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Insulation of heat sources by additively manufactured parts

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Abstract
Temperature stability is mandatory for most high precision measurements. Some heat sources and sinks, like cameras, lasers or motors, influence the temperature stability in an experimental setup as they cannot be removed by reason of their significance for the measurements. Thus, the approach is to isolate heat sources by different methods. Especially additive manufactured parts are interesting to use, as the design of double-walled objects in special shapes is not as easy in conventional manufacturing. Therefore, different approaches of additively manufactured isolating boxes are characterized in real-object studies. As a printing medium for selective laser melting, an aluminium alloy (3.2381) is chosen. A polymer model (PA2200) is produced on a selective laser sintering printer, in order to investigate the influence of material choice to thermal conduction and distribution. In a first study, double-walled boxes are measured with metal powder in between the walls, which is a residue of the selective laser melting process. That metal powder is later removed and after that replaced with a phase-changing material. The results will be presented and discussed in terms of thermal insulation in order to achieve temperature stability.

Thermal stability, temperature, experiment design, additive manufacturing

1. Introduction

Thermal issues are a significant part of measurement uncertainties and are likely to limit the possibilities of modern metrology and machine processing [1]. Virtually all mechanical and electrical characteristics depend on the surrounding temperature. Depending on the type of measurement it is insufficient to just know the temperature distribution of a system exactly in order to calculate thermal errors, but it is necessary to improve the temperature stability of the system.

Before considering active thermal control, all possibilities in design and passive thermal control should be tested [2]. Therefore, the design should be kept simple to avoid unnecessary heat transfer [3]. One approach is to isolate the heat sources (or sinks) of one experiment in order to reduce the influence of a non-removeable essential part of an experiment. It is proposed to use phase changing material (PCM) as a buffer for latent heat without raising the temperature of the whole system [4]. Different and new materials for insulation were tested in the past [5], which has not been performed with additively manufactured (AM) material. These sintered materials are likely to have slightly different characteristics than its conventionally manufactured pendants. It shall be experimentally tested what available AM material and configuration is best to isolate a heat source.

In the following sections one exemplifying AM part for insulation of heat sources is introduced and modified. In addition, a new way of temperature data evaluation is proposed. That way, different materials will be tested with a purposely placed heat source and compared to each other.

2. Experimental setup

The efficiency of AM parts to isolate heat sources is determined in real-object studies. In order to estimate the thermal effect onto a preassigned volume, all measurements are performed in the same experimental chamber with the same heat source and a pre-set temperature. This experimental chamber holds a fixed volume of air, without any kind of flow and is located in a lab with a climate control unit. Inside the experimental chamber, a two-level-controlled heat source is placed in an insulation box (geometry further described in section 2.1). As a heat source, a heating resistor is chosen. For better heat distribution, it is put into a copper cylinder with dimensions of Ø 25 mm x 60 mm. The heat source is then turned on, to monitor the system's reaction to the heat induced. On that behalf, the temperature distribution in the experimental chamber is monitored with six equally distributed PT100 temperature sensors.

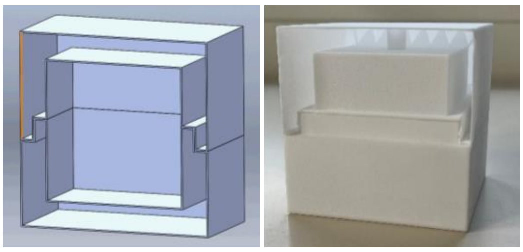

Figure 1. Additively manufactured insulation box. Left: model, right: inside view of a printed version made of PA2200.

2.1. Additively manufactured insulation boxes

A big advantage of AM parts is that components for which conventional manufacturing is associated with a lot of time and effort, if even possible, are relatively easy to manufacture.

This work uses double-walled insulation boxes [fig. 1] made of two different materials, which are a polyamide (PA2200) and an aluminium-alloy (3.2381). The insulation box is manufactured three times for every material: first, the leftover powder in the interspace, which is a residue of the selective laser sintering process, is removed. For the second case the remaining powder is left in the interspace and in the third case the interspace is filled with a PCM.

2.2. Phase changing material

As described in section 1, previous work proposed to use a PCM to cope with local heat sources [4]. PCM can store plenty of energy in its phase change without changing temperature respectively. Each PCM has a specific phase change range, which can be described as a hysteresis. In our approach an organic PCM is filled in the doubled walls of the insulation box.

3. Data evaluation

The effect of the enclosed heat source on the temperature distribution in the experimental chamber is shown in figure 2. An increase of about 15 K inside the insulation box is diminished to around 0.3 K in the chamber. It also causes a delay in the temperature run.

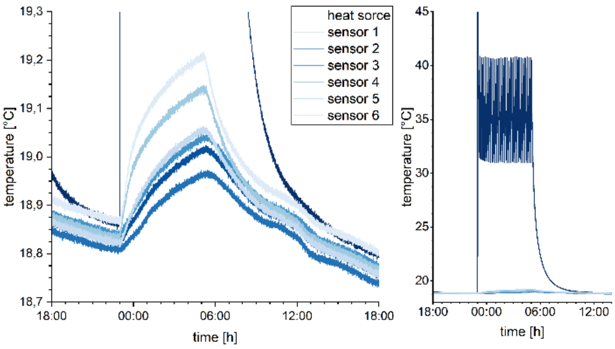

Figure 2. Left: The effect of a heat source through the aluminium insulation box filled with powder in the measuring chamber. Sensors are placed in the edges of the experimental chamber. Right: The heat source has a temperature range of 31 °C < T < 41 °C in a frequency of 0.07 Hz.

For a quantitative description an approach of transfer functions for thermal systems is introduced [eq. 1]. The system response caused by a heat source is described by the convolution of the transfer function g with its input function f.

$$\mathcal{F}(f * g) = (2\pi)^{\frac{1}{2}} \cdot \mathcal{F}(f) \cdot \mathcal{F}(g) \quad (1)$$

Instead of calculating the convolution in time domain, the Fourier transformation $\mathcal{F}$ of the signal is calculated; the product of those two Fourier analysed functions is the equivalent in frequency domain. Results are shown in figure 3 for the insulation boxes made of PA2200 and in figure 4 for the insulation boxes made of aluminium alloy.

4. Experimental results

The baseline of the transfer function of PA2200 is lower than the one of aluminium, which means that the insulation with PA is more effective. This can be explained by the PA's lower thermal conductivity [tab.1]. Several minima are noted: one drastic at 0.0009/s with *PA powder* and a minimum at 0.0013/s at *alu empty* and *alu powder*. Those can be translated to time constants of 18.5 min (PA) and 12.8 min (alu). Compared to the reference data (not shown) those minima and time constants could be linked with the time it takes until the system shows a reaction to the induced heat.

With PCM introduced, the baseline of PA increases, whereas the one of aluminium decreases. One reason might be the thermal conductivity of aluminium, which is much higher, so the heat can spread evenly across the PCM and heat absorption is improved by the high specific heat capacity of the PCM. The PCM data sets have a peak at 0.003/s, which implies a good heat transfer in time scales of ≈ 5 min (which is bad for the overall system). It seems like the PCM tends to let heat go through, before it starts its phase changing process. Whereas this would be true for at a wall thickness of ≈ 10 mm, this is an assumption and should be further investigated.

Table 1 Thermal specifications of the materials used.

Material	**Thermal conductivity** $\lambda \left[\frac{W}{m \cdot K}\right]$	**Specific heat capacity** $c \left[\frac{kJ}{kg \cdot K}\right]$
Air	0.0262	1.005
Aluminium (3.2381)	120...170	0.888
PA2200 (sintered)	0.127...0.144	2.35
PCM (phase change @21 °C)	0.2	2

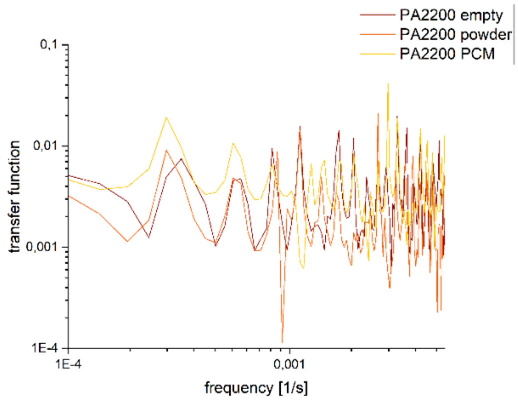

Figure 3. Heat transfer functions for insulation boxes made of PA2200.

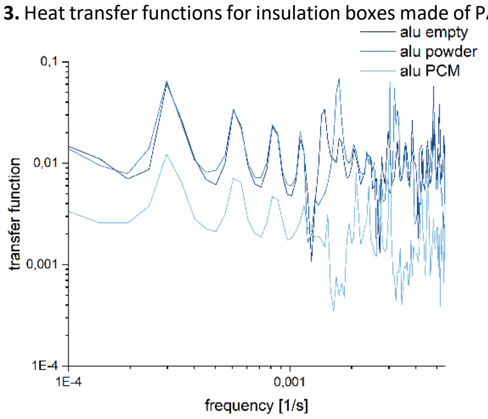

Figure 4. Heat transfer functions for insulation boxes made of aluminium alloy.

5. Summary, Conclusion and Future work

Two AM materials have been experimentally tested in order to insulate a heat source in an experimental chamber. It was shown that PA is usually better for insulation than aluminium. An exception must be made for macro-encapsulating a PCM, which seems to profit from a better heat distribution due to the aluminium alloy. In future work, massive PA2200 walls could show similar results than the PCM due to the similar specific heat capacity. Wall thicknesses should also be varied with PCM. A numeric model to make a quantitative link between measured data and literature is needed but has yet to be discovered.

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