Review on State of Art and Techniques in High Pressure Die-Casting (HPDC)

Devaraj S Patil*[1], Veeresh G Balikai[2], Dr.I.G.Siddhalingeshwar[2]

Abstract— HPDC is one of the important sector in manufacturing industries,majorly in production of complicated geometries commonly used in automobile, aerospace and other service industries. The quality of HPDC products gradually increasing over the period of time due technological advancement in this sector. In spite of these development the casting products still exhibiting some surface defects, poor mechanical properties and porosity. Several researchers investigated reasons for poor quality of the casting products and optimized the process parameters to improve the product quality through optimization, simulation and experimentation. The process optimization done using DoE approach, ANN model and Genetic Algorithms and process simulation were carried out using existing computing tool like Procast, Autocast, MAGMASoft, SOLIDCast and InteCast. The present work reviewed the most relevant literature related to process optimization, simulation and experimentation.

Keywords— Defects, Experimental methods, HPDC, Optimization, Simulation.

1 INTRODUCTION

In recent years the High pressure die-casting process (HPDC) gaining prominence in almost all manufacturing industrial sector. However despite of rapid technological development in this sector,it is still experiencing major casting defects such as shrinkages and porosity caused due to input variants and methodology implemented. The casting defects that leads to poor quality of finished product and also encumbers the product life cycle. From many years several researchers carried out investigations on HPDC system in the view of process parameter optimization, defects elimination, porosity reduction in order to improve the quality and productivity of HPDC systems through simulations and experimentations.

For process parameter optimization the different types of optimization tool were used and they gave best results for optimized selected input parameter such as alloy composition, and selected process parameters namely fluid flow pattern, operating temperature in terms of mechanical properties and product quality.The selection of material for casting process requires many factors to produce a specific part. But the selection of the better material was very necessary because to get good quality product. There are many materials used for casting like magnesium, copper, zinc and lead, the most common material used for casting is aluminum. Aluminum doesn't have a high tensile strength but by adding other alloying elements the properties are increased. A few of the metals commonly used to make aluminum alloys include boron, copper, lithium, magnesium, manganese, silicon, tin, and zinc. The material were selected according to the product requirement. The casting process considerations are fluidity, resistance to hot tearing. Casting design considerations are draft, wall thickness and internal passages.Mechanical property requirements are strength and ductility, hardness, fatigue strength.Physical properties are electrical and thermal conductivity, specific gravity. The volume of production is also necessary because the cost of materials also matters when they are producing in a high quantity. The process must also be cost-effective.

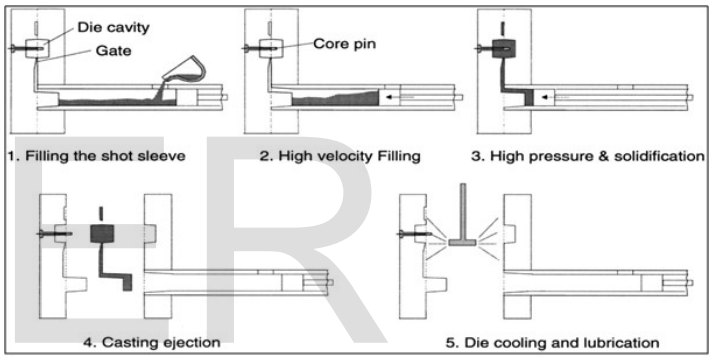


Fig.1 Schematic Diagram of test die and the steps involved in a High Pressure Die-Casting cycle.

The present work paper highlighted the reviews on literature related to different methods that causes casting defects and methods to minimize the defects analyzed by previous researcher through optimization, simulation and experimentations.

2 DEFECTS

Casting method or process is linked with several casting defects that debase the value or quality of casting product. To improve the productivity of the group the casting should be free of defects or very less. This paper shows the different literature review and what causes the casting defects that are taken by the some different expert's

[1] School of Mechanical Engineering, KLE Technological University, Hubli, India.

[2] School of Mechanical Engineering, KLE Technological University, Hubli, India.

devarajspatil456@gmail.com

In today's developing world the use of automobiles is rapidly increasing by day by day. The materials or components that are used should be of high strength and long durability. To achieve this component which are manufacturing or to be manufactured must have less defects in them. In casting the defects are common they are defined as those character that create a scarcity or imperfection to quality specifications imposed by design and service requirements. Even now the most of companies or industries rejection rate is high is up to 20% of the total number of casting produced. Because it reduces the total output and also the production cost increases.

- The different types of defects that occur in casting are:Surface defects, Internal defects, Incorrect chemical composition, Unsatisfactory
- mechanical properties
- Casting defects, factors that are responsible for them are:Swell, Fin, Gas Holes, Shrinkage cavity, Hot tear, Cold shut

The probable causes recommended by the experts are Mould moisture content ,Pouring velocity, Pouring time, Solidification time, Gate and runner and riser design, Mould permeability, Sand binder ratio, Poor venting.

[1] X.P. Niu (Chair.),2000, discussed the significance of vacuum assisted on HPDC. The experimental investigations on different types of specimens. The results showed that the hole sizes in the castings were drastically reduced in vacuum assisted HPDC system. The paper also highlighted that the mechanical properties strength and ductility of cast product were also improved.

[2] A.K.Dahle, 2001, discussed the reasons for formation or appearance of the bands in the components and optimize the process parameters the band formation in HPDC system. The tests results showed that aluminum rich segregation and porosity or combination both greatly influence on band formation. The defects could be minimized by lowering the gradients and die filling before solidification.

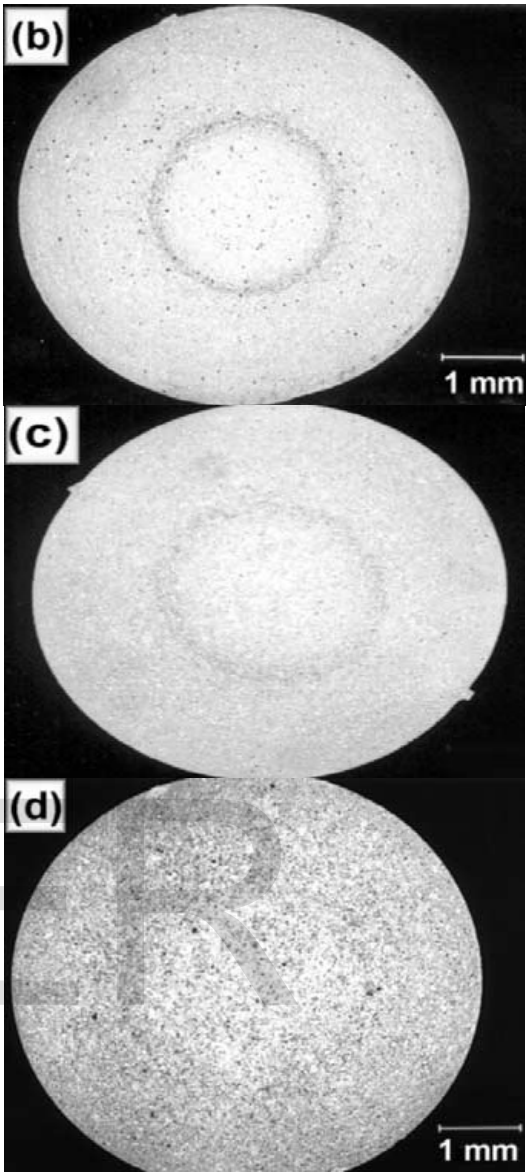
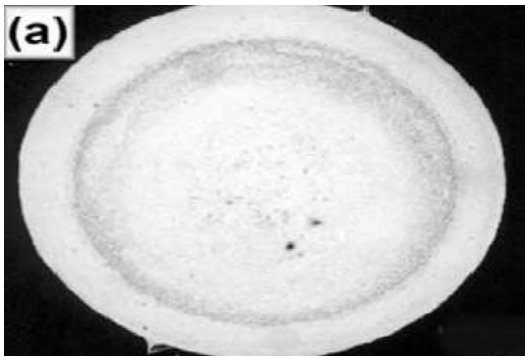


Fig.2 The band width increases from (a) to (d)



[3]S.Guliziaa,2001,summarized the results of experimentations on physical vapor deposited(PVD) coatings in HPDC. It was observed that the PVDcoating eliminated soldering that occurs in HPDC. The PVD acts as physical barrier for soldering and hence its was recommended to use good to use.

[4] H. Mayer,2003, investigated the effects of alloy compositionon porosity the fatigue limit. The experiments were carried out on different types of alloys of aluminum to know its strength and failure in maximum the fatigue crack. It was observed that the porosity was the major causes for crack formation. The crack was initiated even for small porosity, the crack start the fatigue in all the alloys up to certain limit but

[1] *School of Mechanical Engineering, KLE Technological University, Hubli, India.*

[2] *School of Mechanical Engineering, KLE Technological University, Hubli, India.*

devarajspatil456@gmail.com

failure does not occur. The fatigue limit was linked to significant stress intensity amplitude Kcr. The probability for failure at different stress amplitudes was determined by Kcr.

[5]S.G.Lee, 2005, discussed the mechanical properties of Mg alloy castings produced in HPDC. It was observed that ductility of casting was strongly dependent on area of porosity and it was varied with temperature.

[6] S. Otarawanna, 2009, studied the defects bands measured and grain size in HPDC for different types of alloys. The study highlighted that defect bands were caused due to strain localization in partly solidified alloys throughout HPDC.

[7]Wenlong Xiao, 2012, studied the casting defects in Mg-Zn-Al-RE alloys with different combinations of Al and Zn. It was noticed that the defects vary as combination changes and the hot tearing susceptibility changes as Zn increases upto sometime and then decreases. The yield strength was increaseddue presence of Al and Zn. The tensile strength and ductility depends on casting defect. It was concluded that The mechanical properties were increased by adding Al and Zn.

[8] Yasushi Iwata, 2012, investigated effects gas porosity in HPDC. The author indicated that the defects were minimized by optimizing compression behavior even though the entrap air or gas was opaque by high casting pressure during pressurization, finally remain in the castings as defects after solidification.

[9] Rajesh Rajkolhe, J. G. Khan (2014), conducted an organized study on casting defects and its remedies. It was observed that even in totally controlled procedure defects were observed in casting. The study gave root cause for casting defects which could help in analyzing the defects.

[10]R.Vinayagamoorthy, 2015, conducted experimentson reduction of defects in ring blank casting. The author studied the design parameter that affects the cold metal fault in the ring blank casting sand. The main three parameters are choke thickness, pouring basin and runner diameter for reducing cold metal defect. It was observed that thehigher levels sand inclusion, sand mismatch of pattern and increased in pouring base was difficult so it was only used in lower levels and cold metal defect which would reduce the cold metal defect.

[11]Liu Cao,2017 summarized on oxide inclusion defects in casting on walls. The paper highlighted that the oxide inclusion was common defect in casting they were difficult to observe in experimentally to accurately predict.The calculations were to be done the density of liquid metal temperature and the density of oxide inclusion. The boundary conditions were provided and by using the OpenFOAM software, the results were predicted and that were close to experimental results.

[12] Vaibhav Ingle,2017, studied different types of cold shut defects and their causes and remedies. It was observed that the defectwas formed due to the mixing of two different metals or improper fusing, lack of fluidity in metal design and improper gating design. The defects could be eliminated with good design and proper gating system and with proper control of fluidity.

Fig 3. Cold shut defect

[13] Ch. S., 2017, worked on temperature defects aroused in components like the optimum filling time, injection pressure and die temperature for improved solidification of the filling component are analyzed by taking the input parameters molten metal temperature, velocity at spreader, injection time and die temperature. Solidification analysis is done in Ansys CFD. The results were applied for practical method by this method we could avoid trial and error method practically in this way temperature defects are reduced.

[14] Rajesh Rajkolhe,2014, the author summarized the casting defects and to overcome those, the shrinkage was formed due to feed metal was not available to compensate for shrinkage as the metal solidifies. These were formed within the casting, isolated pools of liquid form inside solidified metal, which are called hot spots. The density of alloy in the molten state was less than its density in the solid state. Therefore, when an alloy changes phase from the molten state to the solid state, it always shrinks in size. To avoid this liquid metal under pressure continues to flow into voids as they form.

These are some of the defects which were found while doing casting. These defects make the components weaker and not reliable. The authors try to minimize the defects so to reduce the defects there must be early precautions or steps to be taken that were doing experimental methods on material, optimization must be done before doing practically and the simulation has to be done for the product to get better results.

[1] ***School of Mechanical Engineering, KLE Technological University, Hubli, India.***

[2] ***School of Mechanical Engineering, KLE Technological University, Hubli, India.***

devarajspatil456@gmail.com

3 EXPERIMENTAL METHODS

In the present day the casting is very rapidly growing process many industries are producing different types of components or products. The products which they are manufacturing or producing are used day to day life and these products should be used for long period of time, they should not break or unsatisfied to the customers.

So to make the products or components more strong or strength different types of materials are used and different kinds of alloys are used to make the products more reliable and the materials or alloys which were made each and every materials vary its mechanical properties so while choosing it all properties should be known. So to find out which has more strength or better quality different types of experiments are done each materials or alloys.

The experiments mainly finds out the materials or alloys has:

- Ductility
- Ultimate Tensile Strength
- Uniform elongation
- Fatigue properties
- Tensile properties etc….

After testing these it also experiments on surface quality detection and also the materials which are used later for casting should be defect free and there should be no porosity.

[16]S.G.Lee, 2005, the author done experiment on the HPDC the Mg alloy to discusses about the tensile ductility at room and higher temperatures. The results showed that the ductility decreases for the test temperature the ductility depends on the area of porosity which is done by power law equation.

[17]P.Cavaliere,2006, summarized the Mg alloy in HPDC as cast and heat treatment , friction stir processed are studied. At the initial the fatigue properties are noted down and after the heat treatment the fatigue properties were increased of the HPDC material.

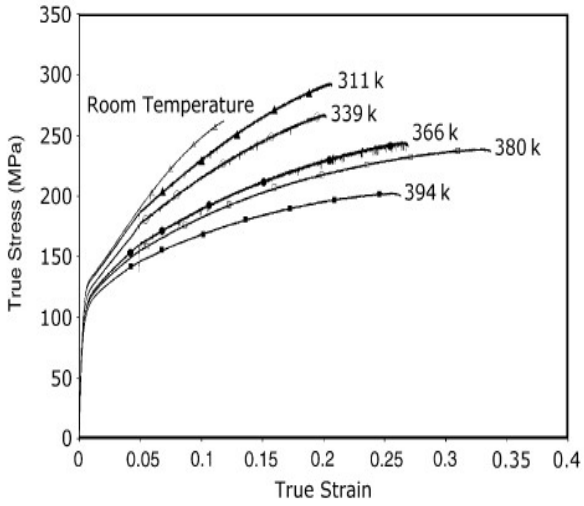


Fig. 4 true stress- strain curve at different temperature.

[18] J. L. Kirtley Jr,2007, the author examined a few of electromagnetic thought for achieving optimum efficiency with the rotor cage copper.The Matlab was used in this to calculate loss budget, high melting point of copper leads to difficult in casting speed/troque, current/speed curves are done and also frequency response also calculated and compared with Aluminium so it was also better to use copper at lower temperatures.

[19]Nan Xu,2016, indicated that using the cold source assistant stir processing helps to improve the mechanical properties of HPDC of mg alloy with using the nitrogen cooling caused the as improvement in grain refinement. The ultimate tensile strength and uniform elongation was increased by using cold source stir friction.

[20]Shouxun Ji,2017, developed a X-Ray computed tomographic investigation of HPDC to study the of porosity at different scanning resolutions. The experimental results showed that the porosity or holes depends on the voxel sizes. To get the clear image quality scan time, field of view should be taken into considerations.

[21]Wei Wang, 2018, studied the heat resistant HPDC of Mg alloy was investigated. The study indicated that presence of rare earths and temperature vary. And the stress was also considered as the main factor in this because of the heat resistant.

[22] M. Łągiewka, 2014, conducted experimentation on vacuum in High pressure die-casting to validate the published theoretical model results. The parameters are same the vacuum system was equipped with die-casting machine. The negative pressure was maintained in the die cavity and used

[1] *School of Mechanical Engineering, KLE Technological University, Hubli, India.*

[2] *School of Mechanical Engineering, KLE Technological University, Hubli, India.*

devarajspatil456@gmail.com

in experiment when the results arrived it was compared with the previous results it is found that smooth surface was exhibited by casting when the negative gauge pressure was used.After doing experimental methods we could find the material which we were going to use what kind of advantages and disadvantages are present so in which part of casting it could be used so that there wouldn't be many defects.

4 OPTIMIZATION METHODS

The High Pressure Die-casting is one of the best used to produce components or products in the automotive sector. To get the best products or components it should be manufactured properly without any faults or defects. And it should have great strength and durability and no problem should occur while using the product or component.

So to produce better quality of product the optimization should be done at the early stage so that we get to know what effects the components or what not so it is important to do.

The optimization mainly done on the design parameters like

- Filling temperature
- Metal temperature
- Piston velocity
- Injection velocity
- Up set pressure etc..

And for doing these optimization there are optimization tools which are available in the form of software and doing the optimization on the required methods we will get the better quality of the product.

The optimization tools are

- Taguchi method
- Artificial Neural Network(ANN)
- Design Of Experiment(DOE)
- Response surface methodology
- Genetic Algorithm (GA)

Using these tools we will get better quality of products. In subsequent section most relevant published results of simulation models developed using above discussed tools were discussed.

[23] Prasad K.D.V,1999, developed Artificial Intelligent Neural Network (ANN) model for die casting filling using MATLAB tool. The model was developed based on governing equations and casting data collected from industries. The model used four different algorithms such as error back-propagation algorithm, the momentum and adaptive learning algorithm, and Levenberg–Mrquardt approximation algorithm. The results showed that Levenberg–Mrquardt approximation algorithm exhibited best fit with experimental results with lowest sum-squared error as compared other models.

[24]G.P.Syrcos,2003, optimized the system performance parameters such as piston velocity (two stages), filling temperature, metal temperature and hydraulic pressure for casting density of aluminum die casting using Taguchi method. The results showed that the quality of casting density was better at optimized system parameters a compared to other conditions.

Parameters	Process	Range	Level 1	Level 2	Level 3
A	Melting Temp.	610-730	610	670	730
B	Piston vel. 1st	0.02-0.34	0.02	0.18	0.34
C	Piston vel. 2nd	1.2-3.8	1.2	2.5	3.8
D	Filling time	40-130	40	85	130
E	Hydraulic pressure	120-280	120	200	280

Table.1 Process Parameters.

[25] Der Ho Wu,2004, published work onoptimization of selected robust process parameters such as die temperature, cooling time and injection velocity were considered for study for magnesium alloy using Taguchi method. The Personal Data Assistant (PDA) computing tool was used to optimize the process parameters. It was indicated that PDA tool precisely optimized the process parameters and eliminated the wastage of experimental trial and error optimization.

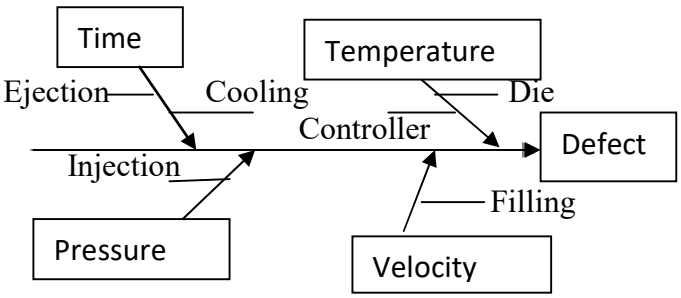


Fig.5 Cause-effect diagram of casting defects.

[26]G.O.Verran,2007, optimized the selected injection parameters such as upset pressure, slow shot and fast shot through Design of Experiment (DOE) approach. The best and worst results of DoE model were analyzed and best results were used in practical experiment for manufacturing components.

[1] *School of Mechanical Engineering, KLE Technological University, Hubli, India.*

[2] *School of Mechanical Engineering, KLE Technological University, Hubli, India.*

devarajspatil456@gmail.com

[27]V.D.Tsoukalas,2008, developed optimization model using multivariable linear regression (MVLR) and genetic algorithm (GA) methods to find the optimum solution and reduce or minimize the porosity in the Aluminium alloy. The furnace temperature, die temperature, plunger velocities in the first and second stage, and multiplied pressure were selected as process parameter. The results of optimization models were validated through experimentation designed based on taguchi method. It was observed that the results obtained by GA method had good agreement with experimental results as compared to MVLR method.

[28]Ko-Ta Chiang,2008, developed Response Surface Methodology (RSM)model for HPDCused for aluminum alloy to optimize the selected process parameters such as die temperature, injection pressure and cooling time. The results obtained were used in practical experiment. It was observed that the product produced based RSM approach shoed improved quality as compared to product produced through conventional approach.

[29] Jiang Zheng ,2009, determined the surface defects in HPDC components and optimized the selected process parameters such as mold temperature, injection velocity and pouring temperature using Artificial Neural Network(ANN) model. It was observed that the after optimization the surface defects significantly reduces and achieved high surface quality products.

[30]M. Arulraj,2017, discussed parametric optimization of squeeze cast using Taguchi method and genetic algorithm.The optimized results obtained through the model were practically implemented. It was observed that the impact strength was considerably improved at optimized condition.

[31] Mohammad B. NDALIMAN, 2007, described the effect of pouring temperature of aluminum alloys at different temperature and speed. Different type of experiments were conducted by varying temperature. The results showed that best surface finish was obtained from range of 680-700 °C. The alloys were free from internal defects when the pouring temperature was less than 730 °C. For both mechanical and quality property assessments, for aluminum best temperature range was between 700-750°C, and the speed was 2.0cm/s and 2.8cm/s.

For magnesium the pouring temperature is from 620-730◦C and for copper it is from 1150-1290◦C.

The optimization processes highlighted the values that should be used for the product to get better quality and less defects. There are different types of optimization methods all will give the best results. Depending on the components should be designed the tool can be selected.

5 SIMULATION

Casting simulation nowadays has become a dominant tool to imagine mould filling, cooling and solidification to expect the location of inner defects such as shrinkage porosity, sand inclusions, and cold shuts in the components. It can be used for correcting the problems existing castings, and also for developing new castings without any trial and error methods practically. It not only helps in identifying the defects but also gives the values at what rate feed should be there and what temperature solidification and cooling takes place. And by the simulation results there are many improved products. So it is better to do simulation at first before going out for practically.

Simulation is the procedure of doing a real experience using a bunch or set of mathematical equations or formulas implemented or presented in a computer program and work on it. Finding the best values or results is the main objective. And after the results are obtained it is used in practical application to get better quality and improved products.

The main process involved in the simulation are first casting geometry has to be made what kind of design or geometry looking to get final and after that what kind of material is to be used which kind of materials suits best or the mixture of materials and then the simulation or process like the parameters temperature, flow velocity, mould temperature, cooling temperature, solidification etc.

- Design or Casting geometry
- Materials
- Process involved
  - The different types of simulation software's are
- AutoCAST
- MAGMASoft
- ProCAST
- SOLIDCast
- InteCast

These are some main software's used more often and they predict the same when compared or done in practical. Each software works differently the results may slight vary one should choose a best software for his product which he is going to use.

[32]Joseph HA,1999, discussed the application of Smoothed Particle Hydrodynamics(SPH) and Magma software tool for die filling in gravity die casting. The results of SPH were used in experimentation and simulation. The simulation results are also helped in capturing fine detail on free surface motion and also hurdles in surfaces. Magma software predicts the level of fluid slightly better than SPH.

[33] F. Scheppe,2002, summarized on the investment casting which was carried out in low SiO2 content. The low SiO_2 in the casting withstand high pouring temperature and also cooling

[1] *School of Mechanical Engineering, KLE Technological University, Hubli, India.*

[2] *School of Mechanical Engineering, KLE Technological University, Hubli, India.*

devarajspatil456@gmail.com

temperature and gave better yield rate and avoid crack. The parameters high mold temperature and low cooling rate are used in Magma software which was used for simulation. The results were obtained crack free or minimum porosity parts. The numerical simulation was done for mold-filling, thermal-stress development and solidification. The software was also helpsto figure out the stress generation parts.

[34] Shuhua Yue,2003, discussed the concept of Concurrent Engineering (CE), CAD/CAE/CAM integrated system established, applied in the primary stage of casting. The platform of CAD/CAM software and MAGMASOFT simulation software was also considered. The integrated system was applied for both Al and Mg alloys, such as the water pump. It was observed that use of this type of system integration could shorten the cycle of die design and manufacture and also results in the production of high quality die castings is a shorter time. The lead-time also of die castings was also shortened.

[35] Yeh-Liang Hsu,2005, described the casting simulation software ProCAST, which was commonly used for simulating the casting process of Al wheels by local producer. The simulation procedure was recognized to simulate the temperature distribution of mould in the real casting process. The Shrinkage Index(SI) was defined to describe the level of casting in shrinkage from casting simulation. The results exhibited the best fit with the leakage test results of 5 different wheels, the SI showed good connection with the Al wheel leakage test results. The effects of the cooling parameters, geometry of mould cavity on Shrinkage Index also discussed as part of the study. The leakage ratio to produce a new wheel was predicted using SI.

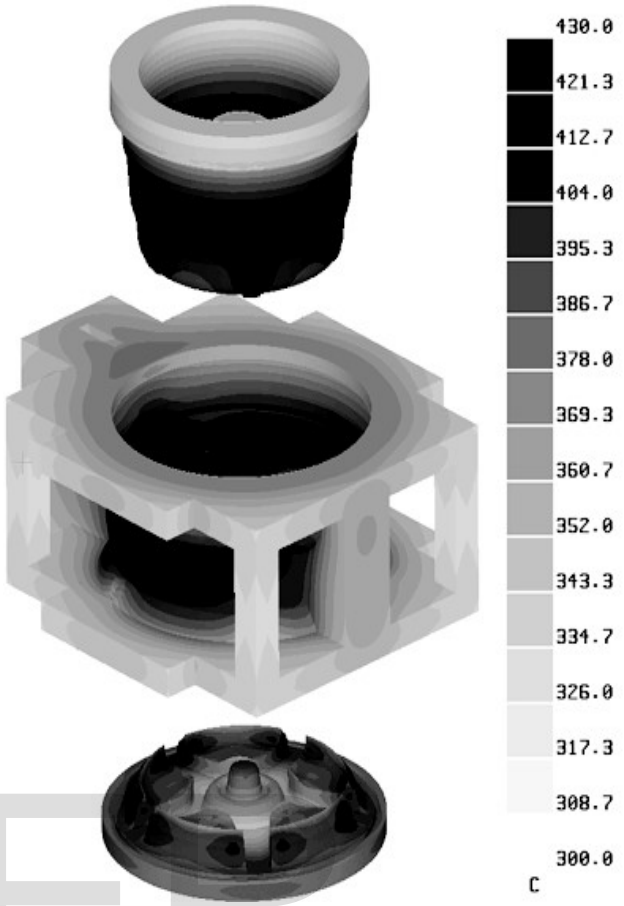


Fig. 6 Temperature distributions of mould during the casting process.

[36] A. Krimpenis et al. (2006), developed artificial neural network (ANN) simulation model to optimize the process parameters of pressure die casting. The ANN model used gate velocity, mould temperature as input parameter and filling time, solidification time, defects as a targets. The target values used in the model were based on the experimental results designed through DOE approach and conducted using simulation software. The results of ANN model were fitted in fitness function of genetic algorithm, which would relate the combination of input variable and target values at the optimized condition

[37]E.Aghion,2007, analyzed different types of magnesium alloys for HPDC and developed new alloy. The tests were carried out in High Pressure Die-casting (HPDC). The simulation software used was Magma software and actual measurements of mechanical properties were given for both the material to obtain the mechanical properties. The materials were studied for wall thickness of specimens and their porosity level.

[1] ***School of Mechanical Engineering, KLE Technological University, Hubli, India.***

[2] ***School of Mechanical Engineering, KLE Technological University, Hubli, India.***

devarajspatil456@gmail.com

[38] Guofa MI,2008, developed simulation model using Z-cast software based on temperature variation at specific positions to eliminate shrinkage. Olympus metallurgical microscope was used for macrostructure of casting and freezing mechanism. The simulated results were compared with practical pouring test. The results showed that for effective feeding the preheat temperature of mould should be low and pouring temperature should be high. The software filling and solidification process of Al alloy gravity casting provide exact flow and temperature positions and also the defects.

[39] Nagnath U. Kakde,2012, discussed rapid prototyping and investment casting methods used for customized product. In casting product advancement, design was important in process purpose, tooling design, product assurance, casting system, and control. The use of simulation software, was an efficient approach in giving design details to casting product design. With fused deposition modeling (FDM) patterns, investment casting was low volume production applications. Making investment casting deigns out of ABS resources saves both time and money on low volume manufacture applications and also tooling in investment casting. This technique was used to get better products.

[40] C. M. Choudhari,2015, conducted experiments on sand casting through computer simulation. The simulation mainly deals with the fluid flow during mould filling and optimization of parameters and solidification. It also help in locating or predicting the defects or shrinkage porosity or gas porosity. The simulation software being used in this wasAutoCast software. With the help of this software it was reliable and helped in predicting defects and also in locating defects.

[41] Zhou Jianxin,2016,introduced a numerical software called InteCast and it also had numerical solution method both are compared for some part they alsoused simulation software FDM integrated of FEM/FDM. The three parts which they had worked on are optimizing the riser, the fluid flow sequence, ductile cast iron is analyzed and it also helps in identifying the porosity and slag defects occurring while mould filling.

[42] M D Ibrahim,2017, studied the effect of design alteration of mold in die casting to improve the manufacturing or production rate. The simulation software used to study the flow of molten metal in mold wascomputer flow simulation. The design parameters also taken into consideration like injection speed, clamping force and die temperature. The results obtained from simulation showed significant improvement in molten metal flow in casting and defects are optimized.

[43] Maria José Marques, detailed about the simulation software ProCast usedin in gating system.The moulding changes are done that reduced the weight of the component from 59kg to 46kg without effecting the quality of the product and yield of the component also increased the dimension of the component also reduced without effecting the quality.

This is last part of casting before doing practically the simulation has to be done so that we will get to know best and worst parts of components. And we can overcome those worst parts by changing the values and there will not be any material wasted. By different authors review we can conclude that the practical results are same has simulation results. So that defects can be reduced by doing simulation.

6 CONCLUSION

Casting defects is very serious effect for the manufacturing industry. For better quality all kind of defects should be minimized or free of defects. In present paper different types review of researchers have explained or discussed regarding to the casting defects how it is affected and how it should be minimized. In the same manner to get the better or reliable or more durable products the optimization methods should be used it gives the better values for the design parameters should be applied to the product. For the product to be high in strength or strong the experimental methods should be done so to get the better quality of products. The mechanical properties will be increased of the product. Computer simulation in the casting is highly established method because it saves time and energy and gives accurate results of the product or component to be manufactured. It also says at where the effect is minimum or maximum it shows a exact location in the component or product. By using simulation techniques we can avoid trial and error methods and we will get the best output. So at finally to get the best component or product this all techniques should be applied while doing casting.

[1] *School of Mechanical Engineering, KLE Technological University, Hubli, India.*

[2] *School of Mechanical Engineering, KLE Technological University, Hubli, India.*

devarajspatil456@gmail.com

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[1] School of Mechanical Engineering, KLE Technological University, Hubli, India.

[2] School of Mechanical Engineering, KLE Technological University, Hubli, India.

devarajspatil456@gmail.com

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IJSER

[1] ***School of Mechanical Engineering, KLE Technological University, Hubli, India.***

[2] ***School of Mechanical Engineering, KLE Technological University, Hubli, India.***

devarajspatil456@gmail.com