The Digital Foundry: Building on the processes of today to meet the demand of tomorrow

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ABSTRACT

Investment casting foundries have been making high quality product for decades with the use of innovative techniques and engineering know-how. Many foundries have amassed tremendous expertise in designing efficient processes to produce superior castings, creating value for industries all over the world. However, there are many challenges the investment casting foundries of the future will face. Product complexity is growing, quality requirements are becoming more stringent, and customers are demanding lower cost product. Now and into the future, foundries that will compete in this space and remain profitable may need to invest in technology to aid in the continual improvement and optimization of their process and products. Businesses are leveraging the digital landscape to support this effort, increasing efficiencies using data driven decision making. In this paper, technology used in the digitalization and optimization of the investment foundry process will be reviewed and how data is used to drive decision making to reduce cost will be explored.

Introduction

The world around us is changing. Business leaders are forced to grapple with a future that will have dynamic market conditions riddled with uncertainty and risk. Changing customer demands, increase product complexity, and cost lowering campaigns will make producing castings in the future more challenging. Planning for these business conditions has motivated foundries to find new and innovative ways to reduce cost and increase their production efficiencies to eliminate waste and increase their agility. A fully digitalized business model is being aggressively pursued by some and is seen as an unavoidable necessity to maintain its competitive position. For others, using virtual models and data in a targeted way will also improve production performance. There are opportunities to move the foundry environment into the digital world while connecting information generated from value producing data across the entire organization. But before a digital conversion is discussed, we need to understand why this change might need to happen. What is driving this increase in complexity, quality, and speed?

The customer of the future

The pace of business is accelerating fast and delays are becoming increasingly more expensive. Staying ahead of competitors in a global economy that is becoming increasingly more demanding for investment casting customers. Technological innovation, environmental demands, globalization, along with dynamic and volatile market conditions have contributed to an increase in product complexity. Shortening product life cycles and speeding up time to market to have spurred rapid development periods that will get faster and faster. In addition, to be more competitive and profitable, customers want product at a lower cost to navigate and era of constant disruption. Therefore, understanding these trends and adapting to a changing landscape is imperative for investment casting business leaders to craft strategies to continue to be profitable in this space.

The foundry process as it exists today is getting faster, but it may not be responsive enough to meet future demand. Introduction of automation and 3D printed SLA/wax/shell into the investment casting process has provided some agility and flexibility that did not exist before. These technologies are getting better and faster, which will fuel their growth in the coming years. Reducing the need or eliminating hard tooling in some cases provides a cost advantages and speed. However, if we look further downstream, development times for new products can be a very long process. With quality requirements that are seemly impossible to meet and complex castings requiring sampling repeatedly just to get a clean casting, delivering high quality castings fast is hard. 3D printed technology can quickly become expensive when multiple prints are needed produce the castings required. “Getting it right the first time” has become even more necessary. Investment foundries have invested in technologies such as casting process simulation to help with this effort, moving the casting process to the virtual world. However, to respond to the ever changing future environment, going beyond simulation and into optimization and analyzing data to inform manufacturing decisions will be required. This is a first step towards a digital transformation.

Digital transformation

The future is now. Industry 4.0, Industrial Internet of Things (IIoT), digital twins and other buzz words have been floating around with the allure of futuristic mysticism around them. However, unlike some manufacturing trends, Industry 4.0 and IIoT has the potential to be disruptive to business as we know it today and change the landscape of how products are produced now and in the future. Business leaders are looking to invest in digitalization efforts in the present have the potential to see large gains in the future and maintain or improve their position in the marketplace. The heart of the revolution is not merely new technological advances, although 5G capabilities will unlock speeds that will aid in the growth of so called “smart factories” – but connectivity and data analytics. Connecting machines to the internet and connecting links in the value chain to each other is the fuel that will propel the rapid responsiveness that customers seek; creating feedback loops that will optimize processes to align business initiatives to customer’s needs at unprecedented speeds. It is this ability to optimize, to use information generated through virtual representation of physical objects (digital twins) and models from virtual simulations that informs production on how to improve on the process that exist today.

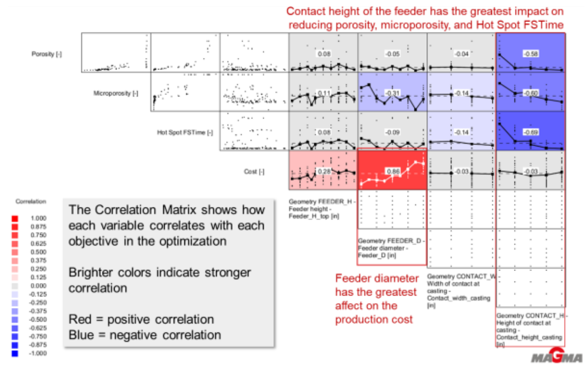
Taking a step back

Imagining the future business climate for the investment casting foundry and understanding the potential role that digitalization will play to compete in that space is useful for formulating strategy during the planning processes, but how exactly do would you get there? What can the investment casting foundry today do to ensure they are taking steps now to meet that future demand. That question is a difficult one to answer and will be unique to each foundry, however, there are clues on where to start with technology you may already have or in the process of procuring today.

There are many technological advancements that investment casting foundries of today are using to their advantage, robotic dipping machines and 3D printing chief among them, however, many processes remain manual and disconnected. Integration of technology with production will be the key to unlocking the full potential of production success. Many stages in the investment casting process that lends itself to increase efficiency, but there are some key questions that might be worth exploring. How am I using my existing technology today and how is it connected to the core processes in the foundry? What kind of data am I generating everyday throughout foundry operation and is that data being captured and used to better the process? Do I have optimization models in place to go beyond human intuition and increase performance more than I thought possible in the foundry? There are many areas of the foundry process to focus these questions on, however, a good place to start may be a place where the foundry would see the largest gains for the smallest investment. The core of the foundry business is making castings and so it seems reasonable to think that production is where these efforts should be targeted. Yet it is unknown if the foundry should invest in optimizing the shell building process or optimize how heats are scheduled and executed at the furnace. Although there are many opportunities for improvements, one could argue that the rigging designs for the investment castings would be an area of focus that would have an immense impact on the foundry’s bottom line. This is somewhat intuitive when you consider yield and how it relates to melt efficiency and material cost, reducing gate contacts and how it relates to lower labor requirement per job in the cleaning room, and scrap rates for its disruptive nature with numerous cost and margin shrinking potential. Many investment casting foundries have adopted technologies such as casting process simulation to aid in virtualizing the foundry process with hopes to address many of these inefficiencies. However, casting process simulation, known by some in its limited form of “solidification software” or “flow modeling,” is often disconnected from the process. Regularly it is used as a rigging tool, setting up one simulation at a time to design a solution that is often free of defects. Even though this method replaces the expensive process of running casting trials on the shop floor, the information is stored in silos, unleashed for a singular purpose instead of a piece of a larger picture. Instead of single simulations you need many, generating data that can be analyzed statistically to understand trends and gain insight into performance under and multitude of casting conditions. This data can then be used to increase casting efficiencies, improve casting quality, and drive down the casting cost.

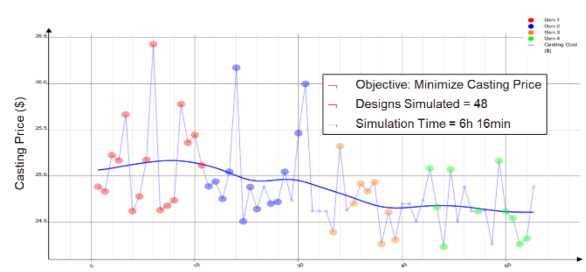
The power of data

Having access to large quantities of data has the potential to make production more efficient, increases productivity, and reduces waste. Uncovering how countless variables are interacting with each other and over time provides insight into the risk of failure and clues into increase efficiency for the production process. Yet on its own, data doesn’t really tell us anything. Having substantive reliable data is a great start, however, analytical tools are needed to make the data meaningful. Analysis tools such as a correlation matrix (Graph 4) for example, highlights the impact of each variable considered in the analysis against the objective set by an engineer. In this case, the analysis used multiple variables related to feeding the castings to determine how to achieve a sound casting free of porosity but maintain a lower production cost. The analysis revealed that the contact height had the greatest impact on casting soundness and that material could be removed from the feeding aid to reduce production cost.



Graph 1. *Correlation matrix showing impact of variables on objective*

Using more material to feed the casting in this case would have led to a quality casting. This conservative approach has its value in preventing casting defects that could lead to scrap castings. Nonetheless, the design is inefficient because there is an alternative design that can both produce a sound casting and reduce the amount of material needed to do so. Decisions like in this example directly effects the casting cost which may or may not be reflected in the casting price. Finding such opportunities to increase yield, decrease contact sizes, and reduce the overall cost to produce castings has a large financial benefit. Analytical tools and the algorithms that are used to generate value producing data combine to facilitate decision making leading to actionable steps to increase production performance by finding all such combination of parameters that exist for a given outcome providing an optimum result. Graph 2 shows an algorithm testing multiple design combination “finding” designs with the lowest casting price based on predefined objectives.

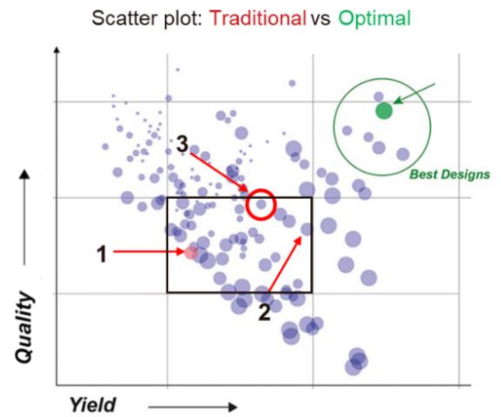


Graph 2. *Algorithm approaching an optimal solution*

Many decision are made in the foundry by highly skilled, trained individuals with impressive intuition, however, data has to ability to illuminate hidden insight and take us beyond intuition. A shift in focus is needed to include understanding how individual parameters effect casting cost during the rigging setup and how can data be leveraged to produce more efficient castings. A good place to focus this attention is on the sampling process itself.

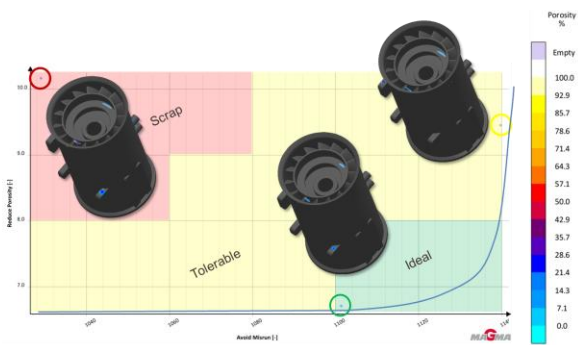
Sampling

How many parts being produced in the investment casting foundries today are setup to perfectly to run with no scrap, little post pour processing, and are at their maximum efficiency? Another way of stating this question might be, how many parts are produced at the lowest casting cost possible? Investment casting shells, generally speaking, are engineered with a focused on casting quality. On the other hand, an important factor is often overlooked during the setup; how much does it cost to manufacture that part? Typically an experienced rigging, tooling, or foundry engineer uses existing knowledge, a handful of calculations, and setups on similar product types if available to determine how many parts on should go on a tree, best gate locations, and so on. A sample is ran with the proposed design and results are evaluated. Often, the criteria used to determine if the design is "good" is based on the evaluation of casting defects. If the part is free of or has acceptable casting defects, then a production run is scheduled and larger lot sized is evaluated. If the initial sample results in casting defects that are not acceptable or lead to a scraped part(s), the rigging design or process conditions are slightly modified to address the issue. The design loop continues until acceptable parts are made and a production run can be scheduled. The second scenario described is more expensive than the first and can be very costly and time consuming to schedule and execute multiple casting trials to produce a good casting. However, the first scenario can also be costly. When a part comes out good, meaning free of or have acceptable/ repairable casting defects, there is no reason to change the design. It is a successful pour and will likely be produced that way for the life of the part. Yet how do you know for sure that the setup chosen is the best possible setup for that job? Does a better solution exist that will give you the same or better quality at a lower cost to produce? If such a design exists, it could either increase the profit margin for that product or open the possibility to compete on price while maintaining profitability. *Graph 3.* illustrates the sampling process. Each dot represents a different design that can be run in the foundry and is plotted with respect to quality and yield. During the sampling process, a few distinct iterations may be run to improve a design, but an optimal solution may never be reached because it needed "out of the box" thinking to achieve or simply more iterations considered. Once castings are acceptable, attention is shifted to other priorities.



Graph 3. *Optimal designs can sometimes lay outside the box*

Even after the sampling process has completed and acceptable castings are produced, problems can arise in production. Often, production conditions differ from sampling conditions. Since production operates under a range of conditions, no two castings are produced the exact same way. Process variability introduces another level of complexity to the process. Production challenges develop daily as quality engineers, production managers, and engineers alike have to put out fire after fire to keep the train on the track. The challenges are not unique to a particular investment casting foundry but pervasive across most and is considered part of making castings. Traditional thinking informs us that variability cannot be contained and thus efforts to attempt to circumvent it with preventative measures are not always adopted. And so a certain level of scrap, rework, and yield is accepted in the process. Yet moving the setup process to a digital environment has the ability to use the creativity and ingenuity of the user coupled with the power of large scale optimization and data analysis of the model to produce robust, reproducible castings that are more efficient than traditional methods, helping secure the foundries bottom line. For example, incorporating an analysis of varying shell temperatures, shell thicknesses, pouring temperatures, pouring rates, and other process parameters into the optimization efforts helps to understand the process window that leads to successful castings and to understand what might lead to a failure. Graph 4 illustrates that given the same tree design; the casting could fluctuate from ideal to tolerable to scrap with respect to porosity due to changes in pouring rate.



Graph 4. *Shows the effects of process variability on casting quality*

A robust, repeatable solution that is optimized in terms of quality and casting cost is the gold standard. It is expensive and, in some cases, impractical to get there on the shop floor. However, the digital landscape powered by optimization, analytics, and data offer a way to better lower-cost solutions.

Reality check

Having the ability to digitize the foundry process will not lead to increase efficiencies and revenues all on its own. Technologies such as casting process simulation and others must be paired with a business strategy that supports the efforts to increase foundry efficiency and to driving down internal cost by creating optimized feedback loops. It seems obvious yet worth stating that if these technologies aren't fully integrated with visibility at all levels of the organization, there will be challenges along the way. In addition, foundries are busy places. Trying to keep up with production demands and ship high quality goods to the customer on time while trying to run projects to put optimized systems and processes in place is a tall order. Staying the course will be a much simpler choice but could lead to being outpaced by the competition. Acting now will allow the investment casting foundry to work through some inevitable growing pains to end up in a better position to meet future demand.

Conclusion

The investment foundries of today work hard to produce high quality castings that meet their customers' demands day in and day out. Nevertheless, customers' demands are changing and will continue to increase in difficulty. Globalization, changing market conditions, and competition will drive more complex and innovative castings, higher quality requirements, and a need for the reduction in the cost of castings. Digitalization of the foundry process will support business efforts to compete in this dynamic environment by enabling an increase in production efficiency that will lead to lower cost fueled by optimizing the casting process.