, for



a) *b)*

Fig. 8. *Cross-section of the unidirectional (Lotus) porous structure [53]; a) transversal cross-section b) longitudinal cross direction*

the perpendicular loading, the crack was propagated along a path in which stress was highly concentrated.

Numerical investigation of the fatigue crack initiation and propagation in a lotus-type porous nodular cast iron was performed by Glodež et al. [56]. In this article, the fatigue behaviour of the lotus structure was investigated under tensile loading in transversal and longitudinal directions. Kramberger et al. [57] and [58] investigated the low-cycle fatigue behaviour of lotus-type porous materials, where the fatigue life was modelled by using the damage initiation and evolution law, based on the inelastic strain energy approach. This method generally offers a capability for modelling the progressive fatigue damage and failure of different porous materials. More about this method is described in [57], where the numerical simulations were performed through simplified 2D computational models with regular and more realistic irregular pore topologies. The computational results showed that the distribution of pores has a significant influence on the low-cycle fatigue behaviour of the lotus-type porous materials. The fatigue damage first appeared around the large pores, and damage was further propagated between pores where the stress was highly concentrated.

2.3 Honeycomb Structures

Honeycombs are 2D cellular structures, which can be found in nature or fabricated artificially from metals or polymers. These types of metal cell structure are fabricated mostly by the expansion process, and from sheet metal rolls by cutting and bending. The production methods and mechanical properties of honeycombs are described in [59]. In general, regular honeycomb structures (with hexagonal cell shape) are used in engineering. However, irregular honeycomb structures can also be found based on the Voronoi cell distribution (Fig. 9).

There are some studies [61] to [70], where researchers investigated the fatigue and fracture behaviour of honeycomb cell structures. In articles [61] and [62], the researchers studied the mechanisms of crack growth in random oriented (Voronoi) and repeated oriented honeycomb cell structures mathematically. Based on the experimental and numerical results, the authors concluded that the random oriented Voronoi honeycomb is more sensitive to fatigue than the repeated oriented honeycomb cell structure. The increased sensitivity arises from the stress distribution within the cell walls of the Voronoi honeycomb relative to the repeated oriented honeycomb cell structure.

2.4 Auxetic Cellular Structures

A recent type of cellular metals are the auxetic cellular structures (Fig. 10a), which exhibit a negative Poisson's ratio (counter intuitive behaviour: A material under compression becomes thinner in cross-section, and vise-versa in tension [71]). The advanced geometrical possibilities of auxetic cellular materials provide many opportunities for their wide application, due to their particular and unique mechanical properties. Initially, they were fabricated with transformation of conventional open-cell foam (Figs. 10b and c). However, their recent breakthrough is associated with current advances in additive manufacturing, that allow fabrication of new 3D auxetic structures [71].

In the article of Bezazi and Scarpa [73], the experimental study of tensile fatigue behaviour of conventional PU-PE open-cell foam and auxetic thermoplastic foam is described. Auxetic foam exhibits counter-intuitive deformation behaviour in comparison with the conventional materials. In the article, the experimental results showed that the auxetic foam has a higher static mechanical resistance and resistance to failure if compared to the conventional one. The auxetic foam also has a significant increase in energy absorption for compressive cyclic loading compared to the conventional foam.

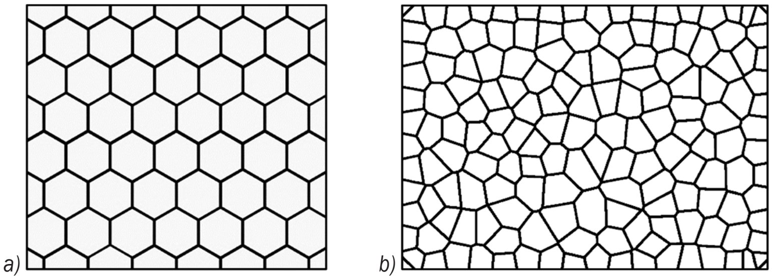


Fig. 9. *Honeycomb cell structures [60]; a) regular cell distribution, b) irregular (Voronoi) cell distribution*

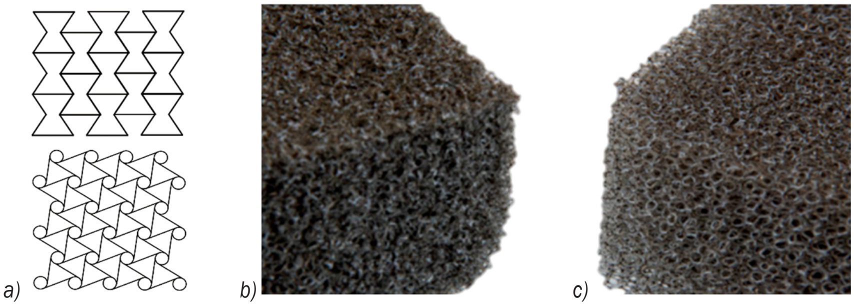


Fig. 10. *Examples of: a) regular auxetic cellular structures* **[12]** *and* **[71]**, *b) irregular auxetic foam, and c) irregular conventional foam* **[72]**

3 COMPOSITES WITH CELLULAR CORES

Further advantages of cellular structures can be obtained in combinations of thin-walled tubes **[74]** and **[75]** or metal sheets **[76]**. In engineering applications, cellular structures are often used as cores: (i) filling the empty spaces in structural parts, or (ii) in sandwich panels (Fig. 11). The honeycomb cell structure is one of the most often used cellular cores of composite sandwich structures, which is shown in Fig. 11. Composite structures with cellular cores are being used increasingly in high-performance structural applications and many industries, from aerospace, automotive and furniture industries to packaging and logistics **[64]**.

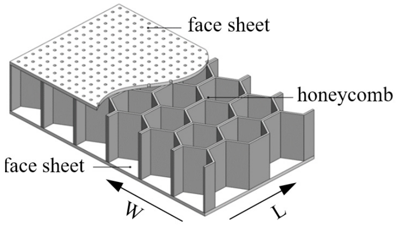


Fig. 11. *Description of the honeycomb sandwich structure* **[77]**

There are some articles **[64]** to **[70]** and **[78]** to **[80]** where researchers investigated the fatigue behaviour of honeycomb sandwich structures. Jen et al. **[64]** investigated the temperature dependent strengths and fatigue bending strengths of adhesively bonded aluminium honeycomb sandwich structures experimentally. In the articles **[65]** and **[69]**, the authors performed fatigue tests of composites with two different sandwich cores (with aluminium core and with aramide fibres core) and with two different cell configurations (W- and L-configuration; see Fig. 11). The experimental results showed that the morphology and topology (cells` configuration) have a significant influence on the lifetime of the sandwich structure made of aramide fibres core. Sandwich structure with L-configuration had a larger lifetime compared to the W-configuration. The difference in lifetime is a consequence of micro cracks formation, which lead to the shorter lifetime of the structure. In case of the sandwich structure made of aluminium core, the cells' configuration had no influence on the lifetime of the sandwich structure. The fatigue failure is constantly caused by cracking in the lower face of sandwich structure made of aluminium core. From the experimental results authors concluded that the lifetime of the honeycomb structure made of aluminium cores are significantly larger than the lifetime of material made of aramide fibres cores in all analysed structures. The lifetime values for both configurations are in the same range for two analysed materials and correspond to the 60 % of the maximum loading **[69]**. In **[66]**, the authors investigated experimentally the influence of the load ratio (*R*) and frequency (*f*) at an arbitrary temperature on the fatigue response. In the articles **[67]** to **[70]** and **[78]**, the experimental results are presented of the fatigue behaviour under four points` bending tests of different materials of the sandwich core and face sheets. The effect of the thickness of the face sheet on the bending fatigue strength of aluminium honeycomb sandwich beams have been studied by Jen and Chang **[79]**, while the effect of the amount of adhesive on the bending fatigue strength of adhesively bonded aluminium honeycomb sandwich beams have been studied by Jen et al. **[80]**.

4 CONCLUSIONS

The paper gives an overview of the fatigue behaviour of cellular structures with consideration of their fabrication and characterization. The review is focused on some of the most typical cellular structures, which are divided into three main groups: (1) pre-designed regular cellular structures, (2) irregular cellular structures, and (3) composites with cellular cores.

For the first group (pre designed regular cellular structures), the experimental investigations have shown that the fabrication methods SLM, or EBM, and the shape of the base cell (diamond, cube, rhombic dodecahedron etc.), have a significant influence on the observed mechanical properties, i.e. yield stress, maximum compressive stress and modulus of elasticity. The extended fatigue testing of these structures indicated that the EBM-cellular structures with diamond basic cells have the highest fatigue strength, while the lowest fatigue strength corresponds to the SLM-cellular structures with rhombic dodecahedron basic cells.

Closed- and open-cell foams, lotus cellular structures, honeycomb cellular structures and auxetic cellular structures have been analysed in the framework of the second group. The following conclusions could be made:

- The available information on the fatigue and fracture behaviour of closed- and open-cell foams is very limited. However, the experimental studies of the fatigue crack propagation of closed- and open-cell foams made of different materials have shown that the shape of cell and the microstructure of the base material of the treated foam have a significant influence on the crack growth rate. Furthermore, the open-cell foams made of titanium and stainless steel have a higher Paris exponent than the foams made of aluminium alloys.
- The experimental and numerical investigations of the fatigue behaviour of lotus porous materials indicated that the fatigue strength in the direction parallel to the longitudinal axis of pores is higher than the fatigue strength in the perpendicular direction. Furthermore, the distribution of pores has a significant influence on the fatigue behaviour; the fatigue damage first appears around the large pores, and further propagates between pores where the stress is highly concentrated.
- The honeycomb cellular structures have also been studied experimentally and numerically. The results show that the random oriented Voronoi honeycomb is more sensitive to fatigue than the repeated oriented honeycomb cell structure. The increased sensitivity arises from the stress distribution within the cell walls of the Voronoi honeycomb relative to a repeated oriented honeycomb cell structure.
- Very limited investigations were conducted considering the fatigue behaviour of the auxetic cellular structures. The initial researches in this field have shown that the auxetic foams have a higher energy absorption under compressive cyclic loading if compared to the conventional foams.

In the framework of the third research group (composites with cellular cores), the available experimental results are related to the aluminium honeycomb sandwich structures. The results showed that the morphology and topology (configuration) have significant influence on the lifetime of the treated structure at a constant load level.

Finally, it can be concluded that the cellular materials and structures show huge potential to become important light-weight structural materials of the future, with further development of additive manufacturing technologies, or with introduction of some new, more cost effective manufacturing techniques. However, the knowledge of the fatigue behaviour of such structures is relatively poor, and should be the subject of the further investigations. The latter is especially related to the auxetic cellular structures, which provide many opportunities for their wide applications due to their advanced physical characteristics. The auxetic cellular structures have also a huge potential in medical applications like cardiovascular expandable stents. The main purpose of the cardiovascular expandable stent is to restore patency of blood vessels, where the volume of the bloodstream is reduced. In the bloodstream, cardiovascular expandable stents are loaded with a cyclic load in high cycle fatigue regime. From that respect, the opportunity for the further research work could be design of a new geometry of the cardiovascular expandable stents made of auxetic cellular structures and further investigation of the fatigue behaviour of such structures.

5 ACKNOWLEDGEMENT

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