IWAM
INTERNATIONAL
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ADITIVE
MANUFACTURING

1ST INTERNATIONAL CONGRESS
ON
ADDITIVE MANUFACTURING
BOOK OF ABSTRACTS

IWAM 22

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INSTITUTO POLITÉCNICO
DE BRAGANÇA

SEPTEMBER 30, 2022

1ST INTERNATIONAL CONGRESS

ON

ADDITIVE MANUFACTURING

BOOK OF ABSTRACTS

IWAM 22

Bragança - Portugal

September 2022

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Instituto Politécnico de Bragança 2022

Campus de Santa Apolónia

5300-253 Bragança - Portugal

ISBN: 978-972-745-310-8

http://hdl.handle.net/10198/23947

Book cover: Jorge Santos, Instituto Politécnico de Bragança

Technical Support: Clarisse Pais, Instituto Politécnico de Bragança

WELCOME

Additive manufacturing technologies are playing a decisive role in the laboratory environment, making a significant difference in STEAM education. Students use additive manufacturing to create physical models, topographic maps, biology artifacts, artwork, all types of engineering prototypes and solving mathematics challenges. By bringing additive manufacturing capabilities to the classroom, educators can raise interest in STEAM, introduce new concepts and capabilities, and help set the future for more skilled STEAM professionals.

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Control of the dimensional variation adjusting the thermal drying cycle of abrasive composites with incorporated PLA

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ABSTRACT

In composite production, during the thermal drying cycle (T<100ºC), size variation of the composite material occurs due to the thermal expansion and water elimination. However, when incorporating PLA components, produced by additive manufacturing, into the abrasive composite, the dimensional variation of the set is very large due to the higher polymer thermal expansion. During this stage, this composite, still in green state, could not have sufficient mechanical strength to withstand dimensional variations. These can result in crack formation. Therefore, the proper thermal cycle is a critical step. To define the convenient heating rate during the drying of composites with a PLA piece, thermomechanical analyzes were conducted. Three different heating ramps were tested, 0.1, 0.5, and 2.0 ºC/min in the most critical phase of dimensional change (up to 60 ºC), after this temperature the heating continues at 2 ºC/min. The results indicate that, the slower is the heating rate, the higher is the absorption of the polymer's expansion by the composite. In the slower heating rate (0.1 ºC/min) it was possible to minimize the dimensional variation of the samples in more than 94%.

INTRODUCTION

Abrasive composites are widely used in various industries as a tool to effectively shape and surface metals. Many industries, such as aerospace, automotive, biomedical, or heavy equipment, depend on the precision of these tools to produce increasingly complex parts from the point of view of the geometry and the surface finish (Palmer et al., 2018; Yin et al., 2017), maintaining the properties of the workpiece.

The manufacturing process of abrasive composites involves a thermal drying phase and a sintering phase, after shaping. During thermal drying phase, up to approximately 100 °C, the elimination of water occurs progressively, while the densification sintering occurs during sintering at higher temperatures, depending on the type of bonds. During the entire process, the composite is subjected to dimensional variations caused by different mechanisms and reactions, i.e., elimination of water, combustion of organic components, decomposition of mineral precursors and matrix material softening (Capela et al., 2018). However, when incorporating a solid piece produced by additive manufacturing (ex: in PLA), higher dimensional variations occur in the drying step due to the polymer expansion (according to material coefficient of thermal expansion, CTE). These high variations can compromise the composite, because as green material, it could not have sufficient mechanical strength and so, it is susceptible to crack formation. A priori, this effect can be mitigated with a proper choice of the thermal cycle. The ideal thermal cycle is one that heats up slowly enough to allow the PLA and composite to expand in a slower controlled manner. In order to define the most appropriate heating ramp, the thermal expansion analysis has been performed under 3 different ramps: 0.1, 0.5 and 2.0 ºC/min.

RESULTS

The abrasive composite used here has a vitreous bond, with 38% porosity and density of 2.5 g/cm^3. The samples have a cylindrical shape with a radius of 2.5 mm and a height of 5 mm. The PLA piece is 1.5 mm thick, with a radius of 2.5 mm (cf. figure 1). The moisture content in the abrasive composite is 2.5 in wt.%.

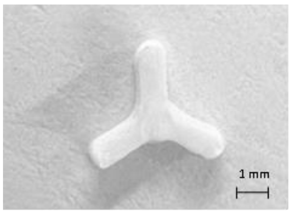

Figure 1- PLA sample before integration in the abrasive composite.

First, a TMA test was carried out with a heating ramp of 2 °C/min up to 75 °C. A high expansion jump (~5%) is detected in the range 40-55ºC (figure 2). Then the height of the sample stabilized/decreases about 0.8% up to 75ºC. In order to alleviate the problem, the heating rate in the critical zone was reduced (up to 60°C). Two other tests were carried out, with two different heating rates: 0.5 and 0.1 ºC/min up to 60 ºC followed by a 2 ºC/min. heating up to 75 ºC. The results of these tests are presented in figures 2a and 2b, as a function of temperature and time, respectively.

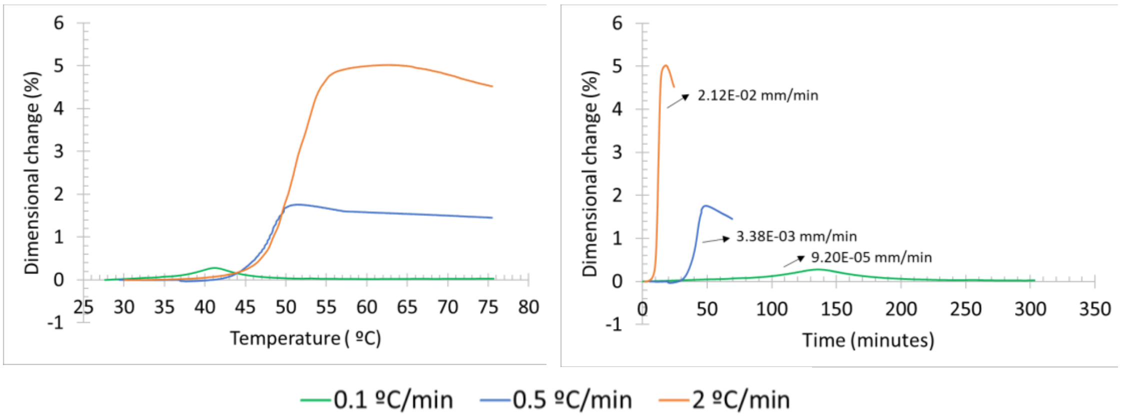

Figure 2- Dimensional variation as a function of temperature a) and time b)

By reducing the heating rate, it was possible to substantially decrease the dimensional change of the samples, especially for the one that was heated at 0.1 ºC/min. In this case, the maximum variation recorded was ~0.28%. Compared to the sample heated to 2 ºC/min, there was a reduction of more than 94% in the values of dimensional change in the sample with slower heating, and of 64% in the sample heated to 0.5 ºC/min.

The results indicate that, with low heating rate, the abrasive composite internal microstructure (namely its open porosity) can absorb or accommodate the polymer's expansion. In figure 2a, it is possible to see that the expansion of the sample happens very quickly, and as the heating rate is reduced, this effect is smoothed. Also, one can note that the thermal expansion starts at lower temperature (33ºC) in the slower thermal cycle, while is starts around 40-42ºC using faster cycles. The evolution of expansion rate versus the heating rate is shown in figure 3. A straight correlation is observed between these two items.

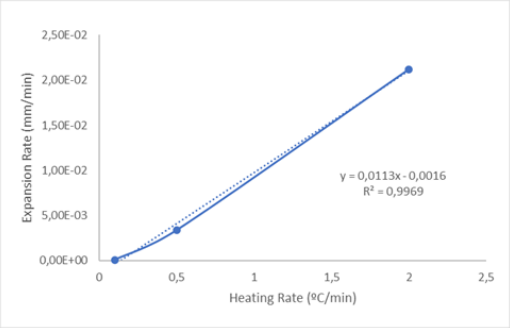

Figure 3 – Expansion rate at the critical zone for different heating rates

Considering dE is the thermal expansion (in mm) the expansion rate is described as:

$$dE/dt = dE/dT \ X \ dT/dt \quad (1)$$

The linear behavior observed in fig.3 confirms that dE/dT, i. e. the dimensional thermal expansion in these samples is almost constant. Here, dE/dT= 0.0113 mm/ºC, in the range 25-60ºC. The PLA thermal expansion coefficient (since the thickness of the PLA piece is constant) remains constant inside of the abrasive composite whatever are the heating rates

CONCLUSIONS

By reducing the heating rate during the drying step of abrasive composites with PLA, it was possible to smooth the dimensional change of the composite material and decrease the variation by more than 94 %. Experimental results show that the composite internal structure has capacity to absorb an important part of the external (polymer) thermal expansion during the drying process. A slower heating promotes the absorption of the PLA polymer expansion by changes in the abrasive composite internal microstructure.

ACKNOWLEDGMENTS

This work is supported by FCT national funds, under the national support to R&D units grant, through the reference project UIDB/04436/2020 and UIDP/04436/2020. This work is also within the scope of the Sharlane Costa Ph.D. degree in progress, financially supported by the Portuguese Foundation for Science and Technology (FCT) through the PhD grant reference 2021.07352.BD. The authors are grateful to the Foundation for Science and Technology (FCT, Portugal) for financial support through national funds FCT/MCTES (PIDDAC) to CIMO (UIDB/00690/2020 and UIDP/00690/2020) and SusTEC (LA/P/0007/2020).

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