Need of Automation in Investment Casting Industry Due to Major Defects Caused by Manual Operations (Case Study)

Nilesh P. Vanikar[1] Dr. Shantipal S. Ohol[2] Rajendra Anjikar[3]
[1]Research Scholar (Ph.D.) [2]Associate Professor [3]Managing Director
[1,2]College of Engineering, Pune, Maharashtra 411005 [3]Siddha Laxmi Engg. Inds. Pvt. Ltd. A-128 H Bl. Maharashtra - 411018

Abstract— Investment casting process is used worldwide to manufacture as cast precision castings specially for super alloy castings mainly for Aerospace and Automotive Industry. The process of investment castings is very complicated compared to other commonly used casting processes. Very crucial stages in this process are 1) first coat of zircon silica on pattern assembly and 2) Metal pouring in preheated shells. These two stages of the investment casting processes are usually performed manually in small scale Investment casting foundries causing defects which increase the cost of quality and scrap. This increases delivery lead time affecting profit gains. This scenario is typical for small scale investment casting foundries making small yet high production castings.

Key words: Defects, Manual Labour, Automation, Consistency, Precision, Cost of Quality, Reliability, Safety

I. INTRODUCTION

Investment casting process is widely used for highly precision as cast products mostly in Aerospace and Automotive industries. Process is also known as lost wax casting process. The investment casting process consists of making wax patterns, making wax tress, put first coat of zircon silica followed by back up coats of shell, de-waxing, preheat of shells and metal pouring followed by finishing processes as shown with conventional flow diagram of the process in Fig. 1. Shelling first coat of zircon shell and pouring molten metal /alloy are very crucial to the process. These are the origin for the defects in cast products. To achieve best results with this first coat and pouring most of the foundries are using various automation techniques, though for smaller manufacturers it is difficult to adapt these heavy and expensive available systems. Based on the high precision as cast products, investment casting is the most commonly used yet difficult to control process [7]. One of the process steps is shelling of wax pattern trees. This consists of initial coating of fine zircon slurry. This coating is important for surface quality and heat transfer properties in the process. To achieve optimum results with this shelling process uniform thickness in all intricacies of the wax trees is required. If this process is not consistent to the optimal set parameters various defects are found in final casting products.

Metal pouring is also a critical part of the investment casting process Multiple variables involved with pouring are, pouring temperature, pre heated shell temperature, metal flow consistency, time to fill the mold etc. This leads to high cost of quality due to rework, scrap increasing lead times [11] for delivery and reduced profits. These problems are worse with manually operated investment casting foundries. In this paper defects related to manual operations in first coat shelling and pouring are discussed. The defects are mainly generated due to inconsistency of the process due to human errors, safety issues etc.

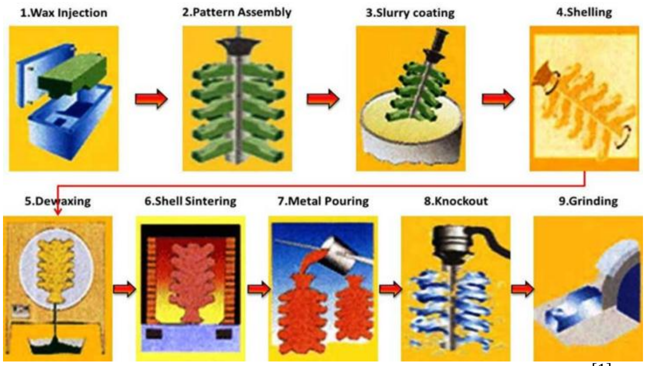

Fig. 1: Process Steps in Investment Casting Process [1]

II. RELATED DEFECTS

Inconsistency of first coat and stucco process plays a vital role leading to defects like, inclusions (Figures 2 and 3), rough surface dimensional discrepancies, fins caused by initiation of cracks etc.

Fig. 2 & 3: Examples of Inclusions [12]

Inconsistencies in pouring parameters lead to cold shuts (Figures 4 and 5), hot tears and flow lines. This can be reduced by standardizing and automating dipping process to get consistency in coat thickness and smooth wax adhering of zircon shelling and automated control of pouring and pouring temperature consistency.

Fig. 4 & 5: Examples of Cold Shut [12]

III. BACKGROUND

Even though large production investment casting foundries can afford programmable robotic arms or units it is not affordable for small scale foundries in the same business. Currently programmable robots arms are available with high payloads ranging from INR 10, 00,000 to INR 80,00,000 per unit. If some procedure is made to standardized simple mechanisms for lower payloads and cheap to manufacture, it will certainly be welcomed by smaller foundries. This can be used to cope with current setup of an individual foundry.

That way it will be less cumbersome to install. Defects for manually operated of these specific processes are shown for a typical small scale Indian investment casting foundry. The data is typical for same process for continuous 2 months. As seen in figures 2 and 3 the most direct scrap is due to inclusions and cold shuts. Reworked castings which are salvaged are not included in this data. Most of the rework is also done due to inclusions and cold shuts increasing cost of quality. Most of the inclusions occurring are due to shelling process. These inclusions are foreign materials and usually are silica particles.

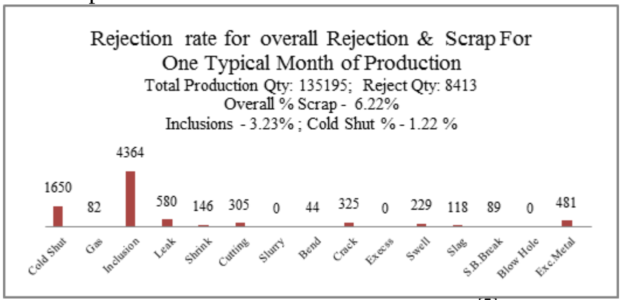

Fig. 6: Scrap data for one month [5]

Most of the cold shuts are due to variability of pouring temperatures preheat shell temperatures and poring process inconsistency.

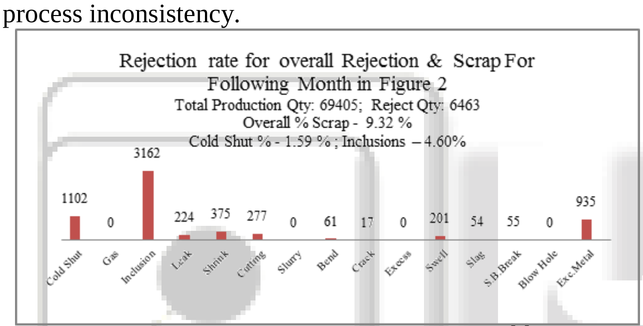

Fig. 7: Scrap data for next month: 2 [5]

Fig. 8: Manual dipping of 1st Coat [5]

If the initial coat is of consistent thickness with proper drying properties can be achieved, these inclusions can be reduced considerably. In typical foundry the dipping [10] operations for the first coat is done manually and is shown in the Figure 3. It can be a representative example for small foundries operating with manual labor operations. There is a need of simple design guidelines to design automatic or semi-automatic mechanism for these foundries. This facility casts around 11,000-13,000 castings per month and averages about 80-90 molds per day. This facility can adopt simple yet uncomplicated and cheap automation system performing same basic operations. These operations may consist of a manually operated dipping mechanism. It will make dipping angle, dip rotation speed, dripping operation consistent and constant. After this operation proper drying time is also important before putting on next shell coat.

Also, as shown in figures 6 and 7 is a general manual pouring process in an investment casting unit. Molten metal is poured from heating induction furnace is poured in poured in small ladle every time to pour in individual shell (Fig. 7). This operation is repeated for no. of shells to be poured. Molten temperature is controlled manually and visually after initial temperature is taken by pyrometer. This produces variation in pour temperature for every shell pour temperature from the same heat. Then during ladle pour to shell, it is poured manually and this produces inconsistency in pour angle, pour flow rate causing more temperature variation effect and mold fill pattern. If the metal meeting from opposite ends is t different temperatures these is a cold shut or cold cracks which are hard to rework and accepted by the customer.

Fig. 9: Manual Pouring into Ladle [5]

These variations causing these common but yet large quantity defects is a major challenge in front of small investment casting foundries. Other defects are also there but these two defects seem to be more common in these typical foundries.

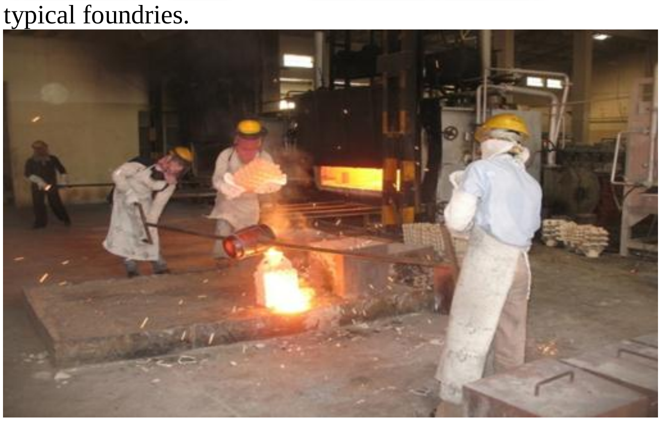

Fig. 10: Manual Pouring From Ladle to Mold

IV. EXISTING SCENARIO

Currently larger robot manufacturers are manufacturing robots with similar configuration of 4-6 d.o.f. robots for large scale heavy shell casting manufacturers. These require more space, more control and sophisticated robots. But for small manufacturers it is not possible to invest so much wait for the the payback. Therefore there is a need with minimum cost yet effective semi automated systems based on simple working principles. This will also give more accuracy and consistency for smaller wax trees. Defects generated due to inconsistency of first coat which in direct touch of poured molten metal between 1100 to 2000 Deg. C. can be reduced considerably. These defects even though now generally categorized as inclusions, they are sometime very hard to rework and also time consuming and most of the castings end up as total scrap at the end of the process. Bigger industries are using systems as shown in Fig. 8 for automated shelling removing inconsistency issues in shelling

Fig. 11: Kuka Industrial Robot [4]

Recently ABB also came up with a shelling solution for a large investment casting foundry in USA.

Similar systems for auto pouring are being used as shown in Fig. 9. These automated systems fill the shell continuously with consistent temperatures. These also have the same fill time for all shells. These systems also have preheating of the shells in the furnace like area where heat loss due to atmosphere is significantly reduced.

Fig. 12: Example of Automated Pouring [13]

V. Suggestions

As seen from the data at manually operated investment casting foundries, inclusions and cold shuts are the major defects. Reducing these defects effectively can be achieved with small scale standardized automation design using common rotational, linear, angular, swivel joints and links. Based on the current layout, quick modification is possible to get required quality with automation. Cost will be cheaper as standard material and Standard available parts can be used for assembly of automation unit. Further modification of system is easier as basic structure is flexible. This will increase overall quality of investments casting irrespective of size and scale of casting manufacturing units.

VI. Future Scope

Investigations for major defects in small investments castings manufactured by manual operations have shown that manual shelling and pouring are the main process steps. These produce major defects are inclusions and cold shuts respectively. There is a need of semi automated or automatic systems to be developed which are economical and easier to operate with existing small layouts for small manufacturing units.

If the available heavy structure for automation units is simplified to light and simplified semi automatic or fully automatic automation unit, it will be a rapid manufacturing process. It will reduce the cost because of selection of easily available components. This can be used as an economical automation practice in pouring or de-waxing areas in small capacity investment casting foundries. These small units can be adapted to individual parts line as per requirements. It will also simplify operational functions. Safety risks for operators due to high torque motors, momentum can be reduced.

VII. Conclusions

1) Investment casting process is well known for its quality for as cast products. It can also handle super alloys with high Nickel and Cobalt additions. It can also be used for titanium castings.
2) For foundries making small parts or specialty parts with limited quantity, cost effectiveness is necessary. Foundries using manual operations for shelling and pouring are facing a large impact of cost due direct scrap and rework cost i.e. Cost of Quality due to major defects as inclusion and cold shuts.
3) After studying the causes for these defects is seen that inconsistency of certain important parameters due to manual operations in investment casting units. To avoid these inconsistencies, larger automated systems are available and used by large investment casting foundries. Yet it is not possible for smaller foundries to afford these fully automatic systems not they have that much floor space and time to install these kind of heavy dusty automated systems. It is still then of importance to reduce these defects caused by manual operations liking dipping of shells and pouring. There needs to be more research done to come up with small and affordable systems for these important processes which re economical to manufacture and operate with existing process layout. This will bring down an overall Cost of the Quality all across the investment casting industry.

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