Optimization of HPDC Process Using Flow Simulation – Case Studies

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Introduction

In 2006, CRP identified the need for an appropriate flow simulation tool to augment its expert team of design engineers for optimizing the high pressure die casting (HPDC) process. CRP undertook a detailed study, and through benchmark of various tools available, zeroed in on CFD software for its accuracy, flexibility, ease of use, computational speed and excellent support.

This article will highlight some of the case studies, where the flow simulation results helped in the HPDC optimization process in terms of the following:

- Optimization of runners and overflows
- Optimization of cost
- Porosity prediction and resolving/fixation of standards
- Porosity prediction and part design
- Optimization of die life
- Alternate designs

Case Studies

The following case studies explain the various approaches towards the application of flow simulations in HPDC process.

Case Study One: Optimization of Runners and Overflows

The die designer is constrained by the part design as it is an end-user requirement, over which he has very limited or no flexibility. Generally, the design of an HPDC die starts with part modeling, followed by the shot design. Runners and overflows are the two important aspects of the die design in general and shot design in particular. The other aspects include the part orientation, parting lines, draft angles, etc. These aspects of the shot design give ample flexibility for the designer to optimize the overall die design to achieve the end requirements of the part.

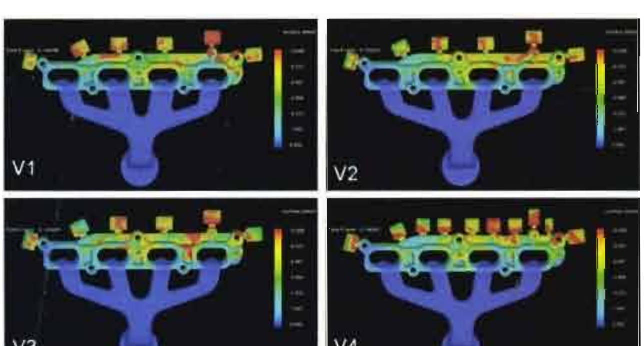

Figure 1 – Potential defects of the four versions.

This case study is a simple example of a methodical approach towards the optimization of runners and overflows of a die casting shot design of an engine part, which needs to be porosity free and leak proof.

Analysis of Results

The flow simulations for defect predictions were done initially for the shot design versions V1 and V2, with variations in the runners. Version V3 was developed to optimize the runner. Finally, the version V4 is developed by redistributing the six large overflows into 10 smaller overflows (Figure 1).

This has resulted in the optimization of capturing maximum defects into these overflows without any addition of shot weight. The parts were approved on first trial itself.

This is the reason for flow simulation being an integral part of the design process.

Key Benefits

- Optimum runner design
- Proper location of overflows
- Proper cavity filling
- Minimum surface defects
- Optimum flow characteristics (more laminar and less turbulent)
- First time OK parts

Case Study Two: Optimization of Cost

The present situation of global financial slowdown has added a tremendous pressure on the industry. Die casting fraternity, which was already in a considerable pressure to reduce costs due to high input costs viz., energy, raw materials, consumables, environment, etc., find the going very difficult to handle. It is high time to optimize the cost.

This case study is a simple example of minimizing the runners and overflows of a die casting shot design of an alternator bracket casting, thereby reducing the cost. Figure 2a shows the shot design before optimization. Figure 2b shows the optimized shot design after numerous iterations. The key aspects of this design can be appreciated by the following:

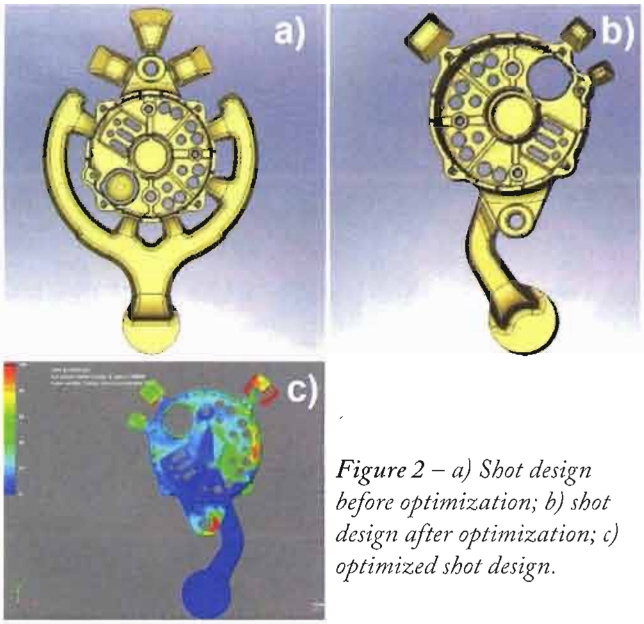

Figure 2 – a) Shot design before optimization; b) shot design after optimization; c) optimized shot design.

- Change of feeding to reduce the length of flow
- Three overflows of different sizes depending on the amount of potential defects
- Elimination of centre overflow altogether due to nil potential defects predicted near it

Analysis of Results

The flow simulation of the optimized design has predicted significantly very low potential defects, as shown in Figure 2c.

Key Benefits

- Projected area reduced by 46%
- Shot weight reduced by 26%
- Downsizing of machine from 250T to 150T

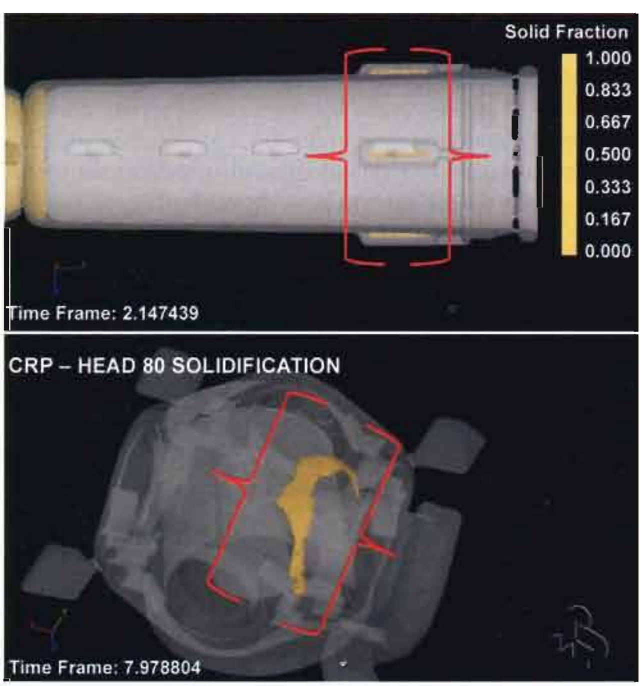

Figure 3 – Top, solidification result of a bowl indicating potential shrinkage porosity; bottom, solidification result of a head indicating potential shrinkage porosity.

- Proper filling
- Minimum surface defects
- Optimum flow characteristics
- First time OK parts
- Significant cost savings

Case Study Three: Porosity Prediction and Resolving/Fixation of Standards

Recently, a group of parts involving air filter heads and bowls were developed for high pressure pneumatic applications. The stringent specifications include design pressure exceeding 20 bar, leak testing pressure exceeding 30 bar, burst test pressure up to 150 bar and S1 porosity levels (as per ASTM E505), in addition to other requirements.

This case study is an example of an approach towards the application of flow and solidification simulations to correlate the location and inevitability of shrinkage porosity.

Analysis of Results

Flow analysis followed by solidification simulations were conducted for each and every part of the whole group.

The results are correlated with areas of thick wall sections, solidification results, radiography and cut-sections, as shown in Figure 3 and 4.

The correlation between the location and inevitability of the shrinkage porosity was well-established and shared with the customer. The new acceptance levels were established based on the simulation results and the trials.

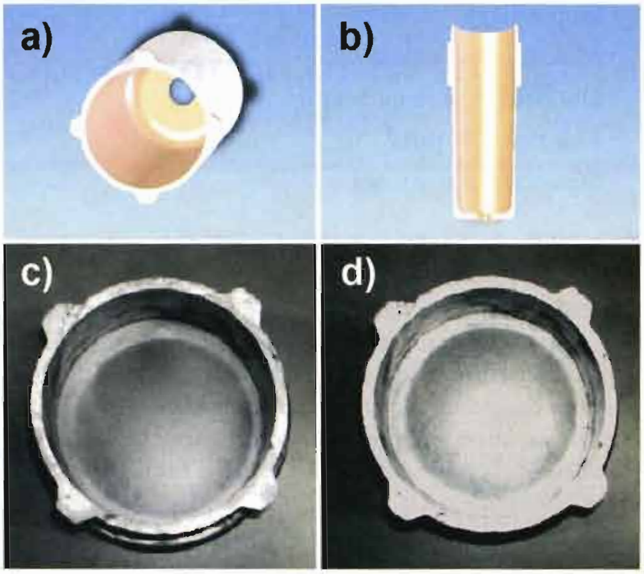

Figure 4 – a) & b) Section views of a bowl model showing significant wall thickness variations; c) & d) cut-sections of a bowl indicating shrinkage porosity.

ASTM E505 porosity level of acceptance relaxed to S3 without compromising any other requirements, including the test pressures.

Key Benefits

- Practical establishment of porosity levels
- Resolving the gap between the specification and actual
- Establishment of cut-section and radiography standards
- Enhancement of feasibility
- Shortened time to mass production
- Low rejections due to new standards
- No leaking parts, no burst test failure in mass production
- No customer complaints in supplies

Case Study Four: Porosity Prediction and Part Design

It is a common practice to make dies with interchangeable inserts and core pins to produce different variants from a same die to overcome the cost implications. This is more so in the case of low volume parts where die cost per piece is very high. This case study is an example of one such die for a part that needs to be free from external porosity.

There are two variants from the same die with part numbers 1200 and 1201. The center core pin is interchangeable between a diameter of 62 mm and 67 mm.

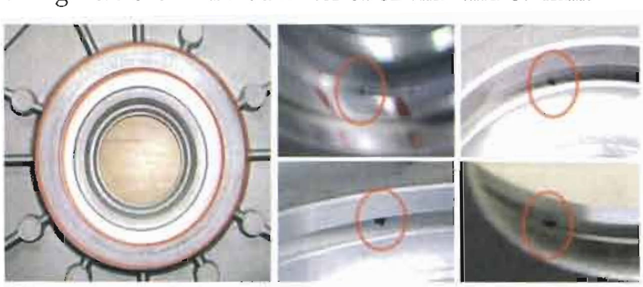

Figure 5 – Machining of bore in variant #1200 results in shrinkage pores of Level 4 exposed to surface in-between the circled area indicated in almost all the parts after machining.

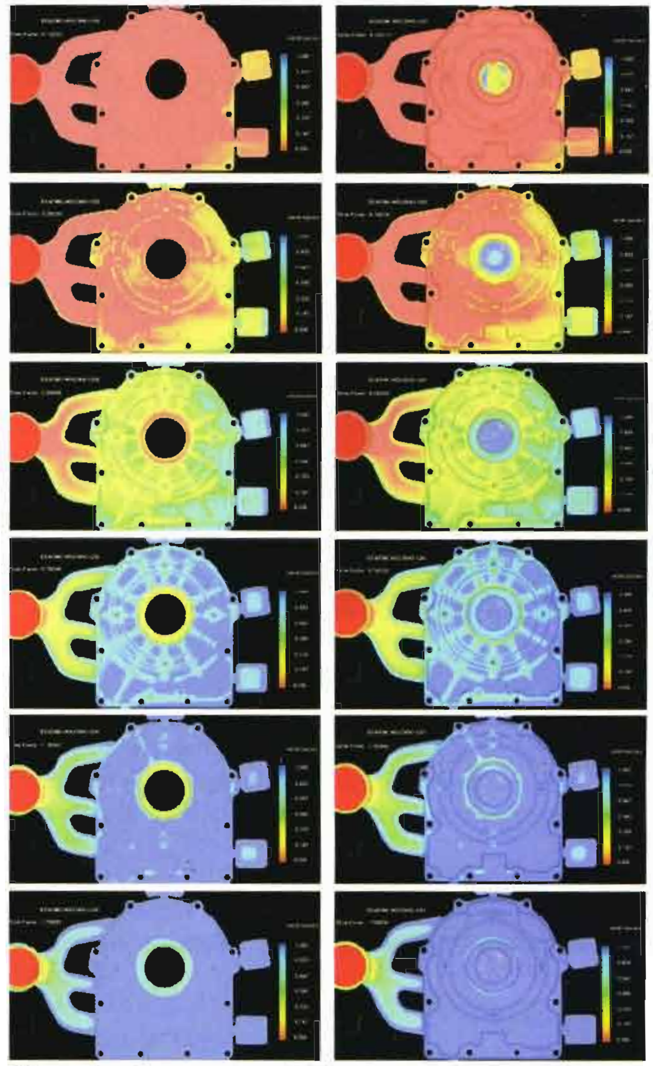

Figure 6 – Comparative solidification results at same time intervals – Left : 62Ø (#1200) Right : 67Ø (#1201).

Heavy blow holes are noticed in the variant #1200 in almost all the parts whereas the variant #1201 was free from any blow holes (Figure 5).

Analysis of Results

The comparative analysis of the solidification simulation at same time intervals as shown in Figure 6, clearly indicates that the variant #1200 is hotter near the core area as well as very slow in cooling, resulting in heavy blow holes.

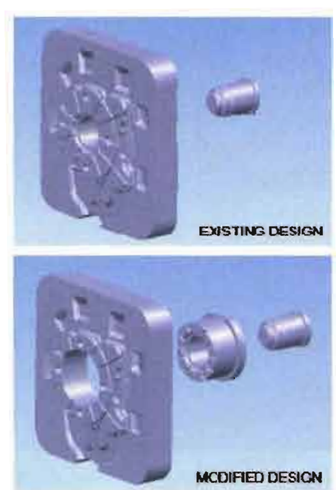

Figure 7 – Proposed suggestion for improvement.

Heavy shrinkage of Level 4 as per ASTM E505, noticed on variant #1200, because of higher wall thickness of 10 mm around 62 mm dia bore, in simulation, in radiographic inspection and after physical machining of the bore.

The variant #1201 is free from the blow holes at all times. Hence, the correlation is well-established between the blow holes and the wall thickness in the area. So, a proposal for redesign of the variant #1200 to maintain the wall thickness as per the variant #1201 is pending for customer approval (Figure 7). Earlier proposal of two separate dies has not been approved by the customer due to higher investment cost.

Key Benefits

- Blow holes will be totally eliminated.
- Uninterrupted supply
- Low additional investment
- Quick and easy to implement
- Increased die life

Case Study Five: Optimization of Die Life

Several instances of repeated failures of the die casting process resulted in high rejects, premature failure/short life of the die, etc., which are yet to be resolved.

This case study is an example of one such die for a part, a filter head of a fuel filtering system of an automobile. This part must be free from leak and external porosity in the machined area. Figure 8 shows an original shot along with an enlarged view of the part where there were heavy die erosions. These failures occurred in less than 20,000 shots. Several experimentations in terms of die material, heat treatments, shot parameters, metal temperature and cooling systems did not yield any improvement.

Heavy rejections due to blow holes in the 3x3 mm O-ring groove areas were also a perennial issue. This will be exposed only after the expensive machining operations were also completed.

The shot design change in terms of changing the metal feeding area was never contemplated. This is because of the collective and unanimous view of the team that feeding elsewhere from the original location would result in more failures. The reason for this opinion was the critical and thin groove areas. Since the die fails more frequently anyway, it was decided to experiment with the feeding system. Several versions of shot designs were developed and flow analyzed, including a version to increase the 3x3 groove area boss length as an alternate to overflows.

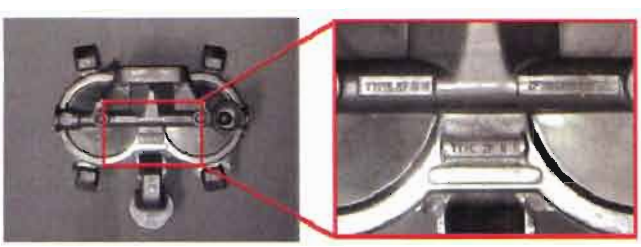

Figure 8 – Original shot with enlarged view of erosion area.

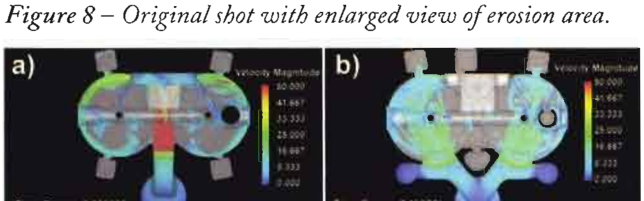

Figure 9 – a) Flow Simulation results of original design showing velocity >50 m/sec; b) Flow Simulation results of optimized design showing velocity <25 m/sec.

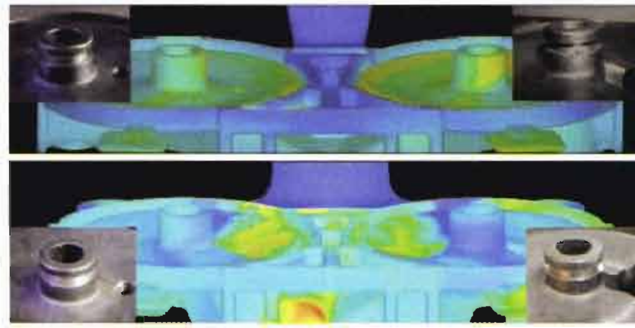

Figure 10 – Comparison of simulation results of original design (top) and optimized design (bottom).

Analysis of Results

The flow simulations for velocity profile and defect predictions were done. The velocity near the gate area of the original design was more than 50 m/sec, whereas it was reduced to less than 25 m/sec in the optimized design (Figure 9). This will result in significant reduction of die wear. The defect predictions of the original design as well as optimized design were correlated exactly with the actual data of blow holes in the 3x3 mm O-ring groove area (Figure 10). This has resulted in elimination of defects at the groove area.

The existing die was modified to convert into the new design. As the verification process is successfully completed, a new die is under development.

Key Benefits

- Velocity, die erosion and heat checks reduced
- Porosity in 3x3 mm groove almost eliminated
- Overall rejections reduced from >20 % to <2%
- Die life expected to be more through low wear and higher throughput
- Proper location of overflows
- Proper filling
- Minimum surface defects
- Optimum flow characteristics

Case Study Six: Alternate Designs

The die casting process is generally associated with dimensionally critical parts and focuses on the specifications. The aesthetical requirements are not exclusively defined and monitored. This results in unpredictable effect on the product quality and acceptance when it comes to the parts associated with good outward appearance, look and appeal.

This case study is an example of one such die for a part — a light dome of a luminary application. This part must be absolutely free from surface defects, die erosion, etc.

Figure 11 shows the comparison of a good and a bad part. The heat checks starts appearing in about 5,000 shots, and the die surface deteriorates very fast, resulting in lots of effort to finish the part by polishing, relishing etc. The die also needs a special attention every 2,000 shots, resulting in production stoppages.

Several measures are taken to overcome this issue by change of:

Figure 11 – Comparison of good (left) and bad (right) parts.

- die material
- heat treatment
- coatings on die surface
- cooling channels
- shot parameters
- alternate metal
- metal temperature

And, the problem still persisted. So, it was decided to study the process more closely to find out the root cause of the problem. As one of the measures, die temperature was monitored using an infrared thermometer. The thermal profile indicated a hot spot at the location which was prone to frequent failure.

Analysis of Results

A thermal die cycling simulation analysis was done to ascertain the reason for the hot spot. The results did not indicate any heat build-up due to continuous thermal cycling of the die even without cooling channels, effectively ruling out this as a cause of failure (Figure 12a).

While analyzing the velocity profile, the author tumbled upon the root cause of the failure. It was observed that the entire volume of the shot flows only through the failure area, leaving all the heat at that location. This explains the reason for the hot spot and failure (Figure 12b).

The heavy die erosion opposite to the gate area was also a worrying factor of this design. Hence, alternate shot designs were developed and flow analyzed to choose the optimum design.

Key Benefits

- Premature and frequent die failures eliminated
- Finishing operation minimized
- Aesthetics improved
- Production stoppages avoided
- No supply failures

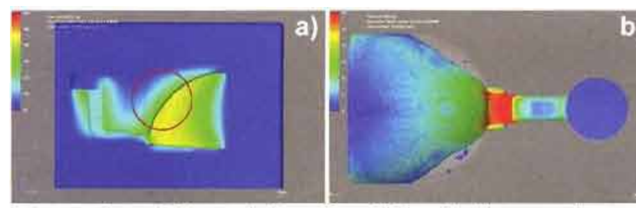

Figure 12 – a) Thermal die cycling did not indicate any hot spot at the heat check area; b) velocity profile indicates complete volume of shot flowing through the heat check area.

Conclusion

Technology is ever upgrading and die casting is no exception. To drive the technology, skill and expertise is essential. CRP was able to apply innovative use of technology coupled with effective application of experience to achieve efficient, swift and successful results. Flow simulations are definitely one of the effective means as far as die castings are concerned in terms of eliminating and pre-empting the wastages.

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About the Author

Adiyapatham Pari has a graduate degree in mechanical and production engineering, a post-graduate degree in plastics engineering and an advanced degree in management. He graduated in 1986 and held various technical positions in the plastic manufacturing industry. In 1989, he joined "The Southern Tools and Services," the parent company of CRP (India) Private Ltd., a leading high pressure die casting manufacturer, and he customized himself to the die casting industry. He is presently in management at CRP as a director, and his primary responsibility is technology development and implementation.