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Simulation based energy and resource efficient casting process chain selection: A case study

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Abstract

Casting processes are among the most energy intensive manufacturing processes. A typical modern casting process contains different stages, classified as melting-alloying, moulding, pouring, solidification, fettling, machining and finishing respectively. At each stage, large amounts of energy are consumed. Since a number of different casting processes exist, it is not always straightforward which process chain to select among the available ones. Up to now the selection is based on cost criteria. This paper focuses on the different criteria that needs to be considered and how they can be simulated focusing especially on the energy and resource efficiency of casting stages. A disruptive technology that uses a rapid induction furnace to melt just enough metal for a single mould rather than bulk melting used in traditional processing is proposed and validated.

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1. Introduction

Energy consumption of industrial processes has been investigated thoroughly in the last years. Manufacturing accounts for 32 % of the total energy consumption [1]. Within the CIRP community a number of papers have been presented focusing on the energy efficiency of manufacturing processes developing methods for improving it [2]. However, these methods are focused on material removal processes and have not been generalized to include primary forming processes such as casting.

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Casting relies in pouring molten metal into a mould and wait until it solidifies. Although it is one of the oldest manufacturing processes, it is also one of the most challenging. A typical modern casting process contains a number of different stages, including melting, alloying, moulding, pouring, solidification and finishing. Casting is also one of the most energy intensive manufacturing processes with the metal melting consuming over half of the total energy.

Aluminium melting in metal casting industry is an energy intensive process, it has been estimated that the energy consumption is of the order of 6 – 17 GJ.tonne⁻¹ in using crucible furnaces and natural gas. The energy efficiency of a casting facility depends largely on the efficiency of its melting and heat treating performance. It has been estimated that these two processes consume over 60 % of the total process energy implying that there are huge opportunities for the metal casting industry to adopt the best energy practices which will provide the great energy saving potential.

Resource efficiency is also an issue in casting processes, with the yield in conventional casting processes being as low as 27 % [3]. Aluminium is a highly reactive material. In particular, when it is molten, it can react with air, moisture, the furnace lining and other metals. Metal loss during the melting process is also due mainly to this characteristic.

However, although energy and resource efficiency are key challenges for the casting processes, foundries do not consider them as key priorities. Cost is still the key decision making attribute for foundries. In this respect, the scope of this paper is to take a more holistic view on how to select between alternative casting process chains, considering energy and resource efficiency as criteria. Simulation can be used for the improvement of both the energy and the resource efficiency of the casting processes as will be shown. Various simulation tools and the potential savings from their use are presented and discussed for the case of conventional sand casting and a disruptive casting technology named CRIMSON.

2. CRIMSON process and case study

In a recent study, the possibilities for saving energy in the foundry sector were discussed [3], assessing the possibility of using lean tools. As an alternative casting process that considers these tools, the CRIMSON process was presented. The Constrained Rapid Induction Melting Single Shot Up-Casting (CRIMSON) process was developed for decreasing the energy consumption and to ameliorate the casting quality within light-metal casting industry [4]. The method is based on using an induction furnace, melting, in a closed crucible, only the quantity of metal required to fill a single mould rather than large batches that use unnecessary energy and increase rejects. The closed crucible is transferred to a station and the molten metal is pushed up using a computer controlled counter-gravity filling method to fill the mould. Due to the rapid melting, transfer and filling; the holding time of molten metal is minimised, a huge amount of energy saving is achieved and simultaneously the possibility of hydrogen absorption and formation of surface oxide film are decreased largely.

In the present paper different simulation methods are used for comparing CRIMSON with counter gravity sand casting. An ASTM standard tensile test bar was the case study product in a previous study [5], in the present paper a more complex product is used for validation. Computational fluid dynamics (CFD) are used for investigating the filling patterns. The energy savings are analytically estimated and fed into life cycle assessment (LCA) model for assessing the environmental impact. The productivity of the process is assessed using discrete event simulation and a cost model is proposed for the comparison with the sand casting. In such a way a holistic comparison is achieved revealing the possible benefits from the adoption of such process.

3. Numerical simulation of the filling process

CFD analysis has been used extensively in the optimization of the various casting processes. Salonitis et al. [5] used CFD for analysing and comparing the filling process of the mould during the casting of a tensile test bar, proving that for such simple parts the counter gravity filling process can result in better filling patterns compared to the traditional sand casting process. Counter gravity casting is used for the CRIMSON process that was introduced in the previous section, and it was shown that the possibility of oxide film generation on the surface of the liquid metal is considerably reduced and the available time for hydrogen absorption from the atmosphere by reducing time for the reduction of atmospheric moisture [5]. Additionally, they proved that the material lost during fettling is reduced, mostly due to the different design of the mould (lack of down-sprue for example). In the present study, a

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