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Reviewed Paper

Analysis of hybrid manufacturing systems based on additive manufacturing technology

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Abstract:
Along the last year, additive manufacturing technologies has been proving to be a real game changer in several market segments. Nevertheless, the main foundation of production and flexible manufacturing systems generally considers classical technologies. For that reason, the present work aim to propose and investigate manufacturing systems which includes additive manufacturing technologies as part of the main or secondary production flow. As result, it was identified that several marketing segments, types of components and different annual volumes tend to be better attended by hybrid flexible manufacturing systems which includes additive manufacturing technologies.

Key words: *Additive manufacturing, Flexible manufacturing Systems, Production*

1. INTRODUCTION

Along the last years, 3d printing technologies and additive manufacturing technologies have been playing a new role in the market in addition to generate relevant changes in different market segments (WELLER *et al.*, 2015; RAYNA e STRIUKOVA, 2016). In spite of that, theses technologies has majorly been handle as single machine cells because of extensive fabrication time in comparison with conventional manufacturing (JAIN e KUTHE, 2013; BAUMERS *et al.*, 2016; RAYNA e STRIUKOVA, 2016).

For that reason, this work main goal is to analyse an hybrid manufacturing system that is based on additive manufacturing technologies in order to compare with conventional manufacturing systems.

The Flexible Manufacturing System (FMS) can not the be considered a single technology, but a set of integrated and computer controlled technologies. According SLACK *et al.* (2009),the versatile of FMS provides a “capabilities package” of the system that involves the production of different products, without sequencing, without delay in the process configurations, volume production adjusted according to the demand. PANDEY *et al.* (2016) features FMS in machine flexibility, production flexibility, mix flexibility, product flexibility, routing flexibility, volume flexibility and expansion flexibility.

Technologies, including 3d printing and additive manufacturing technologies, allied to an FMS, results in meeting with balance a sustainable development model in the economic, environmental and social aspects that have been seeking since the end of the last century. As result, (RAYNA *et al.*, 2015; RAYNA e STRIUKOVA, 2016) exposes that additive manufacturing tends to generate new market segments and business models.

For this study, we analysed 2 cases in order to identify the effect of additive manufacturing on the total productivity metrics. In the first case, a conventional sand casting manufacturing system is exposed while the second case includes additive manufacturing technologies into the process flow.

In this work, we have also indicated where this hybrid manufacturing system is placed in volume-variety diagram, exposing the potential market segments that might be favoured by.

2. MATERIAL AND METHODS

In order to analyse the pros and cons between both of manufacturing systems, we defined a basic manufacturing layout in addition to the essential operation cost and time.

In Figure 1, the basic layout of sand casting manufacturing system is presented, where the main material and product flow is also highlighted. In this figure, patterns and core moulds are fabricated outside of plant by conventional methods generally in wood, aluminium and steel.

In this study, we considered this layout as the reference scenario (case 1), while the scenario that includes additive manufacturing to fabricate patterns inside manufacturing plant is the second study case. The application of additive manufacturing for patterns, cores has already been studied in several works, where the technical feasibility was evidenced (ROSOCHOWSKI e MATUSZAK, 2000; RAO *et al.*, 2003; CHEAH *et al.*, 2005; MALAGI *et al.*, 2014; RAYNA e STRIUKOVA, 2016).

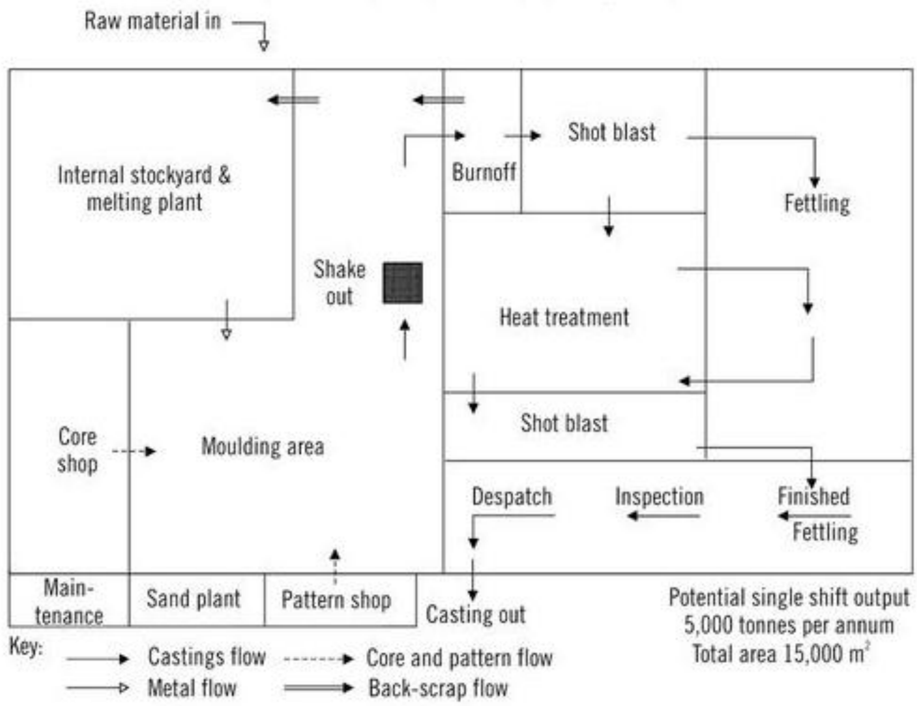

Figure 1 –Simple layout of sand casting manufacturing system

The difference between those study cases is presented in Figure 2, where the general workflow of job shop sand casting manufacturing system is exposed. Therefore, this study considers that this additive manufacturing application, which can also be considered rapid tooling, is going to be incorporated into manufacturing system .

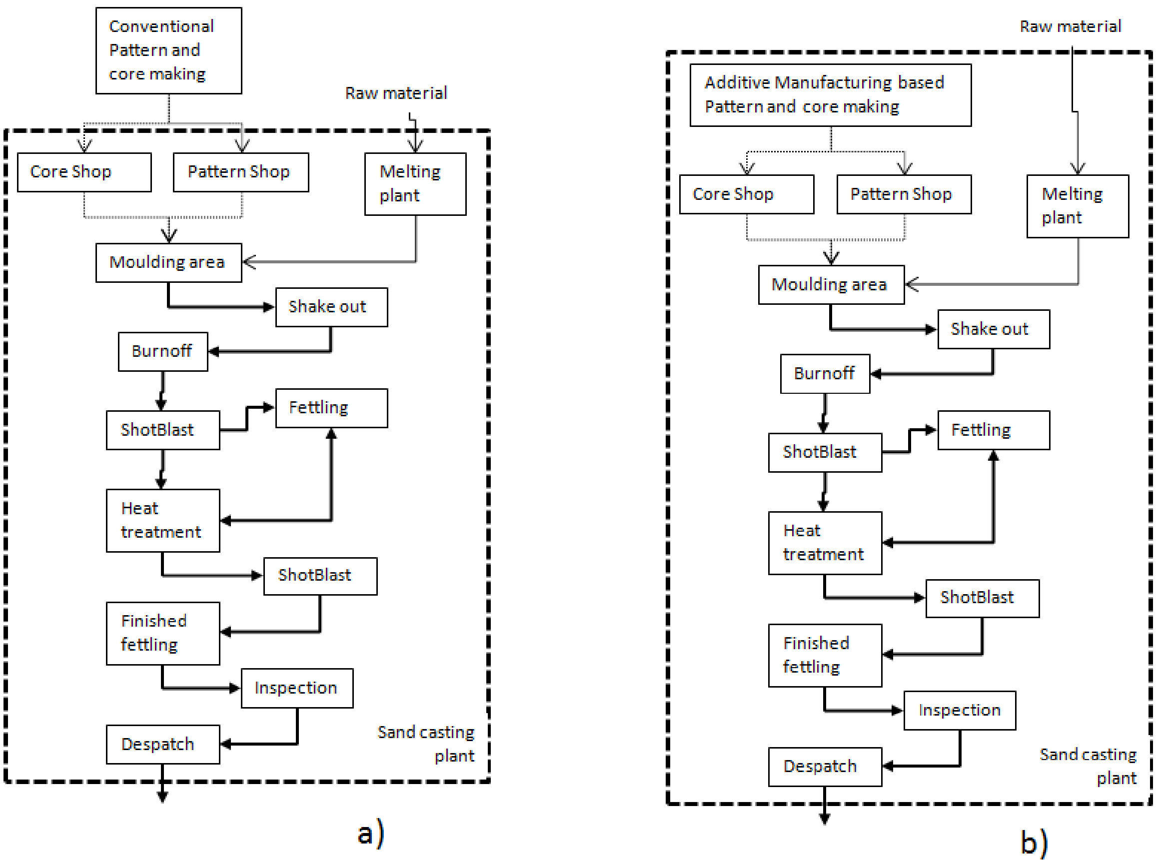

Figure 2 –Workflow of (a) conventional sand casting manufacturing system and (b) (a) hybrid sand casting manufacturing system

In order to compare both cases, we assumed that all processes remain constants apart from pattern and core making. In this situation, the variation of cost and time was majorly related to tooling fabrication and life-cycle.

With regards to tooling life-cycle, previous studies indicated the estimated number of parts that each sort of tooling support. For that, we analysed different types and shapes of patterns and compared against conventional and additive manufacturing based systems. In this case, patterns sizes varied from 100x100x50mm until 300x300x100mm. In Table 1, the average tool investment is presented besides average life-cycle.

Table 1 - Comparison between Tooling material and maximum supported number of parts Metal based on (ROSOCHOWSKI e MATUSZAK, 2000; SOARES, 2000)

Tooling type	Tool investment	life cycle
wood	1000	500
FDM - ABS	200	300
FDM with metal spray	500	600
aluminium composite	600	1500
Aluminium	5000	5000
Steel	10000	15000

Although some of values are extracted from previous works, further investigation is still needed to better understand the cost-life correlation.

As the tooling cost is considered a capital investment, the contribution of tooling for the part cost is amortised by the volume of parts which is fabricated. Therefore, the total tooling cost might be defined as a function of moulding tool cost ($C_{moulding\_tool}$), depreciation factor (f_d) and annual parts amount (N), as shown in (1) (REES, 1996; CHATAIN e DOBRACZYNSKI, 1997; FAGADE e KAZMER, 2000). In Addition, we included the cost of Additive manufacturing equipment (Am).

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$$C = \frac{C_{moulding\_tool}}{N} \cdot f_d \quad \textbf{(1)}$$

Therefore, the amortized product cost by product can be found by Eq. (2), where n is the number of products produced in the manufacturing system.

$$C = \sum_{i=1}^{n} \frac{C_{moulding\_tool_n}}{N_n} \cdot f_{d_n} \quad \textbf{(2)}$$

3. RESULTS AND DISCUSSIONS

In this study, we identified that although tooling that was fabricated by additive manufacturing technologies implies on reduced life, total cost was found to be lower than conventional tooling making. This can be seen in Figure 3, where a comparison between cost amortization against the number of fabricated parts is presented.

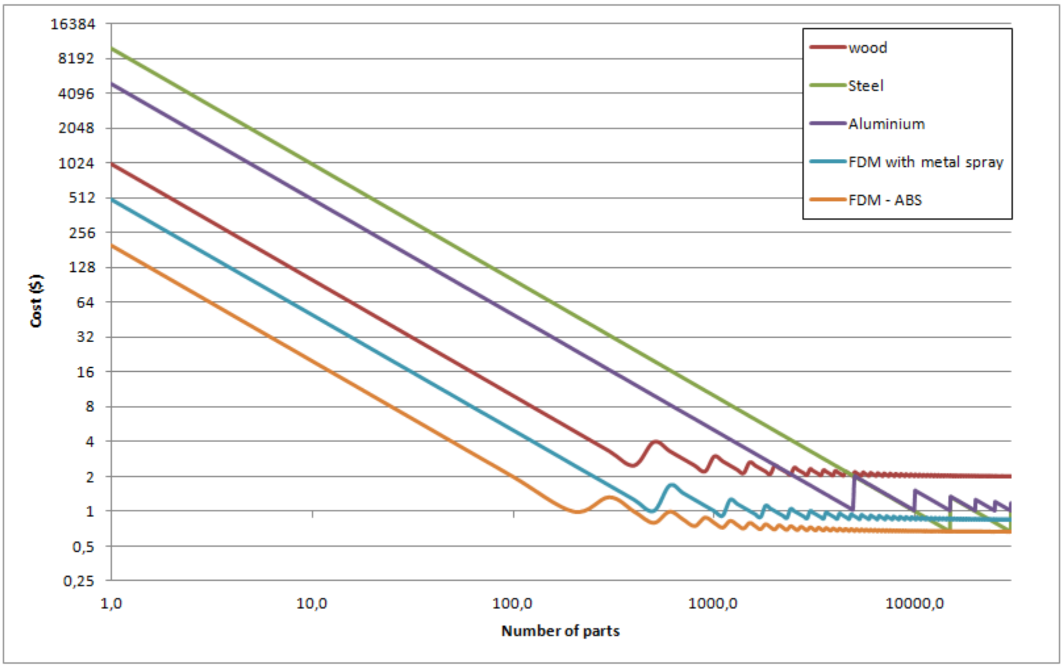

Figure 3 –Comparison between tooling fabricated by conventional and additive manufacturing technologies

On the other hand, Figure 5 compares the cost of 1 product conventional pattern making against 1, 2 and 5 products additive manufacturing pattern making. In this case, it is possible to see that amortized cost of 5 products tooling that were fabricated by additive manufacturing is still lower than conventional cost designated for only 1 product. In contrast, this behaviour can be observed for small and medium product volumes.

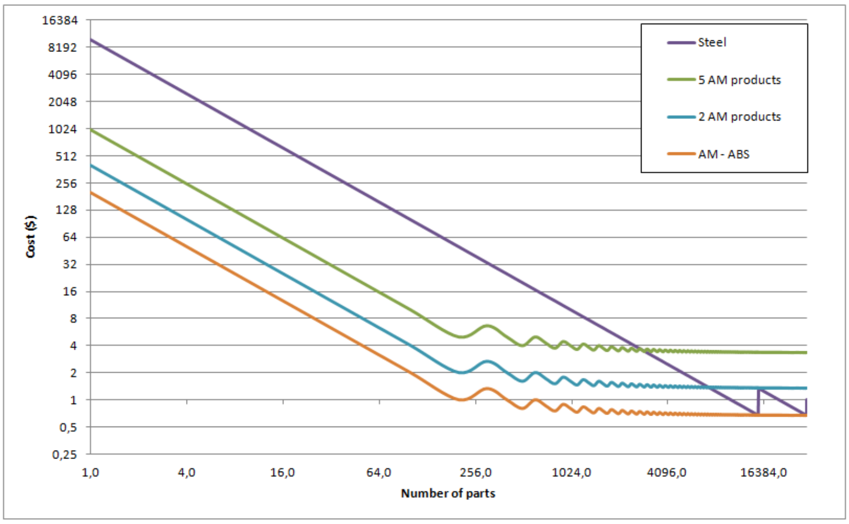

Figure 4 –Comparison between tooling fabricated by conventional and additive manufacturing technologies in accordance with the product variety

As result of this first analysis, we can identify a new manufacturing profile that implies in the constant tooling making. Therefore, each moment that a new tool is needed to be fabricated generates new opportunity to change part or product and increase variety. The main implication of this can be seen in Figure 5, where a comparison between conventional and hybrid manufacturing based in additive manufacturing is exposed.

Therefore, additive manufacturing was proof to attend either small and medium volumes with high variety or high volumes with low variety.

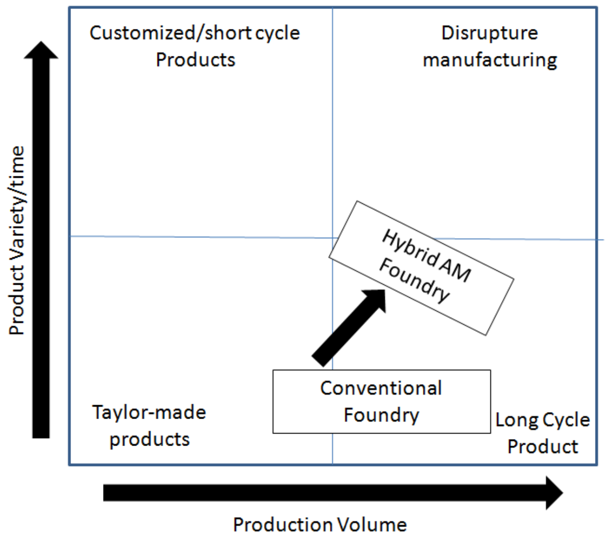

Figure 5 – Analysis of Product variety over the time against production volume

As consequence of this new approach, new economical models might be introduced and new opportunities can be exploited. At the same way, this new manufacturing approach also allows the growing of customer interference into design, whereas new product updates can be easily implemented during the product life.

4. CONCLUSIONS

As consequence of this work, the comparison of conventional and hybrid manufacturing systems which includes additive manufacturing technologies as part of process was analysed. In addition, the economical analysis of pattern making was performed and additive manufacturing tooling was identified as more profitable.

The analysis of variety was also done and additive manufacturing tooling making was found to generate higher variety than conventional tooling with the same cost.

Therefore, additive manufacturing was proof to attend either small and medium volumes with high variety or high volumes with low variety.

Additionally, this new manufacturing approach generates a new economical model that might be a game changer, whereas it increases the collaboration of customers into design, allowing high amount product updates and product changes during the product life cycle besides ensuring conventional manufacturing strategies.

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