Simulation in Investment Casting Process – A Case Study

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ABSTRACT

Nowadays manufacturing sectors are emphasized on investment casting due to its wide versatility, integrity and higher range of dimensional accuracy.Therefore, it is very much suitable for aerospace industries, turbine blades, jewellery castings and many more industrial or scientific components.Product quality of investment casting is improved by using advanced technologies like rapid tooling, rapid prototyping as well as soft tooling like, 3D modeling and latest simulation software to make it time saving and cost effective. The present study deals with past research works on Investment Casting and their importance in the context of present foundry industry.The present study also describes the scenario of Investment Casting Foundriesat Howrah and Kolkata region.The benefits of using simulation software like AutoCAST and Z-Cast is shown here with the help of a case study on a stainless steel component which is casted by Investment casting process.

Keywords: *Investment casting, Wax, De-waxing, 3D Modeling, AutoCAST, Z-Cast.*

INTRODUCTION

Metal casting is the oldest primary manufacturing process as mankind has learnt to use liquid metal around ten millennia. Since about 4000 years, products (low melting point cast products) of "Dhokra Castings" were there in West Bengal. That time the traditional metal smiths were the Dhokra tribes. They used to produce knives, jewellery, arrows, spears etc. Since the material of disposal pattern is wax, it is also called lost-wax process[1]. In this process they used to produce intricate shapes with complex geometry. The dancing girl of bronze was found at Mohen-Jo-Daro (3000 B.C). In Harappan civilization, castings were made in sand or stone molds by pouring bronze[2].

Being one of the oldest casting techniques, Investment casting is used for manufacturing components having complex geometry, higher dimensional accuracy and excellent surface finish. It is generally used for making castings of near-net shape geometry, where machining is not feasible or uneconomical. During the ancient civilization it has been used to manufacture art castings,jewellery and weapons. Now the advancement of technology has transformed it as the most modern and versatile metal casting process. Technologists reengineered the lost-wax process as investment casting process by applying different pattern materials, pattern making mechanism and metal feeding system. The wax replica of the desired pattern is made by injecting wax into the metal die. A casting cluster is formed by attaching a number of patterns to a central wax-stick. Thus the tree is formed which is then dipped again and again into refractory slurry made of grained silica, water and binders to produce a fully hardened refractory shell. The wax pattern is then removed thermally or by steam autoclaving. Residual wax is removed by burning the shells into an oven. Now the refractory shell is ready to hold molten metal. Molten metal is poured through pouring cup or drawn up by vacuum. The casting is then allowed to get solidified. Now the ceramic mold is broken and the parts are cut from the tree to have a number of pieces of desired product[3].

Investment casting is a very expensive process, require very long production-cycle and not practically feasible for very high volume production. It has certain advantages; it can produce value-added products having intricate shapes with better surface finish and higher dimensional accuracy[4]. It can also cast certain unmachinable parts.

THE EARLIEST CASTING

India has a long-established custom of metal casting as the earliest castings were produced more than 5000 years ago.

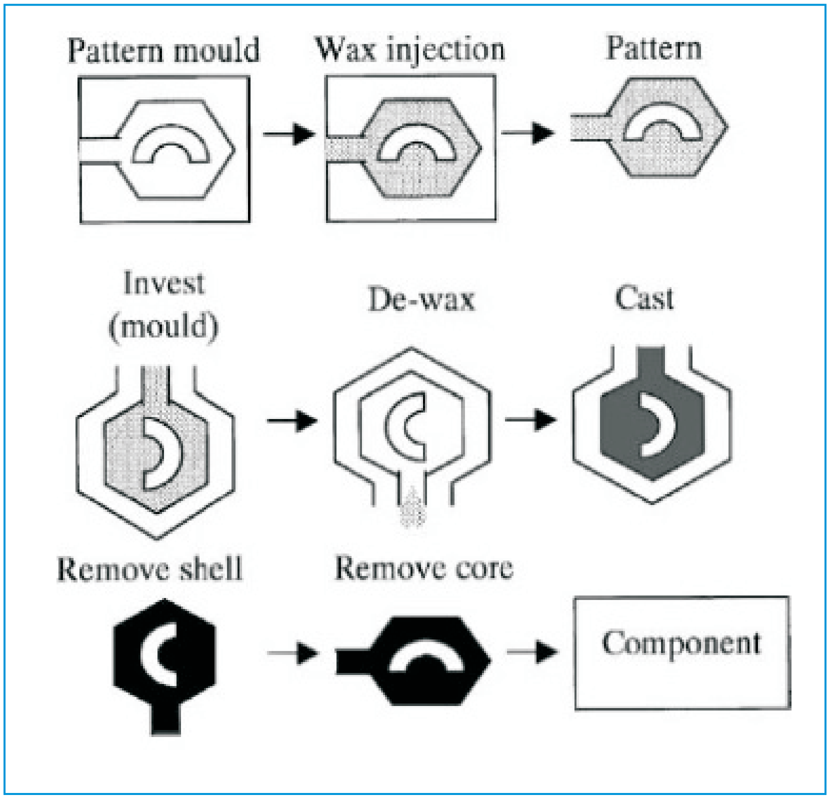


Fig. 1 : Basic principle of Investment casting process

The Chola bronze and Dhokra iron castings had made ancient Indian investment casting famous worldwide. At that time major application areas of this casting were idols for worship, daggers, hooks, bowls, pillars, nails, frames, utensils, weapons etc. of different materials like gold,copper, silver, lead, iron. The excavations at different part of India (Delhi, Ropar, Nashik, Indus valley) have confirmed these facts. Many districts all over India (Tirupati, Salem, Cuttack, Mayurbhaj, Bankura, Kolhapur, Mandi) are still practicing this lost-wax process[5].

At ancient time the mixture of natural resin, bee wax and little amount of cooking oil were used as the material of wax pattern. This mixture was then heated and poured into sheets to produce the desired wax pattern. This pattern was then placed into the clay mould which is made of fine river clay, cow dung, natural resin and gingillee oil. This mixture was followed by coarser clay. The models were then parched in sun for 2-4 weeks and then heated by cow dung cakes for melting out the wax. The mould was preheated.Metal charge was melted by crucible furnace and poured into the mould cavity through gates and risers. Then the final product was removed by chiseling with iron nails[6].

PRESENT INVESTMENT CASTING

The casting requirements of last decade have changed significantly due to the demand of market and technological push (CAD/CAM/CAE). The most widely used casting processes are die casting and sand casting. But they cannot meet all desired requirements (better appearance and competitive cost, zero or just finish machining, continuous design improvements with higher surface finish) of present industry. The lost-wax process can meet these requirements. This process was reinvented in 1940 by west and they have renamed it as Investment casting process.Modern investment casting process can provide higher dimensional accuracy (1 micron/mm) and best surface finish (1-2 micron) [5]. Here the manual crafting of wax pattern of ancient process is replaced by wax injection die. Several advanced technologies have been used in this process to achieve better results. Wax additives have been used to increase strength and fluidity whereas shell strength is improved by using fiber materials. Mould filling is improved by using new material and applying vacuum assisted gravity casting. Computer-aided-technologies, i.e. intelligent methoding (feeders and gating design), creating solid model (for multiple casting), rapid prototyping (for fabrication of wax pattern), are used for speeding up the process of pattern making[7].

SCENARIO OF HOWRAH CLUSTER

India has only 250 investment casting foundries while total foundries are more than 5000. Most of the Investment casting foundries are situated at Ahmedabad, Rajkot, Bhavnagar, Coimbatore and Belgaum as cluster. Being the sixth largest producer of automotive vehicle, India has huge possibility for investment casting. The Indian investment casting foundries used to produce pumps, machinery and industrial valve for automotive industries and also for cookware industries which have extensive scope.

Recently, a few foundries are coming up at Howrah and Kolkata cluster. Particularly at Gujrat the environmental conditions are in favor of Investment casting as the shells are getting dry in a shorter time compared to the foundries of eastern part of our country where de-humidification room is very essential. The demands of railways and automobile industries for Investment casting components are fulfilled by Rajkot and Coimbatore clusters.Therefore the primary investment cost for the foundries of Howrah cluster is little higher.

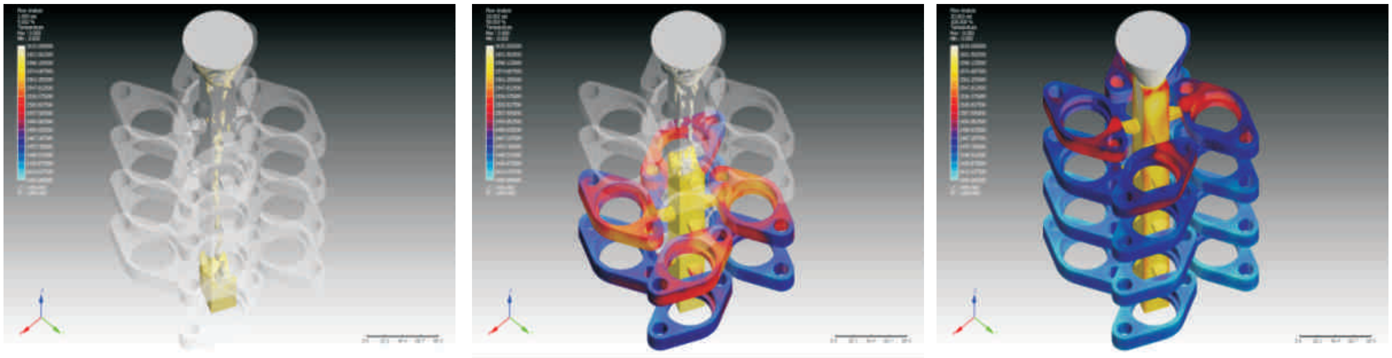
Howrah cluster is an important cluster of foundries for manufacturing cast iron parts. This cluster has around 200 registered and 300 unregistered cast iron foundries along with some cottage type non-ferrous foundries. These foundries used to produce 600,000 Ton cast iron annually[8]. But numbers of Investment casting foundries are very poor due to above mentioned causes. Now only 2-3 investment casting foundries are present at Howrah cluster and some existing foundries are trying to establish investment casting foundries mainly for railway components. One of them is situated at Sankrail Industrial Area. Initially it produces 10-15 Ton/month and in future they are planning to extend it up to 100 Ton/month.

SIMULATION OF INVESTMENT CAST PARTS

Casting simulation is a powerful tool of imitating original process with the help of a set of mathematical equations in a program just to anticipate the mold filling and solidification. Different defects such as porosity, cold shut and shrinkage cavity could be forecasted provided proper shop-floor inputs are being given to computer. Thus it is very helpful tool for developing the existing castings as well as new ones without or minimum shop-floor trials. Casting simulation in earlier step could figure out the defect prone zones which will help to take protective measures[9]. 3D CAD model of the casting part in STL format is the main input of the simulation and the output is animated visualization of mold filling, cooling to room temperature and solidification. Filling time, mold erosion, incomplete filling can be determined by mold filling option whereas cooling rate, temperature and gradients can be predicted from solidification simulation[10]. Some well-known casting simulation softwares are AutoCAST, Z-Cast, Pro-CAST, MAGMASoft, SolidCAST etc. For the present case study AutoCAST and Z-Cast is used for simulation and solidification analysis along with the mold filling analysis.

The de-waxed tree of a component of stainless steel is shown in Fig. 2. Taking pouring temperature 1615°C and pouring time 20 seconds, the first iteration of the simulation is performed. Fig. 3 shows different filling percentage of this flange. Shrinkage has been observed and the shrinkage condition is shown in Fig. 4.

Fig. 2 : De-waxed tree (Ready for pouring)



(a) (b) ©

Fig. 3(a) Begining of pouring at temperature 1615°C, 4(b) 50% filled, 4(c) 100% filled

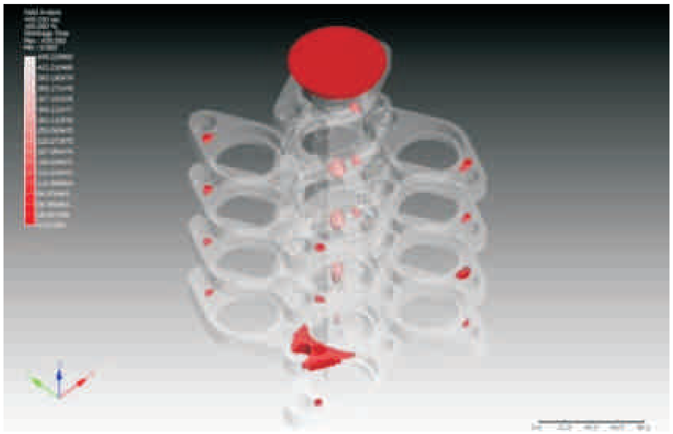


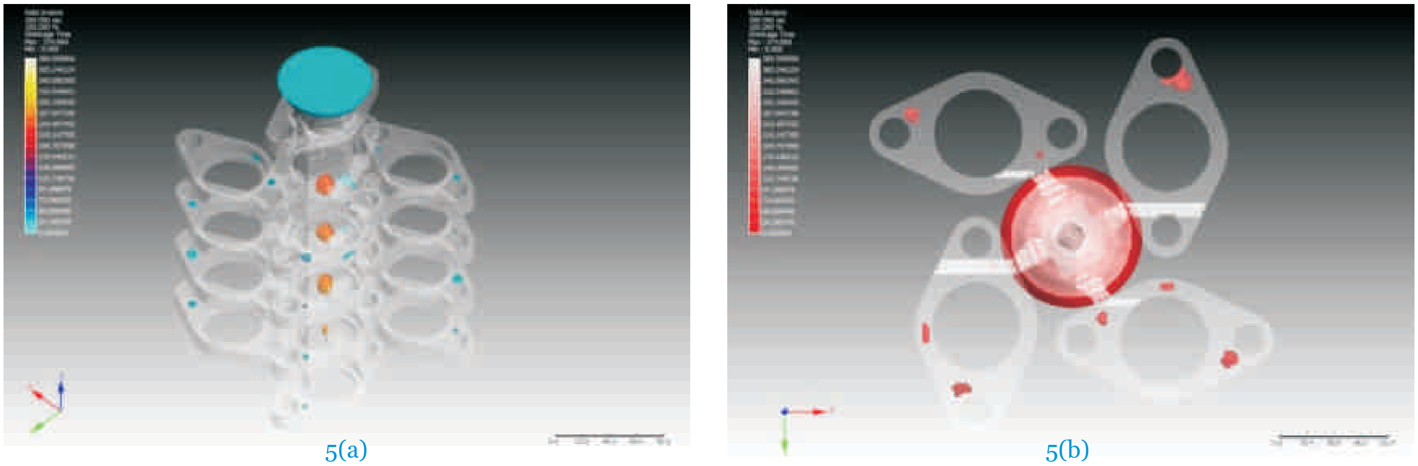
Fig. 4 Shrinkage after first iteration

For reducing the shrinkage a second iteration is needed. Fig 5(a), 5(b) shows different conditions of second iteration. Here the pouring temperature is reduced to 1550°C. It is seen that the size of shrinkage is reduced.

Again a third iteration is accomplishedby placing the components at an angle of 30° with the horizontal and the pouring temperature is about 1550°C whereas pre-heated temperature and shell thickness remains the same. This iteration is shown in Fig. 6(a) and 6(b). Fig. 6(b) shows that the shrinkage has reduced again.

Finally fourth iteration is carried out, where the pouring temperature has been reduced to 1520°C. Fig. 7(a) (b) shows the amount of shrinkages present after this iteration. From fig. 7(b), it can be concluded that the size of shrinkages has been reduced further.

Now taking the same conditions as the fourth iteration (Pouring temperature 1520°C and components are placed at an angle of 30° with the horizontal), the simulation is again performed in AutoCAST. The results are shown in Fig.8. This result is the same as the shop-floor experiment.



5(a) 5(b)

Fig. 5(a) Pouring at 1550°C, 5(b) Shrinkage after second iteration

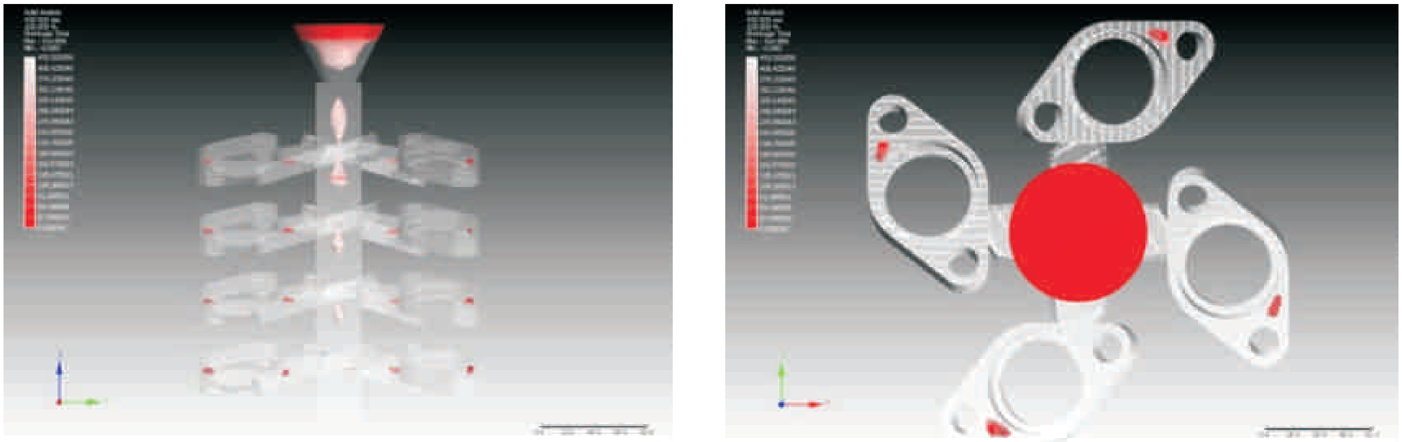


Fig. 6(a) Shrinkage after third iteration, 6(b) Top view of the shrinkage

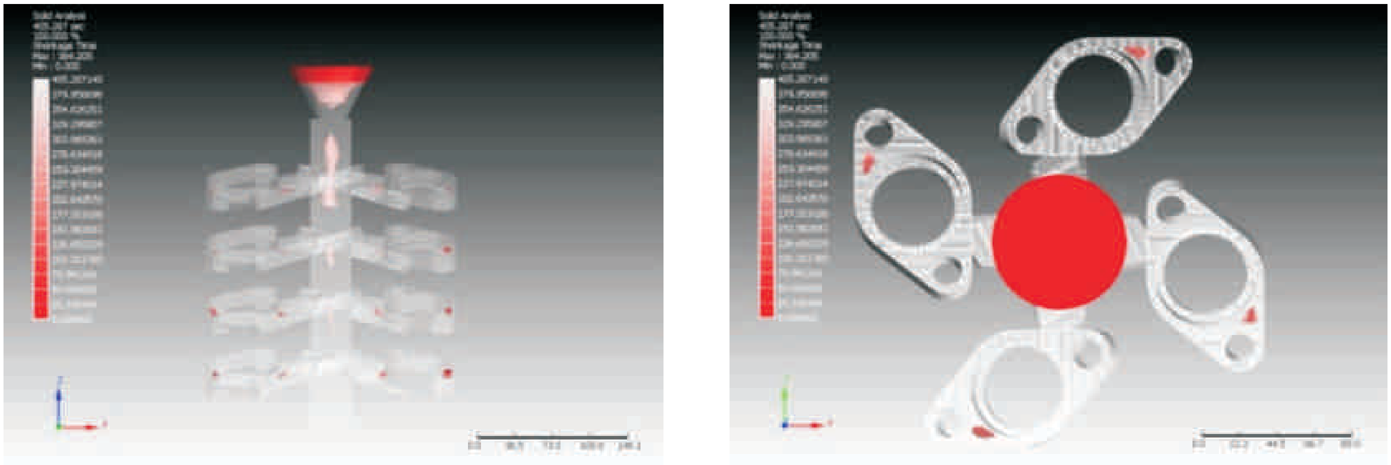


Fig. 7(a) Shrinkage after fourth iteration, (b) top view of the shrinkage

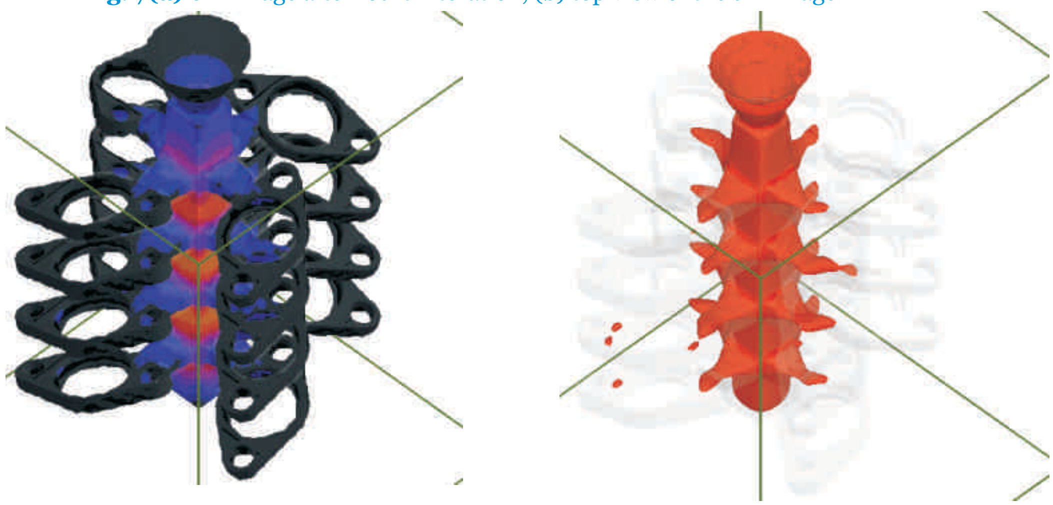


Fig.8(a) 100% filled part, **(b)** Shrinkages after simulation

CONCLUSION

The emerging demands of intricate and near net-shape castings in cookware, automobile and engineering components are increasing by leaps and bounds. Hence, computer aided simulation is essential to increase productivity and decrease lead-time. An attempt has been made to improve the quality and yield by computer aided simulation technique even in Investment casting without any foundry shop floor trials in a shortest possible way. By borrowing the ancient technology and using modern simulation technique investment casting is trying to fulfill customer's demand at very affordable price. The results of simulation are matching with the actual results. So it could be concluded that if the process variables like pouring temperature, shell thickness and pre-heating temperature of the shell are properly found in a systematic manner then better judgment could be taken at the shop floor level. It is expected that shop-floor foundry-men as well as academicians and researchers will get immense benefit from this paper.

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