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Review

3D printing for rapid sand casting—A review

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ABSTRACT

There are many 3D printing technologies available, and each technology has its strength and weakness. The 3D printing of sand moulds, by binder jetting technology for rapid casting, plays a vital role in providing a better value for the more than 5000 years old casting industry by producing quality and economic sand moulds. The parts of the mould assembly can be manufactured by precisely controlling the process parameters and the gas producible materials within the printed mould. A functional mould can be manufactured with the required gas permeability, strength, and heat absorption characteristics, and hence the process ensures a high success rate of quality castings with an optimised design for weight reduction. It overcomes many of the limitations in traditional mould design with a very limited number of parts in the mould assembly. A variety of powders, of different particle size or shape, and bonding materials can be used to change the thermal and physical properties of the mould and hence provide possibilities for casting a broad range of alloys. Limited studies have been carried out to understand the relationship between the characteristics of the printed mould, the materials used, and the processing parameters for making the mould. These deficiencies need to be addressed to support the numerical simulation of a designed part, to optimise the success rate and for economic as well as environmental reasons. Commonly used binders in this process, e.g. furan resins, are carcinogenic or hazardous, and hence there is a vital need for developing new or improved bonding materials.

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1. Introduction

A definition of additive manufacturing (AM) has been given as "*process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies*" [1]. AM began as a method for design engineers to realise design concepts without heavily investing in the subsequent manufacturing processes. Advancements in Rapid Prototyping (RP) enabled the conversion of parametric CAD (computer aided design) data to physical prototypes which could be tested to check if they met the design criteria. This saved not only time but also allowed the testing of multiple models [2]. Since then, its applications have expanded into the aerospace industry, medicine, architecture and more. This expansion has been aided by the wide-scale development and innovation in additive manufacturing processes. As the accuracy and the versatility of the processes improve, the focus of the industry is shifting from Rapid Prototyping to 'Rapid Manufacturing' i.e. the process of manufacturing complete parts from a rapid prototyping device [3,4]. Wohlers [4] states that machines must allow the production of finished parts and an improvement in materials for better penetration of rapid

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Table 1
The 3D printed sand mould for casting and their production method, properties, and applications.

Ref.	Powder	Particle size	Suitable binder	Properties achieved (3PB)	Heat treatment	Application
[14,15]	Plaster-ceramic composite		Zb56		464K(190° C) for 4–8 h	Casting non-ferrous metals
[16]	Chromite		Furan or phenol			
[17–19]	Silica,	140/190/250 µm	Furan	250–300 Ncm^{-2}	No heat treatment required	Casting non-ferrous metals
[18,19]	Silica	140/190/250 µm	Phenolic (hot hardening)	250–500 Ncm^{-2}		Casting ferrous metals
[16]	Zircon		Furan			
[16]	Chromite					Heavy duty grey iron and steel
[16]	Ceramic Beads		Furan			Including steel alloys casting, sand cores

manufacturing in the new markets. This can be seen in the variety of processes that fall under the umbrella of rapid casting which use AM based technology to aid investment and sand casting processes [5]. These include Selective Laser Sintering, Laminated Object Manufacturing, Fused Deposition Modelling, Stereo lithography and especially, the 3D printing (3DP) process to produce sand cores, patterns, shells and entire mould assemblies for sand casting applications. The interest in rapid casting using AM has increased with the general increase in interest and industrial proliferation of AM, as can be seen in Table 1.

Recently, 3DP has gained prominence as a rapid casting process which is a cost-effective [5] and relatively fast method capable of working with a wide variety of materials and post treatment processes [7,8]. 3DP, based on the inkjet printing technology, was developed at Massachusetts Institute of Technology (MIT) [9–11] and licensed to six companies. Since then the process has been used for the production of ceramics, metal parts with copper infiltration and then polymer moulds for patterns in rapid casting. The process is similar to other powder-based processes and uses an inkjet printer head to spray the binder onto the job box (the build platform). The process begins with a fine layer of sand, pre-mixed with the activator, distributed on the job box surface by the recoater and followed by spraying binder in the selected area of the job-box plane, according to each slice (cross section) of the part to be printed. As the bonding reaction takes place, the sand particles stick together only within the region where the binder was sprayed;the other region is covered by loose sand. The platform moves downward by a set distance (layer thickness), and the process repeats until all of the slices of the part are completely printed and a final sand layer is spread. Fig. 2 shows a schematic of the process. Recently, companies such as ExOne^{TM}, Voxeljet^{TM}, and ZCorp^{TM} have expanded this system to produce sand moulds using binder jetting technology. Thus, while the process has been used for rapid tooling, its application in the field of manufacturing of sand moulds for direct casting is rather new and unexplored, Fig. 1(b-the green colour plot). However, this application is imperative, not limited to, for small volume production of complex parts as it offers significant advantages such as large reductions in the lead time for the design of moulds, easy integration of cores and gating system in the design of mold assembly, and production of parts with complex internal geometries. Amongst all the rapid tooling and manufacturing processes, this makes the most sense for quick integration into existing industries as it can produce high quality and complex sand moulds with the required properties for a better casting solution within a short time frame [12]. Furthermore, compared to the traditional sand mould making process, binder jetting can produce optimised part designs for weight reduction up to 33% without losing the engineering requirement of the component [13]. This has been possible due to the vast body of knowledge relating to sand casting and the evolution of cast parts .

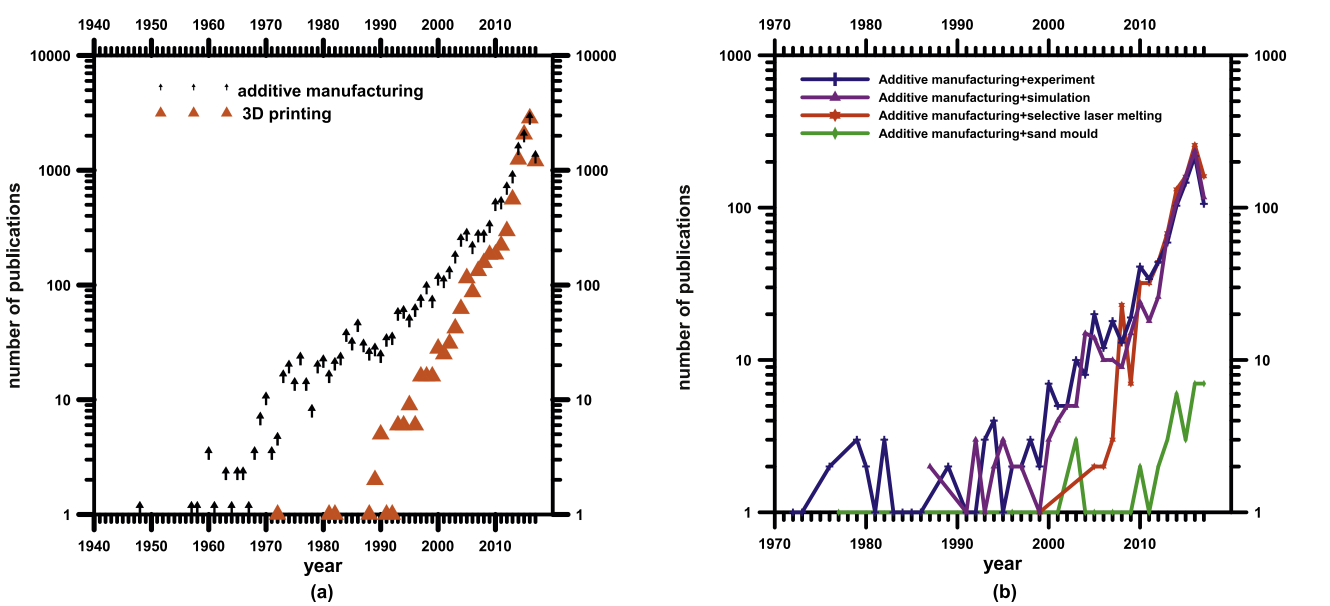

Fig. 1. Classification of the number of scientific publication appeared during the search with the particular set of key words in the Scopus database (June 2017, with permission) [6], showing the growing trend in the research of (a) additive manufacturing/3D printing as well as (b-in green) 3D sand mold printing. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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