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Heat transfer and dynamics characterization of porous structures for high-density adsorption storages

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1. Abstract

In the present work, different metal foams, were realized and experimentally tested in order to define the most suitable ones for heat storage applications. At first, morphology characterization of the materials through an optical microscope was carried out. Subsequently, heat transfer capacity was evaluated by means of a self-developed apparatus at CNR-ITAE, which makes use of Peltier cells for cycling the foam samples, while the temperatures in different part of the foams is measured. By means of cycles with different amplitudes and length, the effect of pore size and thickness of the sample was evaluated. Dynamic characterization of the coated foams was carried out by means of a gravimetric Large Temperature Jump apparatus at CNR-ITAE.

Keywords: adsorption storage, experimental characterization, porous structures; coatings.

1. Introduction

The exploitation of Renewable Energy Sources (RES) is strictly connected to the use of Thermal Energy Storage (TES). Different technologies are available to accumulate and store renewable energy: sensible, latent, thermochemical storage[1]. Among them, thermochemical adsorption storage is especially attractive, due to the high storage density, the virtually infinite storage time and the use of natural fluids as refrigerants (mainly water)[2]. However, thermochemical storages are still far from a massive diffusion and from the market. One of the critical aspects for their implementation in new or retrofitted energy systems, is the increase of heat and mass transfer inside the reactor [3]. Different methods have been investigated up to now, among which the coating [4] or direct synthesis [5] of the adsorption material on the metallic substrate. However, such methods, while proving effective for heat pump and chiller applications, present one main drawback: the thickness of the adsorbent layer is thin, thus reducing the energy density in storage applications. As an alternative solution, metal foams allow for a higher amount of adsorbent to be deposited, increasing at the same time the overall conductivity of the structure [6]. Indeed, metal foams have often been exploited also in latent thermal storage technology, to enhance the stability of components and the heat transfer [7].

In the present work, the direct synthesis of zeolite on aluminium foam was evaluated as a mean to improve the dynamics and energy density of a thermochemical storage.

2. Materials

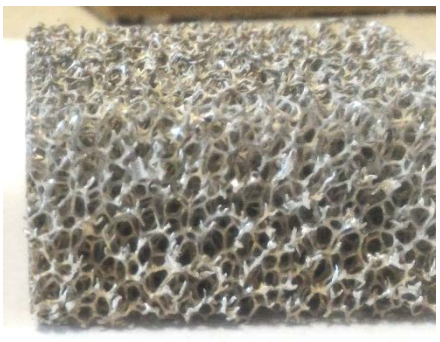
The starting alloy for the foam production is Al 99,5 alloy. Samples with different pore densities and thicknesses were realized by Mikrometal s.r.o. A list of the tested samples is shown in Table 1. Instead, Figure 1 shows the pictures of the samples with different pore densities.

Table 1: samples of Al foam tested.

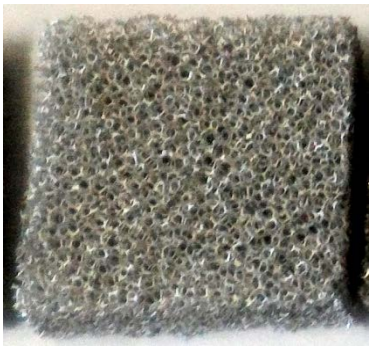
Sample n.	Pore density (PPI)	Thickness (mm)	Sample n.	Pore density (PPI)	Thickness (mm)
1	10	10	6	20	27
2	10	20	7	30	12
3	10	40	8	30	20
4	20	8	9	40	15
5	20	15			

(a)10 ppi

(b)20 ppi



(c)30 ppi



(d)40 ppi

Figure 1: pictures of the samples with different pore densities.

3. Morphology characterization

The first characterization carried out, was a morphological characterization on an optical 3D digital microscope (Hirox HK- 8700). The pictures in Figure 2 show the details of one cell for each sample with the average dimensions of the pores and the thickness of the walls.

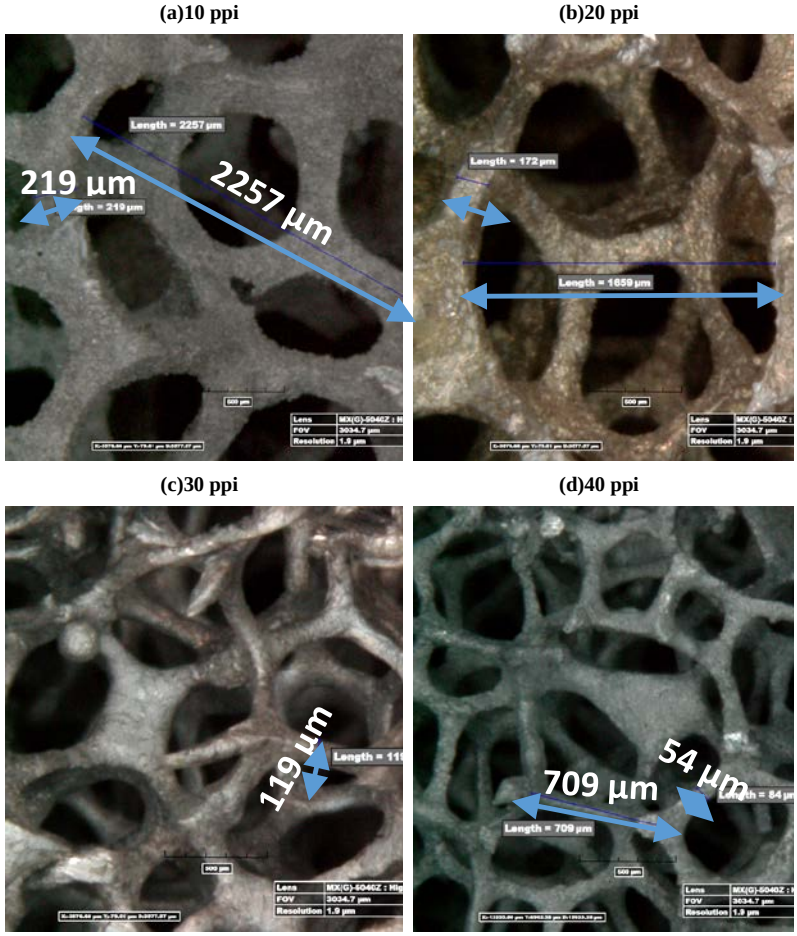


Figure 2: microscopic enlargement of the samples with different pore densities.

4. Evaluation of heat transfer

For the measurements, an experimental setup already present at ITAE was used, whose schematic layout is shown in Figure 3. It consists of a series of Peltier cells onto which the samples have been placed, using thermal paste to improve thermal contact between the cell and the sample. The bottom part of the Peltier cell is connected to a heat sink with fans for the dissipation of the heat. The cells are electrically connected to a time-controlled relay circuit that allows changing the polarity of the voltage on the cell, thus performing heating and cooling cycles. The temperature of the cell and on the upper surface of the sample is measured by means of type T thermocouples. In addition, a Raytek Instruments Marathon MM infrared temperature sensor is used to monitor and record the temperature of the sensor without the need for thermal contact with the foam. All the temperature signals are acquired and monitored by means of a NI cFP acquisition system.

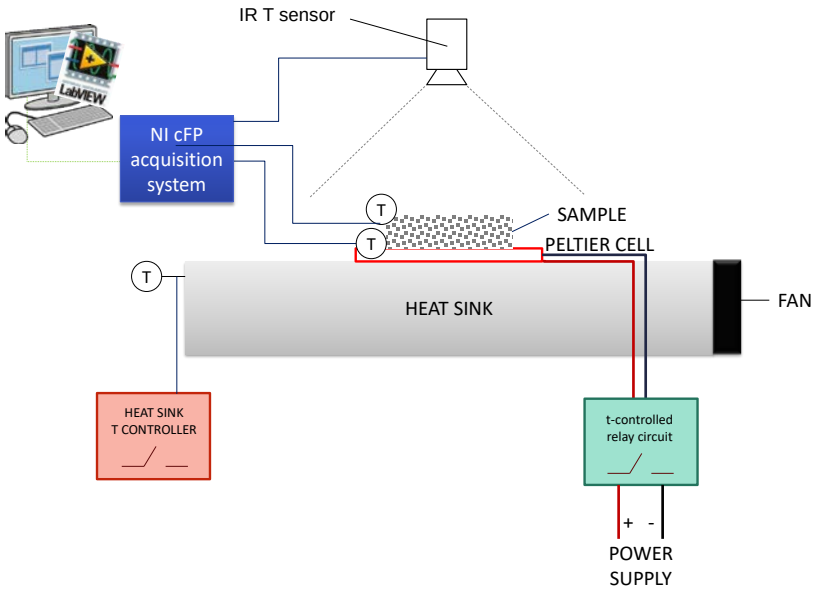


Figure 3:schematics of the apparatus for heat transfer measurements.

Figure 4 gives an example of the results recorded during a test with a cycle time of 6 minutes (3 minutes heating + 3 minutes cooling), showing the temperature evolution of the Peltier cell and of the upper surface of the sample measured with two thermocouples (T1 and T2) and with the IR temperature sensor (T_IR). The results refer to a sample with pore density of 30 PPI and 10 mm thickness. It is possible to notice a plateau in the maximum temperature reached by the sample. The results for the three consecutive cycles analysed are very similar, thus indicating a good reproducibility of the measurement.

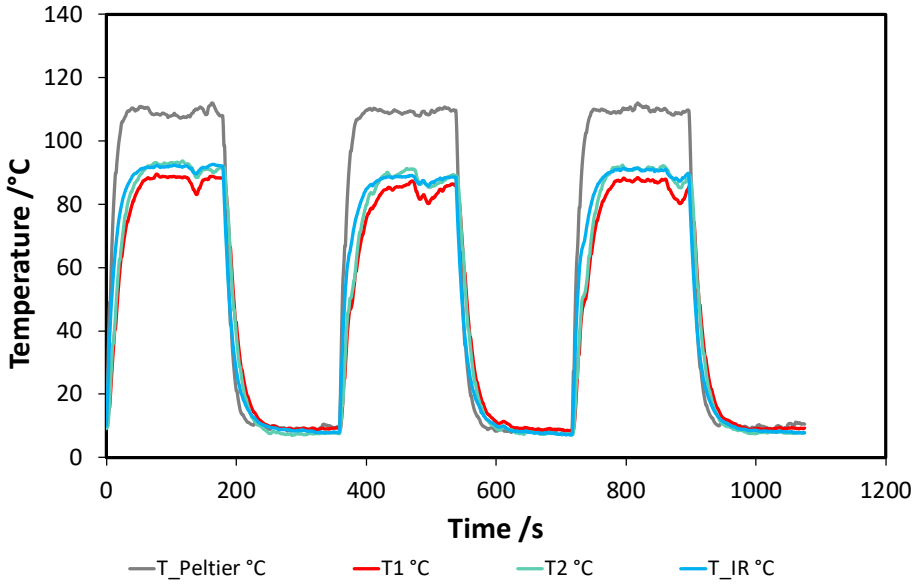


Figure 4:temperature evolution for a test with cycle time of 6 minutes. Sample: 30 PPI, 10 mm thickness.

In addition, an equivalent heating rate was calculated as:

$$\alpha = \frac{T_{max,3} - T_{min,3}}{\Delta T_3} \left[\frac{°C}{s}\right]$$

The effect of the sample thickness on the heating rate, for samples with different pore densities is shown in Figure 5: it is evident that the points relative to different pore densities but the same sample thickness are almost superimposed. Consequently, in order to derive a parameter useful for system sizing, a corrected equivalent heating rate was calculated, averaged on all the measures taken:

$$\alpha' = 5.2 \cdot 10^{-3} \frac{K}{m\,s}$$

Such a parameter can be useful for sizing of a system employing the materials tested.

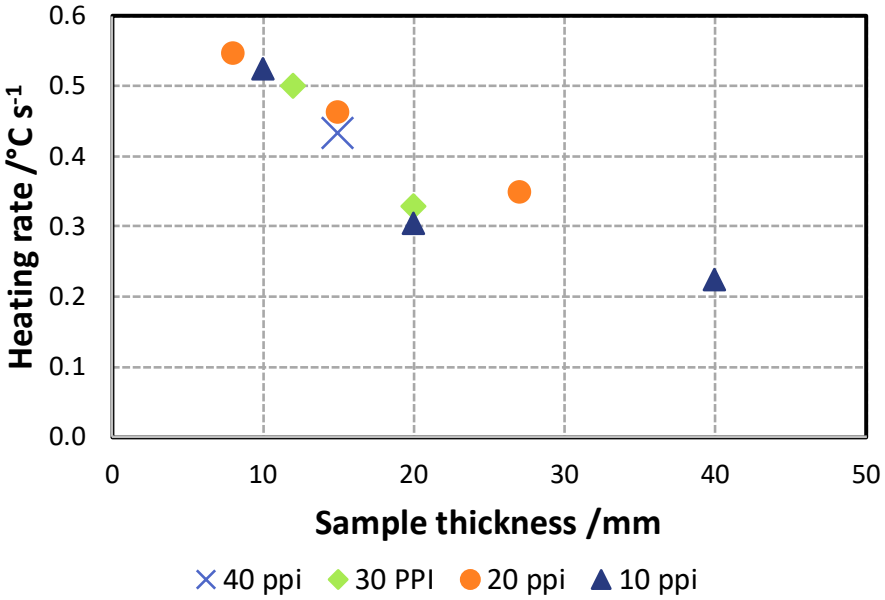


Figure 5:effect of sample thickness on α.

5. Dynamic measurements

Following the heat transfer evaluation, the samples with 20 ppi pore density were compressed by Fahrenheit GmbH and used for the direct synthesis of zeolite, using a patented process [9]. A zeolite density up to 140 g/dm^3 was obtained. The samples were place on a plate heat exchanger, using thermal paste to improve the contact, and tested in a gravimetric version of the LTJ apparatus, described in [10] and widely applied for design and evaluation of different heat exchangers and materials. It consists of 2 vacuum chambers: the adsorber and the phase changer. The heat exchanger to be tested is placed on a load cell and the evolution of weight, when subjected to a large temperature jump in isobaric conditions, is recorded. The layout of the apparatus is shown in Figure 6.

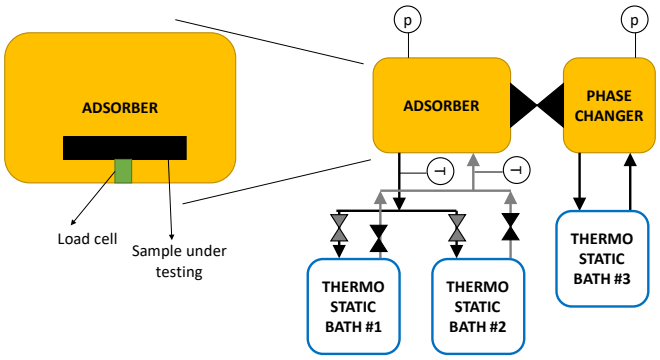


Figure 6: schematics of the experimental apparatus.

An example of the results from the test is shown in Figure 7, where the evolution of weight and the adimensional uptake (i.e. the uptake normalised over the uptake in equilibrium conditions) are presented. The results refer to a test simulating an adsorption process from 66°C to 30°C temperature jump. As expected, the trend can be approximated by an exponential equation, as described in [11], with a characteristic time to complete about 63% of adsorption equal to about 700 s.

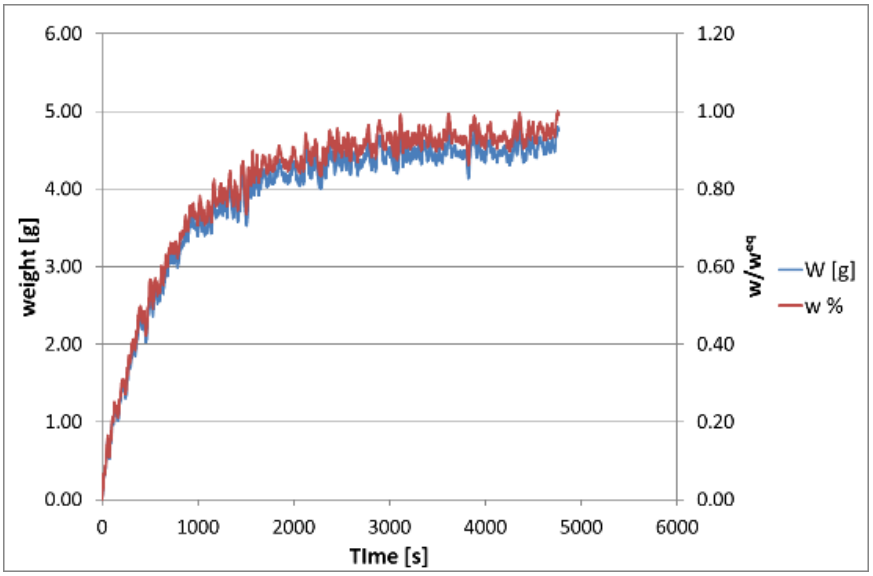


Figure 7: weight and uptake evolution of a reference test.

6. Ongoing and future activities

Tests are still ongoing, to evaluate and optimize the performance of the structures for the target application. In particular, the first results were used to realize a heat exchanger in representative dimensions, by brazing the foam between two channels for the heat transfer fluid, as shown in Figure 8, which was manufactured by AKG.

Figure 8: the heat exchanger with coated foams that will be used for sorption dynamic evaluation.

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