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The development of a tool to promote sustainability in casting processes

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Abstract

The drive of the manufacturing industry towards productivity, quality and profitability has been supported in the last century by the availability of relatively cheap and abundant energy sources with limited focus on the minimisation of energy and material waste. However, in the last decades, more and more stringent regulations aimed at reducing pollution and consumption of resources have been introduced worldwide and in particular in Europe. Consequently, a highly mature and competitive industry like foundry is expecting challenges that an endeavour towards sustainability can turn into significant opportunities for the future. A tool to undertake a systematic analysis of energy and material flows in the casting process is being developed. An overview of the computer program architecture is presented and its output has been validated against real-world data collected from foundries.

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Keywords: Energy efficiency; Sustainable development; Casting

1. Introduction

Metal casting is an energy intensive, technically challenging, manufacturing process with a long history that plays a vital role in the production of a large variety of products. In very simple terms, casting can be summarised by the following description. Melt metal is poured into a mould that has been shaped as required and then removed after solidification. Casting is usually competitive over other manufacturing processes when it is necessary to produce parts with complex geometries or when dealing with materials difficult to machine [1,2].

In the last years, two significant forces are imposing a change to the mature technology of the metal casting industry. On the one hand, there is broad consensus within the society about the necessity to minimise waste and pollution derived by anthropogenic activities. This urge reflects in the more and more stringent regulations at national and European level as well as in worldwide agreements like the one settled in December 2015 at the UN Climate Change Conference.

On the other hand, the increasingly aggressive competition deriving from the modern global economy pushes towards a more energy effective use at a reasonable cost. Sustainability appears as an appealing strategy to tackle these challenges bringing together additional benefits. According to its most famous definition (given by the Brundtland Commission of the United Nations in 1987), “sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [3]. Given its extensive impact on modern society, manufacturing (and, in turn, casting) is required to play an important role in this context, evolving swiftly to cope with the changes, if not anticipating them. For example, Salonitis and Stavropoulos [4] propose to improve the established approach based on the “manufacturing decision tetrahedron” comprising cost, quality, flexibility and time adding sustainability as an additional fundamental driver of modern manufacturing.

In practice, a sustainable approach requires a broad and comprehensive view that covers the entire life-cycle of a product during its design and aims at maximising environmental, economic and social Key Performance Indicators (KPIs). The tool presented in this work assists foundries in this direction with an initial focus on the environmental aspects without encompassing the whole supply chain or “end of life” aspects.

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2. Rationale

Among the key findings of a workshop attended by foundries, suppliers and consultants, it has been highlighted the need for an energy auditing framework and a tool for the fast analysis of measurements [5-7]. The software under development is designed to respond to this industry need supporting a systematic analysis of the full energy and material chain of casting processes from charge materials through to waste. The visualisation of flows in different forms (e.g. process flow or Sankey diagrams) can support decision making in exploring the impact of potential improvements. For example, waste that can be considered non-trivial or traditionally unaccounted can be identified alongside opportunities for scavenging and the associated cost. Moreover, the visual nature of the computer program output can be effectively implemented in the training of foundry personnel whose behaviour plays a vital role in implementing sustainable improvements. Finally, this thorough analysis can be used for benchmarking performance of the plant against similar ones.

Although some of the mentioned goals might be obtained using established Discrete-Event Simulation (DES) tools, the time, effort or skills required to set-up a realistic model of the plant can be unacceptable for many SMEs. Hence, the program presented in this work has been designed to require minimum effort to map out the required flows and the amount of information corresponding to the desired level of accuracy can be flexibly adapted to the user's needs.

3. Energy flows

The cost of energy affects significantly the competitiveness of energy intensive enterprises like foundries. Thus, there is an interest in pursuing measures aimed at reducing the consumption of fossil fuel and electric power. Options to identify opportunities to reduce energy consumption include audits and the application of "lean philosophy" [8].

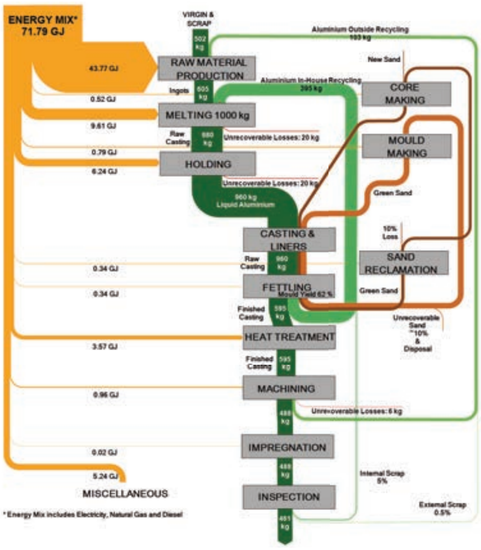

Fig. 1. Example of material and energy flows in a foundry represented by a Sankey diagram.

Suggestions derived by energy audits generally focus on equipment updates that would guarantee the maximum return on the investment [9,10]. However, the relevant capitals required could prevent the adoption of the most beneficial measures from an energy saving point of view. In fact, SMEs (that represent a major fraction of foundries) seek relatively short payback times [11-13].

Alternatively, the adoption of one or more lean philosophy tools may allow energy savings avoiding the larger investments in equipment previously mentioned. Salonitis *et al.* review more in detail the available options also remarking that lean tools are generally less implemented in firms where large stocks of raw materials are present, like foundries [8].

4. Material flows

Material flows represent another important source of information to improve casting processes. A schematic example in the form of a Sankey diagram of material and energy flows within a foundry is shown in Figure 1.

Unrecoverable material losses like (for example) hot flue gas derived from the combustion of fossil fuels, deteriorated scrap metal or sand that cannot be re-melt or reclaimed, are mainly a source of pollution for the environment. Furthermore, waste also "contain" a certain amount of energy that was previously spent in the foundry for its production, even without considering a more comprehensive and complicated life cycle analysis that would extend along the whole supply chain.

More virtuous examples like re-melting scrap metal after fettling (i.e. the operation that separates the casting from its gating system) where there is no transfer of metal outside the boundaries of the plant, still contribute significantly to reduce the efficiency of a foundry. Thus, any action focussed on the limitation of any form of waste is useful to improve the process. For example, a reduction of the scrap metal internally re-melt determines an inherent reduction in the energy consumption for unit of shipped casting. Salonitis *et al.* revise a number of opportunities to improve the energy efficiency of a foundry through the indirect means of controlling material flows [8].

An effective metric that can be adopted to describe the overall material efficiency of a foundry in terms of cast metal is the Operational Material Efficiency (OME) expressed as the ratio between the amount of shipped casting over the amount of metal melt measured over a given amount of time [14].

5. Methods

The computer program presented in this work is written in modern Fortran language. Its work-flow starts from a textual input file containing a description of the plant. This information is parsed, categorised and stored into an internal, suitable data structure that is the key component of the tool allowing a flexible conversion of its content according to the final representation required. A modular architecture interfaces the tool with other packages for the final graphical representation of the information (Figure 2).

Currently, the tool interfaces with the open source graph visualisation software graphviz [15] to draw Process Flow Diagrams (PFDs). This feature will be used for the validation presented in Section 7. Work is undergoing to create an