Fatigue behavior of aluminum foam sandwich panels

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ABSTRACT. Metal foams represent a new class of materials that seems to be very promising for light structural applications. Recently different technological processes have been developed to build metal foams and the principally goal pursued was to decrease as much as possible their production costs. Therefore the interest for their mechanical properties and potential engineering applications is greatly increased. In their applications, such materials are loaded not only by quasi-static forces but also by cyclic forces.
Due to the lack of official standards specific for this new material, tensile and compression tests (edgewise and flatwise), shear, bending and fatigue tests have been executed in order to understand the mechanical response of aluminum foam sandwich (AFS). The aim of this work was to study the fatigue behavior of AFS panels through shear fatigue tests. The closed cells foam studied in this work has been produced by the Fraunhofer Institute in Brema (IFAM) by adopting the powder-rolling technique. Mechanical behavior of AFS appear to be strongly related to the manufacturing process, particularly to cells distribution and morphology.

INTRODUCTION

Metal foams are today used in various applicative field, such as automotive, rail transport, aeronautic, nautical and aerospace [1]. Particularly aluminum foams are frequently used in sandwich structures. This investigation has been performed on a commercial closed-cell aluminum foam made by the powder-rolling technique, which allows, through the establishment of metallic ties between metal foam and skins, the production of sandwiches without any bonding agent. The mechanical characterization of this material is still incomplete, due to the lack of official standards related its mechanical response under load. Crack initiation and its propagation within the core material are still relatively unexplored and, currently, the knowledge about this class of materials is to be developed. Although many studies have been carried out on this topic, to date the analysis of the mechanical behavior of this material under static and dynamic shear stress has been scarcely investigated, and shear fatigue data, in many cases, have been extracted by three or four point bending tests.

MATERIALS, SPECIMENS AND TEST METHOD

The aim of this work has been the study of aluminum foam sandwiches subjected to fatigue shear stress. The setup used for testing was previously used to carry out static shear tests. Experimental data are in according with [2] about the evaluation of shear modulus G through the following analytical relation

$$\frac{G}{E_s} = \frac{3}{8}\left[\varphi^2 \cdot \left(\frac{\varrho}{\varrho_s}\right)^2 + (1-\varphi) \cdot \frac{\varrho}{\varrho_s}\right] \tag{1}$$

where ϕ is fraction of solid which is contained in the cell edges. The experimental average shear modulus G* is 1122 [MPa], the calculated shear modulus G by (1) is 1203 [MPa], for $\phi = 0.90$. The load amplitudes for the fatigue tests were based on static test results. Standards ASTM [12-13] have been used for implementation of the load system and specimen measuring. Load frame has been designed so that the line of action of direct tensile force passes through the diagonally opposite corners of the sandwich respecting the condition $l \geq 12*t$, where l is the height of the core material and t is the thickness. It is very difficult to obtain pure shear, particularly on this type of composite material, but setup condition allows to reproduce stress next to pure shear and reduces presence of secondary bending. The specimens were obtained from the same panel, with relative density foam of 16.93%. The foam density of each specimen has been calculated by weighing the specimens on a electronic balance and subtracting the weight of skins. In order to make possible the clamping of the specimens in the load frame, the cutting process has been realized so that at the furthest sections only the skin is preserved. The specimens dimensions are 240x50x20. The load frame presents a junction that allows the auto alignment of the system and the transmission of the load according to the desired direction. The tests were carried out considering a stress ratio R = 0.1 with frequencies variable between 5-10 [Hz]. In this investigation the fatigue threshold was fixed in 5×10^6 load cycles and is defined as the value for which, if no crack begins, the test is considered concluded. In many cases the crack growth was observed until threshold value of 20 [mm]. The test machine used is a servo-hydraulic machine INSTRON 1342, with maximum load capacity of 100 [kN] and MTS control electronics.

a)

Specimen	Foam density [g/cm3]	Relative density %	Fmax [N]	τmax [MPa]	Δτ/2 [MPa]	Cycles Number
TF_1	0,434	0,161	5000	0,4149	0,1867	76248
TF_2	0,25	0,093	4000	0,3307	0,1488	2012256
TF_3	0,288	0,107	4500	0,3741	0,1683	49481
TF_4	0,379	0,14	4300	0,3552	0,1598	93980
TF_5	0,335	0,124	3800	0,3143	0,1415	1020656
TF_6	0,461	0,171	3900	0,3271	0,1448	5278404
TF_7	0,32	0,119	4200	0,3488	0,157	614278
TF_8	0,553	0,205	4300	0,3568	0,1605	140404
TF_9	0,418	0,155	4300	0,356	0,1602	1504329
TF_10	0,313	0,116	4700	0,3896	0,1753	133629
TF_11	0,713	0,264	4100	0,3396	0,1528	126543
TF_12	0,278	0,103	4400	0,3609	0,1624	425584
TF_13	0,504	0,187	4500	0,3706	0,1668	248630
TF_14	0,317	0,117	5000	0,4138	0,1862	615497
TF_15	0,693	0,257	4800	0,3992	0,1796	65382
TF_16	0,336	0,124	4000	0,3325	0,1496	1829401
TF_17	0,645	0,239	4000	0,3319	0,1493	520224
TF_18	0,358	0,133	4100	0,338	0,1521	64120

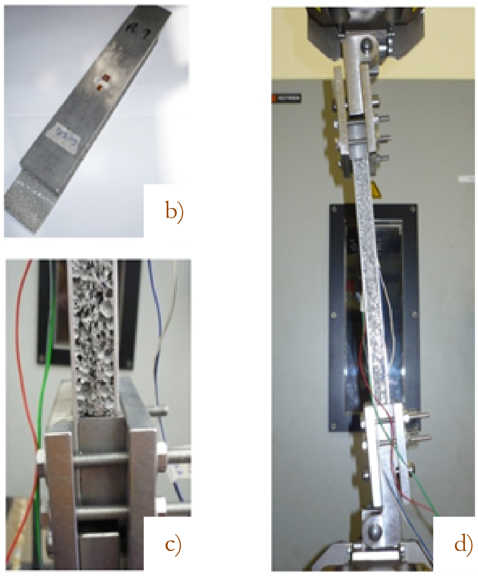

Figure 1: a) Specimens used in the testing program and results; b) Type of specimen tested; c) Clamping method; d) Specimen loaded in test machine.

RESULTS AND DISCUSSION

In Fig.1 a) are reported the testing program and results. The value of τ_{max} is calculated according with [12]:

$$\tau = \frac{F}{l \cdot b} \qquad (2)$$

where b is the width of the specimen. The semi-amplitude Δτ/2 was evaluated from the relationship (2). Fig. 2 shows the resistance curve for shear fatigue test. The curve trend is almost horizontal and this shows how the material behavior is not so predictable. The results vary from specimen to specimen despite all of them were made by the same panel. Only in one case, the sandwich has exceeded five millions of cycles without any type of damage.

More samples have been tested at the same load amplitude and frequency. Through the control of the stages of nucleation and propagation of the crack, there were differences and trends not comparable. For specimen TF2

($\Delta\tau/2$=0.148 [MPa]) crack begins near to 1.4x10^6 cycles and failure occurs after 2.1x10^6 cycles with a propagation phase of about 30% of the number of cycles to failure, while for TF11 ($\Delta\tau/2$=0.152 [MPa]) the propagation phase until the failure is about 86% of the life of the specimen. During several tests there were observed some creaking inside the foam cells, not visible from the outside and due to failure of cellular structure.

Figure 3 a) shows the trends of crack growth versus cycles number for two specimens tested under the same conditions of load amplitude and frequency. The crack nucleation occurs at different times. The failure for TF9 occurred for a number of cycles 10 times bigger than the number of cycles for TF8. This is an example of how the material behavior is not predictable but depends on the morphological characteristics of cellular structure.

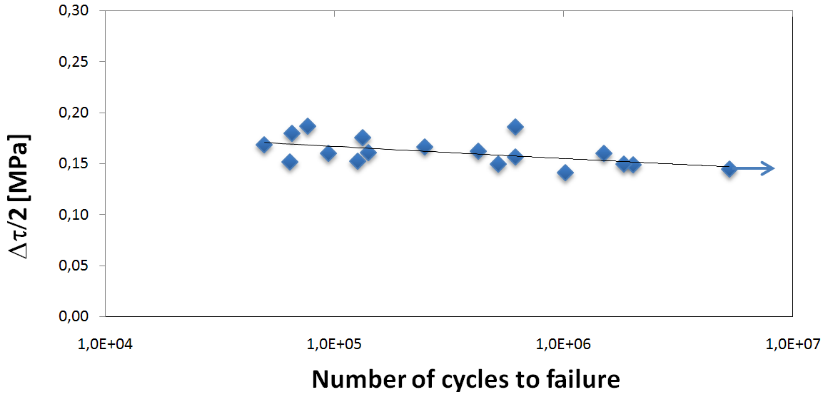

Figure 2: Shear fatigue curve for AFS.

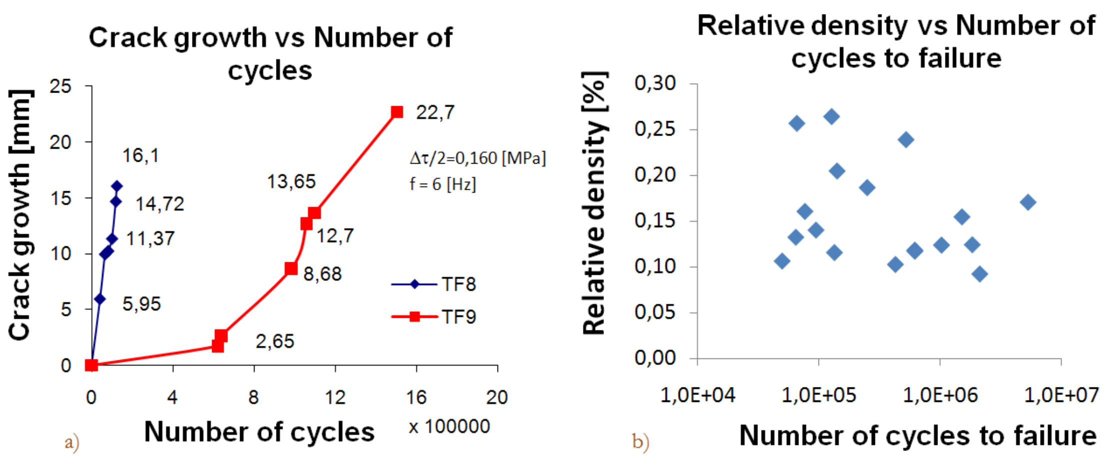

Figure 3: a) Crack growth for two specimens at the same load conditions; b) Relative density vs Number of cycles

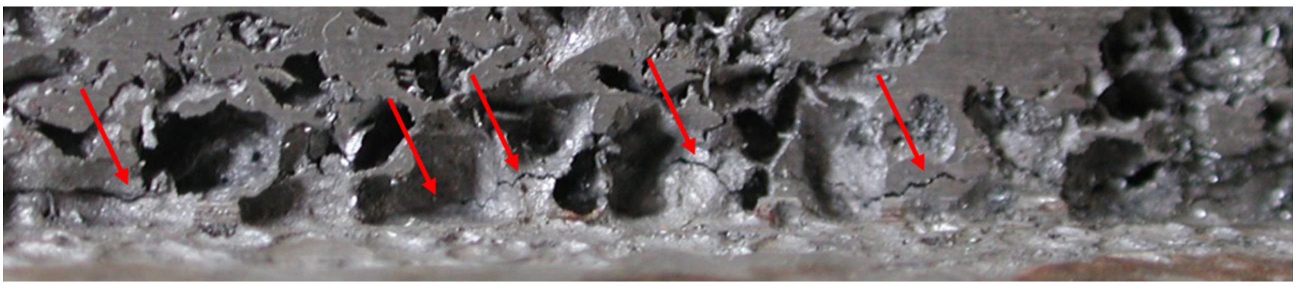

Figure 4: Fatigue failure at the interface core-skin

Density seems not to be the cause of premature fracture. On the contrary, for specimens with highest density values, the failure occurs before of 0.5 x10^6 cycles (Fig. 3,b). However in many cases the crack nucleation and its propagation has concerned the interface core-skins, growing in direction of load, affecting all transverse extension of foam in fracture zone and crossing the typical voids of foam structure, due to air bubbles created during the machining process.

It has been found a strong dependence of the material behavior in relation to the presence of defects or inclusions inside to the material. An example of crack propagation is visible in Fig. 4. The fracture interested all the transversal extension of the sample.
Experimental data obtained from fatigue tests are many scattered but only in one case there is a deviation more than 10% of the $\Delta\tau/2-N$ curve tendency.

CONCLUSIONS

Aim of this work has been the shear fatigue characterization of aluminum foam sandwiches. Tests don't produce pure shear, so specimens dimensions have been chosen in order to reduce the effect of secondary bending in according with standard ASTM. Trend of $\Delta\tau/2-N$ curve shows that the material behavior is very scattered. During the shear fatigue tests, failures have been observed to initiate at the corner interface of the specimen. The crack nucleation has been always found at the interface core-skin, influenced by the presence of morphological defects and wall dimensions of the single cellular structure. Crack grows along the walls of the cells, in the direction of load application, where stress is more concentrated, as attended, but above all in areas where the cells are crushed and not fully developed. Foaming by the powder-rolling technique produces a closed cell foam with a significant degree of irregularity and imperfections within the cellular microstructure The effects of such irregularity within the foam microstructure is evident in the scatter of results presented. During the foaming process is probably that some problems occurred due to not uniform temperature distribution.

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