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Study of the viability of manufacturing ceramic moulds by additive manufacturing for rapid casting

Edwin Ocaña Garzón[a,b] *, Jorge Lino Alves[b], Rui J. Neto[b]

[a]*Departmento de Ciencias de la Energía y Mecánica (DECEM), Universidad de las Fuerzas Armadas ESPE, Sangolquí, Ecuador*
[b]*INEGI, Faculty of Engineering, University of Porto, 4200-465, Porto, Portugal*

Abstract

Additive manufacturing (AM) has been considered one of the best processes to manufacture components with complex geometries, many times impossible to achieve with traditional processes, such as moulds with conformal cooling. Binder Jetting (BJ) technology uses an ink-jet printing head that deposits an adhesive liquid, layer by layer, to bind a powder material that can be ceramic, metallic, or other, which allows manufacturing parts to be used in research and industry.
The aim of this work is to study the possibility of using BJ to produce plaster moulds for directly cast metallic parts at a lower cost than with metallic AM processes, using different types of infiltrates and post-processing parameters to improve the mechanical and thermal strength of moulds in order to be able to cast an aluminium alloy. The mechanical and thermal resistance of moulds with a thickness range of 2.5-4mm were analysed, as well as the surface roughness of metal samples, and compared with those obtained by traditional processes. Although all the moulds had good heat resistance during the casting, some did not have enough mechanical strength to withstand the metalostatic pressure, especially those with walls of 2.5 to 3.5 mm.

Keywords: Additive manufacturing; 3D printing; rapid casting; plaster moulds.

1. Introduction

The ASTM International Committee F42 on Additive Manufacturing Technologies (AM) defined AM as the process of joining materials to make objects from 3D model data, usually layer upon layer [1] which is commonly known as 3D printing (3DP). This technology does not subtract material and has a wide field of applications, producing parts in minutes, hours or few days (depending on complexity) in different types of materials [2], and its main advantage is that it does not rely on the operator's ability to manufacture unimaginable parts.
Since 1987, when the first commercial AM System, SLA-1, was launched by 3D Systems in USA [3], the growth of this industry has accelerated, with an increasing number of organizations adopting AM products and services. The compound annual growth rate (CAGR) of worldwide revenues produced by all products and services, over the past 26 years, is an impressive 27.3%. The CAGR from 2012–2014 is 33.8%. The market has nearly quadrupled in the last five years [1].
The first use of AM parts as sacrificial patterns in traditional investment casting (IC) started in 1989. Since then, all major AM techniques have been used in different casting methods to provide Rapid Investment Casting (RIC) solutions for producing metal parts, using direct and indirect conversion technologies [4-6].
IC allows the production of accurate components in low or high volumes as a competitive alternative to

* Corresponding author.
E-mail address: emocania@espe.edu.ec

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forging or metal turning since the waste material is kept to a minimum [7].

The economic benefits derived from AM patterns are limited to small quantity production due to high AM material costs [8]. The choice of the AM technique to be used will depend on many factors such as shape, dimensional tolerances, the cost assigned to the model, among others [9].

The Projet 660 Pro machine uses a ColorJet Printing (CJP) technology that consolidates a plaster-ceramic powder by selective jetting of a water based binder. Complex cores and cavities can be produced directly from the CAD model, completed with the gating system and air vents, avoiding the construction of patterns and core boxes [10]. Post-processing is a critical important aspect of 3D printing, but it is often overlooked or underemphasized in product literature and by the media. 3D printing requires specific knowledge and techniques to produce a "finished" part [1]. Typically, post-processing is needed to remove support material from parts by water jet, air jet, dissolution, or other mechanical process. In the Projet 660 Pro (Fig. 1) the loose powder is removed with a brush and by air jet, and the part is posteriorly infiltrated with hardeners as cyanoacrylate, polymeric resins, or other material to increase the strength and brighten colours to get a functional component.

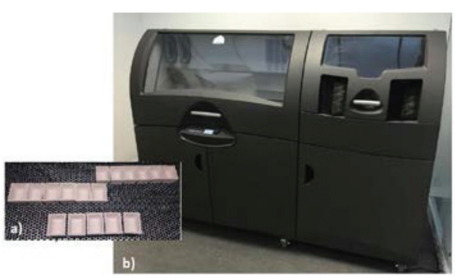

Fig. 1. a) Printed specimens; b) FEUP's ProJet 660 PRO Series machine.

This research has the following objectives:

- Feasibility of making moulds for casting aluminium by 3D printing, using the Projet 660 Pro;
- The raw material is the one recommended by the manufacturer: calcium sulphate hemihydrate 80-90% (3D Systems USA) by selective jetting of water-based binder [11]. It is known that the binder does not support high temperatures, so the research will focus on finding adequate infiltrates, in the post-processing, to provide satisfactory results for a mould with enough strength to withstand the casting of the selected aluminium alloy;
- Determine the tolerance and surface roughness of the castings.

2. Experimental work

2.1. CAD design

The experimental process began by defining a simple shape mould, as shown in Fig. 2. This geometry was initially adopted because the goal was to test different infiltrates to harden the mould. This geometry was modelled in 3D CAD software, and the internal dimensions were maintained, according to Fig. 2. Four different wall thicknesses were selected; 2.5, 3.0, 3.5 and 4.0 mm to evaluate mould resistance.

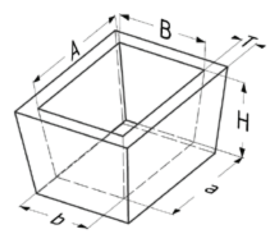

Fig. 2. Specimen shape used as mould.

2.2. AM of moulds

The CAD file was saved in a STL extension and later used along with the 3D Edit Pro 2.0 printer software; all the specimens were located in optimum position for printing. The samples were printed in different batches, and Table 1 specifies the main characteristics of the job, in terms of printing time and amount of powder and binder. It should be noted that although this printer has the possibility to print in colour, in this work, this feature was not necessary; thus, all the samples were printed in the monochrome mode, so the amount of binder basically reflects clear binder.

Table 1. Specimen printing characteristics: time, volume of powder and binder.

Wall thickness (mm)	Build time; 12 samples (min)	Volume binder/part (mL)	Volume powder/part (cm^3)
2.50	77.94	8.30	8.20
3.00	82.78	6.07	10.29
3.50	82.78	7.08	12.01
4.00	87.00	8.13	14.31