Thermal Expansion of Porous Metal Foams

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Introduction

In two very recent publications, measurements of the thermal diffusivity on porous metal foams using LFA (Laser/Light Flash Analysis) were comprehensively discussed [1, 2]. The intention of this application note is to discuss another important thermophysical property of these materials: thermal expansion provided by DIL (dilatometry).

The materials investigated were open-cell foams based on AlSi7Mg (EN AC-42000) aluminum alloy, provided by Exxentis AG (Wettingen, Switzerland). The foams are created by aluminum alloy casting with crystal salt. Different pore sizes are achieved by variation of the grain size of the salt. Such foams are used as vacuum foaming molds, as thermoforming tools, for vacuum plates in vacuum tables and clamping systems, as silencers, as filters and as heat exchangers. Ultralight metal foams are also used in applications in catalysis, fuel cells, hydrogen storage and acoustic insulation [2].

Experimental

Three open-cell foams with nominal pore sizes in ranges from 0.2 to 0.35 mm ("small pores"), 0.40 to 1.00 mm ("medium pores"), and 0.63 to 4.00 mm ("large pores") were investigated. Photos of these samples are shown as inserts in figure 1b). All foam samples had a nominal density ρ = 1.09 g/cm^3, or a nominal porosity of about 60%. The expansion behavior of the three porous metal foams was compared to the fully dense AlSi7Mg material with a density of ρ = 2.68 g/cm^3. A photo of this sample is shown as an inset in figure 1a). The density of the foams was calculated as mass divided by volume. For determination of the density of the fully dense sample, a density balance was used. All samples were cylindrically shaped with a diameter of 12.6 mm and a thickness of 10 mm.

Measurement Conditions

The measurements were performed with a DIL 402 *Expedis Select* pushrod dilatometer, equipped with a steel furnace capable of operation between -150°C and 1000°C. The system is vacuum-tight, allowing measurements to be carried out in pure inert or oxidizing atmospheres as well as under vacuum. A set of primary standards, including fused silica, sapphire, platinum, tungsten, etc., is available for length calibration. The expected expansion of the specimen and the temperature range of the measurement dictate which standard should be used. The measurements were performed with a fused silica sample holder in the temperature range from -100°C to 500°C at a heating rate of 2 K/min in a helium atmosphere. Each sample was heated twice; the results of the second heating were used to calculate the density curve based on the density at room temperature and the measured thermal expansion assuming isotropic expansion behavior and no mass loss during heating. In order to correct for the expansion of the sample holder and pushrod, a correction measurement with an Al_2O_3 reference was conducted prior to the sample measurements.

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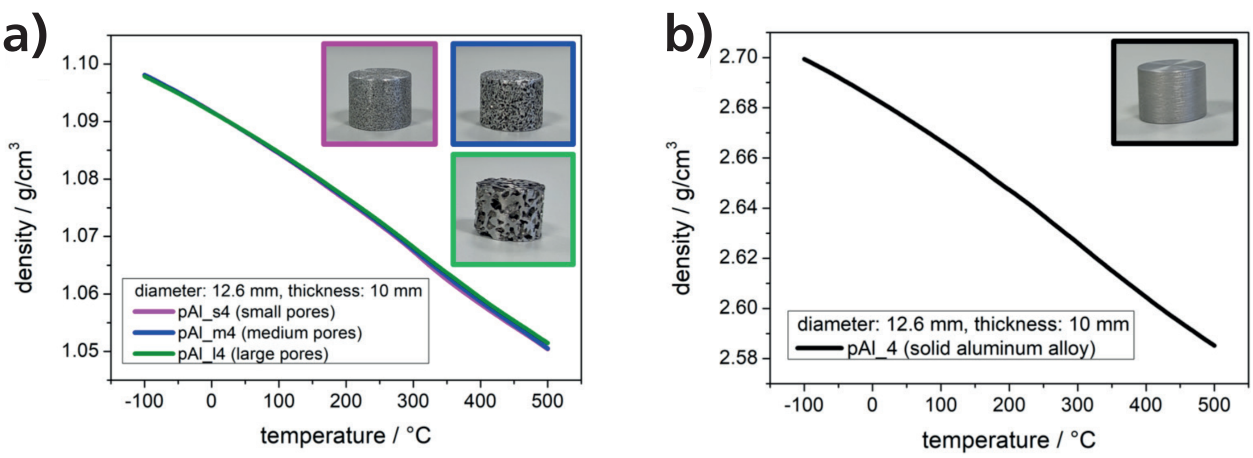
Measurement Results

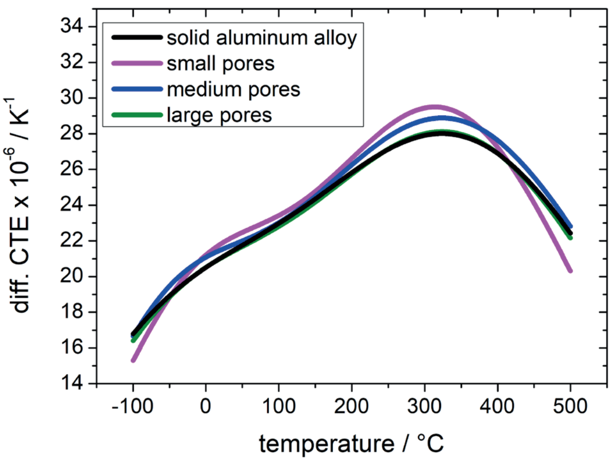
Figure 1a) presents the data for the three foam samples with different pore sizes and 1b) the density data of the fully dense sample.

Due to the thermal expansion, the density of all samples decreases with increasing temperature, showing a consistent trend. For the fully dense sample as well as for the foams, the density decreases by 4.3% in the temperature range between -100°C and 500°C. Introducing porosity into a fully dense AlSi7Mg sample does not seem to significantly affect the change in density with temperature. Different pore sizes in AlSi7Mg foams do not seem to have any significant effect on the density behavior either.

It is reported in literature that for metal foams, the behavior of the CTE (coefficient of thermal expansion) remains similar to the fully dense material [3], while the thermal diffusivity will be reduced [2]. Clearly, this is also true for the materials investigated here, as can be seen from the CTE data presented in figure 2.



1 Density plotted versus temperature for a) the three AlSi7Mg foam samples with small, medium and large pores and b) the fully-dense AlSi7Mg sample



2 Coefficients of thermal expansion for the fully dense material as well as for the three AlSi7Mg foams with different pore sizes

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Comparison of the CTE curves in figure 2 reveals that the curves of the fully dense sample and of the sample with large pores are, interestingly, nearly congruent. These two samples have lower overall surface areas (internal plus external) than the samples with medium and small pores and might thus exhibit more pronounced inertia versus temperature changes. Since, in dilatometry, measurements usually are performed dynamically at a specific heating rate, these samples are expected to equilibrate slower than the samples with medium and small pores and could therefore easily lag behind in their response behavior. This is a possible explanation for the slight differences in the measurement curves in figure 2, which could therefore be caused by a mixture of sample-specific and metrological effects.

AlSiMg alloys are known to exhibit precipitation/post-hardening effects, which could also play a significant role. Specific heat capacity data for the samples yielded by DSC (differential scanning calorimetry) revealed slight exothermic effects in the temperature range between 250°C and 400°C [2]. The thermal diffusivity, investigated by LFA, shows a deviation from the monotonous trend in this temperature range, too [2]. In this temperature range, the CTE curves also show extrema, probably also related to precipitation hardening. The difference in intensity of these effects could yield the differences in the curves shown in figure 2.

Conclusion

Dilatometer measurements on a fully dense AlSi7Mg material and three AlSi7Mg foams with different pore sizes revealed similar behavior of the CTE for all samples investigated, independent of the pore size. The trend regarding the change in density is about the same for all of the samples. The thermal diffusivity of the samples, as another highly important thermophysical property, does not show such invariance to the pore size of the samples: It was found to decrease with increasing pore size.

References

[1] A. Lauerer, A. Lunev, Experimental evidence of gas-mediated heat transfer in porous solids measured by the flash method, Int. J. Therm. Sci., under review, June 2022.
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https://doi.org/10.1016/j.ijthermalsci.2022.107743
[3] URL: https://slidetodoc.com/metal-foam-introduction-a-metal-foam-is-a/, visited on 06/22/2022

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