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Thermal behavior of open cell aluminum foams in forced air: Experimental analysis

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ABSTRACT

This paper deals with the study of thermal and fluid dynamics properties of the open cell metal foams. A thermo-fluid dynamic analysis of three different types of aluminum alloy foams, 5, 10 and 20 pores per inch (PPI) was carried out by using a novel *ad hoc* built instrumentation. In particular, it has been investigated the Heat Transfer Coefficient (HTC^*) and the Pressure Drop (PD) under a flow of forced humid air. The influence of the main parameters, temperature of the metal foam and speed of humid air, both on the HTC^* and on the PD was examined. Design of experiments (DOE) approach was used as support to interpret the experimental findings and the physical phenomena involved in HTC^* and in PD, between foams and air. The analysis permitted to detect the effects of the operational parameters, foam pore size, air flux and temperature on the HTC^* and on the PD.

1. Introduction

Aluminum foams are a recent class of cellular materials with very interesting mechanical and thermal characteristics. These new materials have been stimulating great interest in many technological domains.

As structural materials, aluminum foams have been creating high interest due to their lightweight structure and good physical, chemical and mechanical properties like high specific stiffness and good energy absorbing. These properties make them suitable for many industrial applications in fields like automotive, aerospace, packaging, etc. [1,2]. Moreover, metal foams with open cell structure have attractive heat-transfer properties, hence allowing its employment in cooling equipment and as heat exchangers [3–5].

Different foaming processes have been developed and reported in literatures [1,6,7] and [8]. Each method can be chosen with selected metals, depending on the morphology (closed cell or open cell structure), density and cell size desired. The final properties and the morphology of the foam produced make it suitable for specific applications in different industrial domains [9,10].

Open cells metal foams present structures randomly oriented and mostly homogeneous in size and shape. Most commercially available metal foams are produced in aluminum, copper, nickel and metal alloys. Metal foams have interesting applications in heat exchangers, cryogenics, combustion chambers, cladding on buildings, strain isolation, geothermal operations, petroleum reservoirs, catalytic beds, compact heat exchangers for airborne equipment, air-cooled condensers for air conditioning and refrigeration systems, and compact heat sinks for power electronics [9,10].

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In the past years, many researcher have investigated on the thermal transport in metal foams for practical applications. [11–13]. Mancin et al. [11] found a correlation between the Heat Transfer Coefficient and the pressure drop. Bhattacharya et al. [12] proposed an analytical and experimental investigation for the determination of the effective thermal conductivity, the permeability and inertial coefficient of high porosity metal foams. Fourie and Du Plessis [13] presented a theoretical model for the prediction of pressure drop in a Newtonian fluid flowing through highly porous, isotropic metallic foams. Lu et al. [14] analyzed the forced convection problem in a tube filled with a porous medium subjected to constant wall heat flux. Calmidi and Mahajan [15], have performed a detailed study of forced convection in metal foams. The aim of this study was to quantify thermal dissipation and thermal non-equilibrium effects in metal foams.

In this context, this work is focused on the investigation of the thermal properties of open cell metal foams. A thermo-fluid dynamic analysis of three different pore size of aluminum alloy foams, 5, 10 and 20 PPI was carried out. A novel *ad hoc* instrumentation was built to investigate Heat Transfer Coefficient (HTC*) and the Pressure Drop (PD) under a flow of forced humid air. The analysis was focused to highlight the influence of temperature of the metal foam and speed of humid air, both on the HTC* and on the PD. Design of experiments (DOE) approach was used as support the experimental findings and the physical phenomena involved in HTC* and in PD. The analysis permitted to detect the effects of the operational parameters foam pore size, air flux and temperature on the Heat Transfer Coefficient and on the pressure drops.

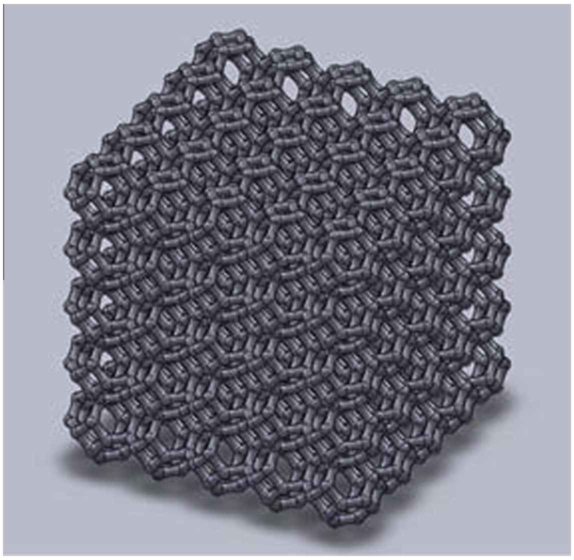

Fig. 1. CorelDRAW Graphics Suite X6, open cells metal foam structures.

2. Materials and methods

Three types of self-made aluminum alloy (AlSi7Mg) open cell foams, 5, 10 and 20 PPI were characterized by the determination of the porosity and of the transfer surface. The porosity in Eq. (1) defined, was obtained by the relative density calculating (ρ^*/ρ).

$$\varepsilon = 1 - \frac{\rho^*}{\rho} \quad (1)$$

where ρ^* is the density obtained from the ratio between the mass and the volume that are experimentally measured, and ρ is the density of the bulk material. According to the literature, different models were used for the calculation of the transfer surface [12,13]. On this basis a new model for 10 PPI foam was developed. The approach can be replicated for the other porosities. This model is based on the assumption that 14 hexagonal faces compose the elementary cell, so for a complete determination only two parameters, t and l, were sufficient, where t is the diameter and l is the length of the side of the hexagon that builds the cell. For the determination of these parameters several measurements was performed by using CorelDRAW Graphics Suite X6 software, by photographs of various portions of foam. Instead it was rebuilt a portion of the foam (Fig. 1) of cubic geometry using SolidWorks software, assuming the average values of t, l. Thanks to this geometry

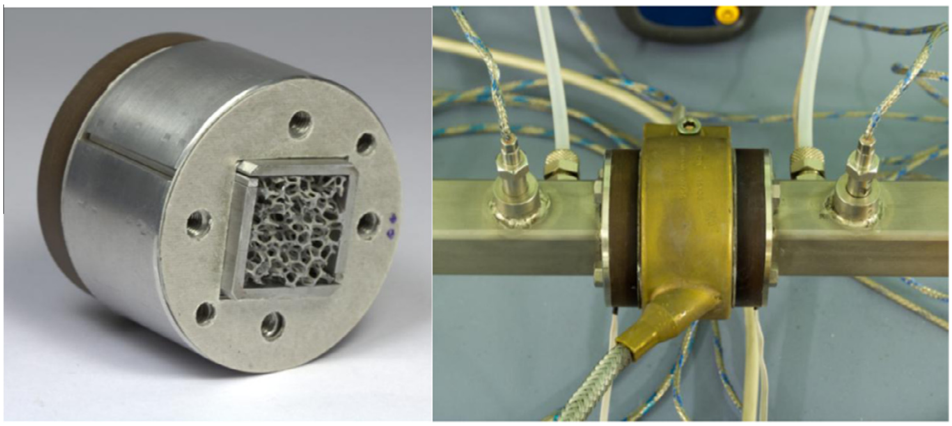

Fig. 2. Experimental measurement system.