



Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical & Industrial Engineering

**Analysis and minimization of sand- cast defects for casting aluminum
A356 alloy through Pro CAST simulation.**

A Thesis Submitted to the School of Graduate Studies of Addis Ababa Institute of Technology, Addis Ababa University in Partial Fulfillment for the Degree of Master of Science in Mechanical Engineering (Manufacturing Engineering).

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Addis Ababa, Ethiopia



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School of Graduate Studies
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Declaration

I hereby declare that the work which is being presented in this thesis entitled *Analysis and minimization of sand cast defect for casting aluminum A356 alloy through Pro CAST Simulation* has been carried out by Mr. Tibebe Malata in the School of Mechanical and Industrial Engineering, Addis Ababa Institute of Technology, Addis Ababa University, Addis Ababa, Ethiopia. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma. Moreover, where others' ideas or words have been included, adequately cited and source referencing have been made.



Tibebe Malata



Date

This is to certify that the above declaration made by the candidate is correct to the best of my Knowledge.



Dr. Desalegn Wogaso (Advisor)



Date

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Abstract

In this research analysis of the existing casting process through scientific tools at the case company, Selam Children Village Tsehayi Roschili Industrial and Agricultural Engineering in Addis Ababa Ethiopia is conducted. Inside foundry shop of case company defect becomes the most series problem, which makes the product to reject due to certain quality and bad surface finish. From different products, pulley product are selected using failure mode analysis and further analysis is conducted on it. In this investigation, various casting process parameters such as mold initial temperature, molten metal flow rate, newly designed model with three different scenario and pouring temperature considered. Then simulation are conducted according to Taguchi L18 orthogonal array. 3D model for the product designed on solid work 2022 and imported to Pro-CAST software for simulation. Different real time parameters given as input and various simulation carried out. From meticulous simulation, it is achieved a remarkable 100 percent void-free casting process. This outcome ensures structural integrity and enhances the reliability of the final components. Hotspot occurrences also reduced from an initial 35 points to an impressive 14 points. This optimization mitigates localized stress concentrations and enhances overall part performance. On further investigation, total volumetric of shrinkage porosity is also successful decreased from 5.67% to 4.77%. This improvement has direct impact on material density and mechanical properties of products. Additionally total defect distance on the ISO surface of product was significantly minimized from 55.62 cm to 25.59 cm. Finally, from selected trial according to Taguchi method and grey relational analysis with Minitab 21.2 software 52.22% total defect minimization is achieved.

Depending on the simulation result, selected pulley part fabricated inside foundry shop from aluminum A356 metals. Comparison between previous fabricated products with ought casting simulation software and new product that made after simulation result done and result of sample tested under scanning electron microscope machine presented.

Key words: - Casting, Aluminum A356, Defect, Pro CAST, Simulation, Foundry.

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List of Abbreviations and Acronyms

| | |
|---------|--|
| LPDCM | Low Pressure Doe Casting Machine |
| ANOVA | Analysis of Variance |
| EN | European Standard |
| AOM | Analysis of Mean |
| DOE | Design of Experiment |
| GVM | Gradient Vector Method |
| RTR | Real time radiographic inspection |
| FMEA | Finite Method Element Analysis |
| FMEA | Failure Mode Effect Analysis |
| HPDC | High Pressure Die Casting |
| LPDC | Low Pressure Die Casting |
| MACROFS | Macro Porosity calculation |
| FEEDLEN | Feed Length |
| MOLDRIG | Rigidity of Mold |
| VFREQ | Velocity Frequency Result |
| PREF | Pressure Flow |
| LVMASS | Mass and Volume of liquid |
| WSHEAR | Shear of Mold Wall |
| PERNUCL | Nucleation Parameter of the Pearlite |
| PERGROW | Pre-factor of the Pearlite Growth |
| PFREQ | Particle tracing launch Frequency |
| WALLF | Wall Friction (Mold wall) |
| TRIAE | Tsehayi Roschili Industrial and Agricultural Engineering |
| RPN | Risk Priority Number |
| OA | Orthogonal arrays |
| GRA | Gray relational analysis |
| QC | Quality Check |
| CAD | Computer Aided Design |
| CAM | Computer Aided Manufacturing |
| S.N.1 | Scenario Number One |
| S.N.2 | Scenario Number two |

| | |
|-------|----------------------------------|
| S.N.3 | Scenario Number three |
| SO1 | Code for Sample S01 |
| SN1 | Code for Sample S02 |
| MO1 | Code for Sample MO1 |
| MN1 | Code for Sample MN1 |
| MN3 | Code for sample MN3 |
| MO3 | Code for sample MN3 |
| SEM | Scanning Electron Microscope |
| SED | Secondary Electron Detector |
| TEM | Transmitting Electron Microscope |

Chapter One

1 Introduction

1.1 Background of study

Metal casting is the process of producing desired-shaped metal parts by pouring the molten metal into the prepared mold and then allowing the metal to cool and solidify. Then the casting removed from the mold, and excess metal removed by shot blasting, grinding or welding processes. The manual casting production method is most common in foundries. The activities involved in the casting process are pattern making, mold preparation, core making, gating system preparation, pattern removal and setting for pouring, filling the mold cavity with molten metal, allowing it to solidify and at last removing the cooled desired casting [1]. Among all the castings, sand casting is the most widely used (over 70%) metal casting process in the manufacturing industry. A great advantage of sand casting in manufacturing applications is that sand is inexpensive. Sand casting can range in size from very small to extremely large. It is natural to have certain defects on the finished product, but there is also a solution to minimize those defects primarily before reaching the finishing operation [2].

Aluminum casting used widely throughout the world in the recent past due to its specific characteristics like being lightweight, corrosion-resistant, malleability, ductility; thermal conductivity and 100% recyclability [1]. Inside the aluminum foundry shop of the case study there are many pulleys, which various defects like pinholes, cavities, gas holes, inclusions, and other defect that does not easily identified with the naked eyes. Defect and imperfection physiologically generated by different casting techniques because of the process stages, alloy properties and die or mold design [3]. Well-designed feeding system reduces the casting defects drastically. Quality of product relies on the quantity of risers and location of runners and risers. Making changes in the feeding system and relocating the positions of risers manually is time taking hence simulation can become an important technique to improve the feeding system that will help to develop quality product [3].

Computer-aided casting design and simulation provides much better and faster insight for optimizing the feeder design of castings. The application of computer aided method and casting simulation in foundries minimize the bottlenecks, non-value added time in casting development, and reduces the number of trial casting required on the shop floor [4].

In the past, the optimal casting design was achieved by trial and error method. Conventional method is time consuming and ineffective, can no longer satisfies the needs of the foundry. This problem can be addressed with the use of computer aided design/engineering technique [5]. Computer design and casting simulation become popular in recent years. With the help CAD/CAM, a number of commercial packages for the simulations of the casting have been developed and implemented in the foundry. Recent technology development helps identification of the defects and their causes using 3D modeling and simulation software [6]. In this research, metal-casting operations of component with different size and shape identified to analyze the methods further. Proper design of the casting system is needed to meet two important requirements which are short flow paths and fast metal flow to prevent casting miss-runs by avoiding premature solidification. Especially heavy sections that solidify more slowly require direct contact of gating system for resisting shrinkage.

1.2 Problem statement

Defect is a major problem inside aluminum casting foundry of a case study company, there are many products casted through sand-cast processes. Most of the time high rejection rate and longtime machining a product happen due to very poor casting quality that leads to-

- High consumption of materials with high expenses
- Wastage of human resources and
- Power and time consumption may lead to heavy losses.

So that conducting casting simulation before actual casting process plays a great role in order to minimize certain losses, to visualize the available rate of casting defect, upgrade the production rate and minimize unwanted rework. Mainly defect like that of hotspot, void, shrinkage porosity, pin holes, blow holes, surface cracks etc. are the main defects which happened on products casted at case company foundry as shown on figure 1.1.



Figure 1.1:-Rejected pulley product due to defect (Photos taken from the case company)

A: - Rejected product due to defect

B: - Rejected product due to defect

C: - Sample of porosity visited

D: - Extended surface sample

This research tries to represent analysis of these defects with different scientific tools in order to correct cause and remedial factors to improve quality level and productivity of company.

1.3 Objective

1.3.1 General objective

The main objective of this research is to analysis the existing casting process of aluminum A356 using different scientific tool and design a casting process that can yield less defect cast parts.

1.3.2 Specific Objective

- Identify the product that mostly faced to casting defect from aluminum foundry shop of industries.
- Identify types of sever casting defect visualized on the products through visual inspection and using PROCAST simulation.
- Identify the root causes for casting defect through Pro CAST Simulation Software.
- Design improved casting process that will yield minimum or no defect.
- Conduct computer aided simulation of casting process for selected part.
- Validate the simulation result using conducting a test experiment.

1.4 Scope of the research

Various information's was gathered about currently status and progress data from aluminum foundry shops of industrial and agricultural engineering in order to know the various reasons which makes a defect and a product which mostly defect happened on it. Then one product that faces more defect selected through visual inspection and PROCAST simulation. Beside that for product selected detail part design, detail-gating systems design and 3D modeling, designing takes place on solid work software. After that designed 3D model is converted to the format which provident to the simulation software on PROCAST. Various simulation results recorded and certain analyze conducted before product fabrication. Finally, one product fabricated according to simulation result another additional product as current existing model (with ought simulation) was fabricated inside foundry shop of case company. After product fabrication casting defect test under SEM (Scanning Electron Microscope) machine conducted.

1.5 Research Question

During this research paper, there was different question that needs to answer through conducting detail study. From them those listed are the majors:-

- ✚ Shall Pro CAST simulation support to predict different casting defect size and their size locations in an exact manner for selected product.
- ✚ Is that possible to observe the size and exact location of different casting defects in an exact manner using Pro CAST simulation.
- ✚ How is difference of product quality between the product casted using Pro CAST simulation software and a component casted with ought to using casting simulation software.
- ✚ How many percentages of defect minimization was possible through design casting process using Pro CAST software?
- ✚ What and which kinds of defect mostly visualized inside the pulley product (selected product).
- ✚ How many percentage of defect minimization was possible to achieve only through varying a process parameter using Taguchi Orthogonal Array L-18 for selected product.
- ✚ How many percentage of defect minimization was possible to achieve with varying process parameter, gating system design modification with different scenario using Taguchi Orthogonal Array L-18 for selected product.

1.6 Motivation Statement

From a lot of factor the following factor is the major reason to study this research, like that of-

- ❖ Casting defect problem is serious one, which needs to better solution.
- ❖ The number of products that rejected at aluminum foundry shop increased from time to time due to various factors.
- ❖ There are little researchers, which conduct defect minimization on Aluminum alloys; rather most of researchers can conduct research on defect minimization on various carbon steel.

1.7 Significance of study

Final result of these study can directly implemented inside the aluminum casting foundry shops of the company which expected to play a great role through minimization of defect, effective utilization of resource and time, customer satisfaction and making easy and simple types of production process. Simulation based trials do not involve wastage of material, energy and labor, by using casting simulation method the percentage of rejection of casting due to defects has been reduced.

1.8 Organization of study

This thesis is an organized of five chapters and its content is about analysis and minimization of sand cast defect for casting aluminum A356 alloy through Pro CAST simulation with experimental validation. The thesis paper structured as follows:-

Chapter One: - Presents about the background study of casting and simulation software with the statement of the problem, thesis objectives, scope, research question with motivation statement, and significance of the studies are included.

Chapter Two: - It divided into nine sections and presented on previous works. The chapter starts from casting section and continues toward sand casting and various casting defect and remedies description between sections one up to section three. Then under section four it describes various literature those focused on casting design then section five, six and seven focused on Aluminum A356, casting simulation and simulation software respectively. Finally, on section eight, various previous research paper presented with summaries format and additional section nine concludes with listing certain research gaps.

Chapter Three: - Provides a detailed description of materials used in the study, the methodology followed during the research work, various analysis of casting process of case company and approved casting system are included in this chapter. During design mathematical calculation, modelling of various part and casting simulation software analysis are included and presented.

Chapter Four: - Presents with the detail outcomes and result of simulation, experimental studies. Meanwhile it also details discussions on the results on simulation and experimental results.

Chapter Five: - Presents the conclusion and recommendation for future works.

Chapter Two

2 Literature review

2.1 Casting

Metal casting is one of the ancient techniques used to manufacture metal parts. It is also the process of producing desired shaped metal parts by pouring the molten metal into the prepared mold and then allowing the metal to cool and solidify. Then it removed from the mold and excess metal rejected by shot blasting, grinding or welding processes. The product undergoes a wide range of processes such as heat treatment, polishing and surface coating or finishing and inspection [5]. **Datau.et.al**, described casting as a metal object produced by allowing molten metal to solidify in a mold. The shape of the mold cavity determines the shape of the object. It also present casting as interplay process of certain parameters such as melting temperature, the mold condition (temperature, moisture content, sand and type of binders used), pouring temperature, and the gating design (i.e. pouring speed, runner size and included gases), the casting size and the type of alloy [7].

Casting processes are widely used to produce metal parts in a very economical way, and to obtain complicated shapes with little or no machining. The manufacture of a part involves several steps, the first of which is the design of the part itself, and the specification of the material used. Then information passed to the method engineer, who will choose casting process, and then design the gating system necessary to get the molten metal into all regions of the part to produce a sound casting. Two major considerations in the casting design are the quality of the final product and the yield of the casting [8].

2.2 Sand Casting

Sand casting is one of the most common production technique used for manufacturing ferrous castings. It has been used to manufacture complex shapes of various sizes depending upon the customer requirements [9]. The basic requirements casting are pattern making, preparing a mold, pouring a molten metal, cooling of mold, shakeout, fettling. The main causes of rejection in castings are due to improper pattern, improper gating system, improper control of sand parameters, improper molten metal composition [7]

The most widely used method for small to medium-sized castings is green sand molding. Other casting and molding processes include shell molding, permanent molding, investment casting, plaster molding, and die-casting. In addition, there are a number of innovative and relatively new casting methods such as lost foam casting and squeeze casting [18]. Among the industrial activities, sand casting process remains as one of the most complex and indefinite activities. Due to the complex relationship between casting defects and green sand properties, it is imperative to control many green sand characteristics that influence casting quality.

Traditional method of trial-and-error based on expertise and experience has many disadvantages such as being nonsystematic, time consuming, error-prone and requirement for long durations of experimentation. There is a necessity to replace this traditional approach to produce higher quality casting products within reasonable periods making better use of statistics, artificial intelligence knowledge acquisition, neural networks and data mining tools [10].

The main area of optimizing green casting process are, optimizing and reducing riser mass, optimizing gating system, simulation of mold filling and solidification to avoid casting defects, optimizing process parameters of sand mold, optimizing pattern plate utilization, Optimization of melt composition and temperature, Efficient cooling during solidification and reducing oxidation and controlling deformation of casting in heat treatment [10].

2.3 Casting defect and their categories

The standard EN 12258-1:2012 defines “defect” as a quality characteristic, which does not allow the product to carry out the requested function [11]. This European Standard (EN 12258- 1:2012) defines general terms relating to products made from aluminum alloys such as processing, sampling, testing and overall characteristics. On the contrary, the presence of an imperfection does not necessarily mean the product is not suitable for use. An imperfection should be evaluated by means of a proper scale, based on the related specifications, to decide if the product has the necessary level of quality to make it suitable for use [11].

A defect in castings does not just happen, not by accidents, they occur because some step in manufacturing cycle is not properly controlled and somewhere something goes wrong

[12]. Defects prediction visualized and fixed computationally before actual castings in foundry is the main target on this paper analysis.

2.3.1 Internal defect and imperfection

Internal defect are mostly happen on the inside parts of surfaces. Shrinkage defects are the one, which mostly happen internally due to volume contraction during solidification and occur in the regions with insufficient or even absent feeding. Such regions are the last to solidify (hot spots) and are normally well inside the casting, but sometimes they are sufficiently close to the casting surface to give rise to surface defects [11].

Table 2.1:- Categories of internal defect and imperfection [11].

| 1 st level | | 2 nd Level | | 3 rd Level |
|---|----|---|------|---|
| Internal defect and imperfection | A1 | Shrinkage defect and imperfection | A1.1 | Macro Shrinkage |
| | | | A1.2 | Inter dendritic shrinkage |
| | | | A1.3 | Layer porosity |
| | A2 | Gas related defect and imperfection | A2.1 | Air entrapment porosity |
| | | | A2.2 | Hydrogen porosity |
| | | | A2.3 | Vapor entrapment porosity |
| | | | A2.4 | Lubricant and Die release agent entrapment porosity |
| | A3 | Filling related defect and imperfection | A3.1 | Cold Joint |
| | | | A3.2 | Lamination |
| | | | A3.3 | Cold shot |
| | A4 | Undesired phase | A4.1 | Inclusion |
| | | | A4.2 | Undesired structure |
| | A5 | Thermal contraction defect and imperfection | A5.1 | Cold crack |
| | | | A5.2 | Hot tear, hot crack |

During this research focus are conducted on the internal defect and imperfection visualize and correction through using simulation software's.

2.3.2 Surface defect and imperfections

Mechanically induced defects such as surface marks, undercuts and bending occurs during ejection of casting and due to insufficient draft angle. Under cuts are formed due to erosion of sand by the stream of molten metal. It shows the pattern around the gates and causes dirt in casting. Bending and surface mark are caused by external pressure loads and improper ejection methods. These defects can be avoided by giving proper draft angle and using standard ejection methods and modified casting designs [13].

Table 2.2:- Surface defect and imperfection categories [11].

| 1 st level | | 2 nd Level | | 3 rd Level |
|--|----|--|------|-------------------------|
| B Surface Defect and Imperfection | B1 | Shrinkage defect and imperfection | B1.1 | Sink |
| | B2 | Gas related defect and imperfection | B2.1 | Blister |
| | | | B2.2 | Pin Hole |
| | B3 | Filling related defect and imperfection | B3.1 | Cold Joint, Vortex |
| | | | B3.2 | Lamination |
| | | | B3.3 | Cold shot |
| | A4 | Undesired phase | B4.1 | Surface Deposit |
| | | | B4.2 | Contamination Inclusion |
| | A5 | Thermal contraction defect and imperfection | B5.1 | Cold crack |
| | | | B5.2 | Hot tear, hot crack |
| | A6 | Metal and die interaction defect and imperfections | B6.1 | Erosion |
| | | | B6.2 | Soldering |
| | | | B6.3 | Thermal Fatigue mark |
| | | | B6.4 | Ejection mark |
| | | | B6.5 | Corrosion of the die |

2.3.3 Geometrical defect and imperfections

Geometry defect are mostly affect the shapes of parts due to lack of material, excess material and out of tolerance movement of molten metal.

Table 2.3:- Categories of geometric defect and imperfection [11].

| 1 st level | | 2 nd Level | | 3 rd Level |
|---|----|-----------------------|------|-----------------------|
| C Geometrical defect and imperfections | C1 | Lack of material | C1.1 | Incompleteness |
| | C2 | Excess material | C2.1 | Flash |
| | C3 | Out of tolerance | C3.1 | Deformation |

If proper control does not exercised, a variety of defects may result in a casting. Defect happen because of following reasons:-

- ✚ Improper pattern or tool design or lack of allowances,
- ✚ Improper mold and core constituents,
- ✚ Improper melting and pouring practice,
- ✚ Because of molding and core making materials,
- ✚ Improper gating system along with lack of feed aids,
- ✚ Improper metal composition,
- ✚ Inadequate melting temp and rate of pouring,
- ✚ Unskilled post melting treatment like shakeout, fettling etc. [14].

2.4 Design of casting process

Casting design mainly consists of pattern design, gating system design and finally the feeder design. To compensate for any dimensional and structural inadequacies, which will happen during the casting or patterning process, allowances usually provided to the pattern. Various allowances considered are shrinkage allowance, draft allowance, machining allowance etc. Nearly 40 % of casting defect attributed to faulty design of gating systems and poor pouring practices. The solidification is essentially a phase transformation of metals from liquid to solid state in a pre-shaped cavity. This phase transformation accompanied by volumetric shrinkage in most of the cast metals [4]. The starting point for casting design is the 3D solid model of the part to produce. The solid model can created in CAD packages such as AutoCAD, I-DEAS, Pro-Engineer, SolidWorks or UNI GRAPHICS and exported in a standard format. Starting from this solid model, Auto CAST generates the complete casting design through several steps, which include casting orientation, mold box, parting line, cores, risers and gating. At the end of each step, the user has the option to provide their suggestion for the corresponding design parameters. Given a part model, single iteration of casting design usually takes 20-30 minutes on a Pentium computer [15]. A 3-dimensional model of the cast product is an important input for design and analysis functions in Auto CAST. The user may get the model from the customer, contract the part-modeling task to a service bureau, or create the part model using solid modeling software. Then part model imported into Auto CAST through a data exchange interface using the industry standard STL format [16].

2.4.1 Design of gating system

Gating system serves as a channel by means of which molten metal delivered to the mold cavity and feeds during shrinkage that develops during casting solidification. Proper design of the gating system is critical in meeting two important requirements, such as short flow paths and fast metal flow prevent casting miss-runs by avoiding premature solidification. Relatively heavy section which solidify more slowly require direct gating contact to provide molten metal for feeding shrinkage that arises during solidification [6].

A gating system usually made up of - **Pouring Basin - Sprue - Runner and Flow-off Gate**. Gating system refers to all the passageways through which the molten metal passes to enter the mold cavity. From different components of gating system pouring cup, sprue, sprue base, runner, gate and riser are the majors.

Proper design of gating system can come with certain advantages such as [2]:-

- ❖ To provide continuous, uniform feed of molten metal, with little turbulence as possible to the mold cavity. Excessive turbulence results in the aspiration of air.
- ❖ To supply the casting with liquid metal at best location, achieve proper directional solidification and optimum feeding shrinkage cavities.
- ❖ To fill the mold cavity with molten metal in the short possible time in order to avoid temperature gradient.
- ❖ To provide with a minimum of excess metal in the gates and risers. Inadequate rate of metal entry.
- ❖ Also used for prevent erosion of the mold walls and
- ❖ To prevent slag, sand and other foreign particles from entering the mold.

2.5 Aluminum A356 Alloy

Aluminum is the most common element in the earth crust and exists as aluminum oxide. It possesses some peculiar properties such as high resistance to corrosion, ease of fabrication, high thermal and electrical conductivity, low weight and bright color. When aluminum used for casting it has a melting temperature of 660°C and pouring temperature range between 649°C -750°C. The knowledge of melting temperature of metals and alloys is necessary to estimate their corresponding pouring temperature [7].

Aluminum is the world's most abundant metal and thus the third most common element comprises eight percent of the earth's crust. The versatility of aluminum makes it the most widely used metal after steel. It derived from the mineral bauxite. Bauxite converted to aluminum oxide (alumina) via the Bayer Process. The alumina then converted to aluminum metal using electrolytic cells and the Hall-Heroult Process [17]. Aluminum-based alloys casting dominate the non-ferrous castings market, accounting for 74 percent (\$6.0 billion) of total U.S. non-ferrous casting shipments in 2002. Aluminum-alloy castings contain varying amounts of silicon, copper, magnesium, tin, and zinc [11].

2.6 Sand Casting Simulations

Casting simulation enables envision of whole casting process. Simulation helps to see the differences made to the product and helps to take decision, which will lead to technically sound product. Simulation also finds the defected area like shrinkage, blowhole, cracks etc. It used for improving the existing casting and for manufacturing newly design casting within very less time. It primarily helps to improve the superiority of product and its faster growth [3]. Casting simulation used for the production of reliable, cost-effective and high accuracy cast component. In addition, it was a second hand to increase the casting yield and diminish the shop floor experimental time. With the help of casting simulation techniques, casting system and design optimization is easily possible. It also supports to predict the defects and their locations in an exact manner. With use of a casting simulation technique, the feed ability of casting process can be analysis and optimized [18].

Casting simulation can minimize the wastage of resources required for trial production. In addition, the optimization of quality and yield implies higher value-addition and lower production cost, improving the margins [2]. It is also one of the powerful tools in the casting process without involvement of physical work. This improves the confidence of the engineers in the functionality of feeding system with design optimization. Solid-Cast simulation software was experimented in the guiding face, which is a body part of pulp valve made from cast iron. Use of this software is of immense help in designing an optimum gating and feeding system that can improve the yield and the quality of casting and eliminate internal defects [6].

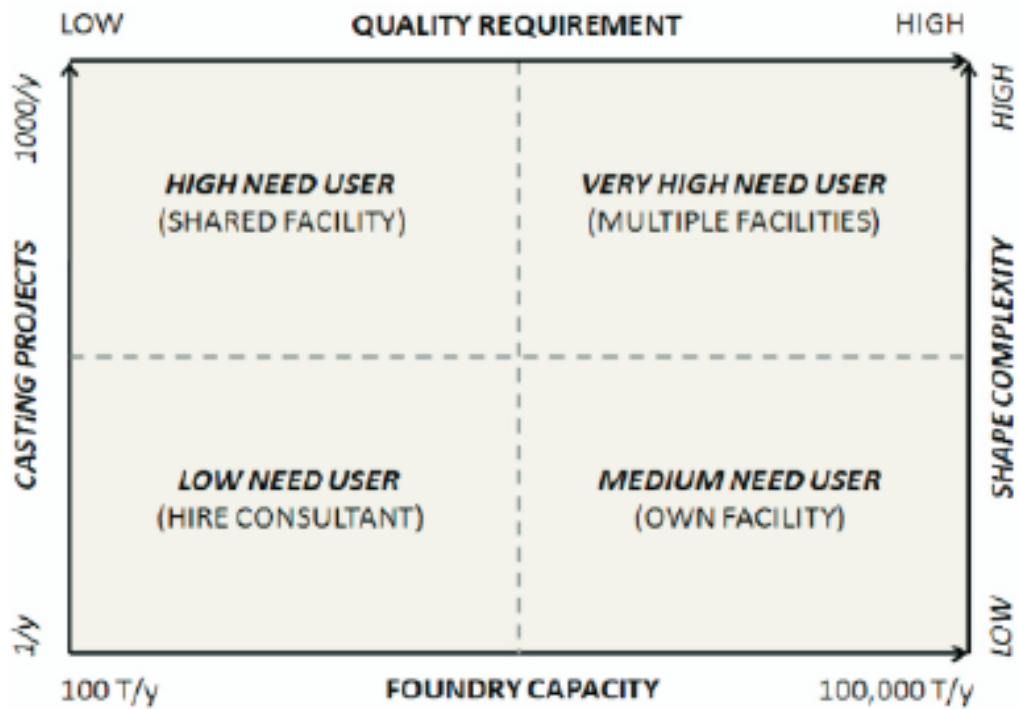


Figure 2.1:- Casting simulation users based on project, capacity & quality and shape [19].

2.6.1 Benefit of casting simulation

The benefits as well as bottlenecks in various computer programs for foundry applications shown on Fig2.2. Both tangible and intangible benefit described below. Tangible benefits mainly lead to cost reduction, and intangible benefits lead to value addition.

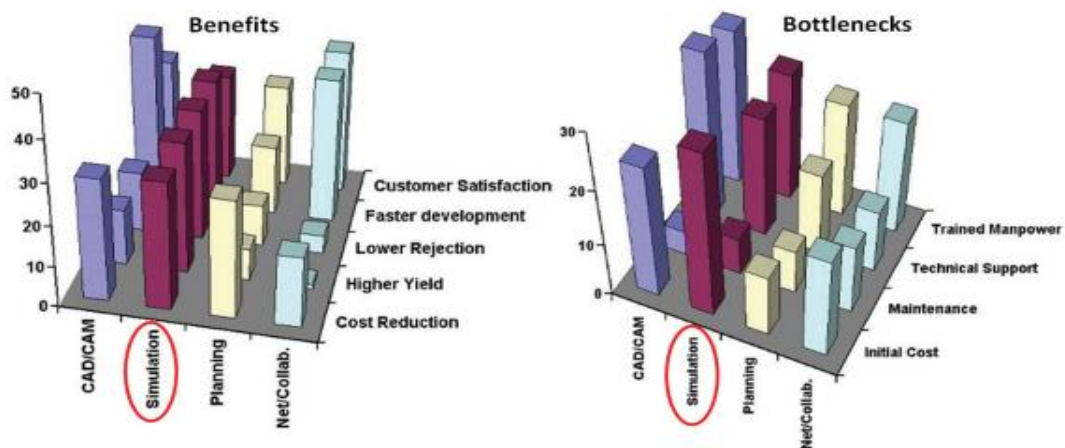


Figure 2.2:- Survey of computer application, benefits and bottlenecks in Indian foundry [20].

2.7 Simulation Software

Simulation performed by using Auto CAST-X software according to the design dimensions obtained for pattern with allowances, gating system and feeder. Simulation study of castings aims at identifying the hot spot locations, solidification time and thereby minimizing the shrinkage porosity etc. [21].

Selection of casting simulation software is a critical and the knowledge of commercially available software is required beside selection. Casting simulation software is compared in terms of casting process selected, add on modules, solution method used, defect prediction, typical client/user and advanced simulation capabilities [19]. Computer simulation provides a clear understanding of the casting phenomena to identify the location and extent of internal defects, ensuring defect-free castings. Thus, numerical simulation of casting considered as an important method to make casting technique change from experience test to science guidance [4].

Table 2. 4:- List of casting simulation software

| Casting simulation software | Vendor |
|-----------------------------|---|
| Pro CAST | ESI Group, Paris, France |
| Auto CAST | Advanced reasoning technologies P. Ltd., Mumbai |
| Nova-Solid/Flow | Nova cast AB, Ronneby, Sweden |
| CAPCAST | EKK, Inc., Walled lake, Michigan USA |
| MAGMA Soft | MAGMA GmbH, Aachen, Germany |
| Cast CAE | CT-Castech Inc.Oy,Espoo,Finland |
| FLOW-3D Cast | Flow Science, Inc.,683 Harkle Rd,Santa Fe, USA |
| SOLID Cast | Finite Solution Inc., Hamilton, OH,45013, USA |

Among the listed software on Table 2.4, Pro CAST, Flow-3D Cast, Nova Solid/Flow are actually high end simulation packages and also simulates most of the metal available inside foundry [19]. For this research because of its market availability and various defect analyze capabilities Pro CAST simulation software was used.

2.8 Related research

Various authors conducted research works in reducing the casting defects and enhancing the quality of product.

Akash et.al reviewed on investigation of casting defects; provide remedies and simulation of casting process by using simulation software. In this review, several casting defects and their occurrence cause identified. Review also tries to put clearly, as most defects occur due to improper feeding system. Simulation is helpful in minimizing the casting defects. In addition, he concluded as well-designed feeding system reduces the casting defects drastically and quality of product relies on the quantity of risers and location of runners and risers [3]. **Mohit Kumar et.al**, studied on defect of an aluminum alloy casting and the ways to improve the quality of casting using quality control tools. Casting defect analysis carried through using techniques like historical data analysis, cause-effect diagrams, design of experiments and root cause analysis. Data from X-ray inspection (Radiographic Inspection) has been collected along with the production parameter data. Using Pareto chart major defects in the aluminum casting noted. The major defects for the rejections during production identified as shrinkages, inclusions, porosity/gas holes and cracks. Finally, each defect studied thoroughly and the possible causes for each defects shown in Fishbone Diagrams (Cause Effect Diagrams) [22].

R. Kumar et.al created a gating system for investment casting with the help of fascinating advancements in the casting field. In this study advanced techniques were utilized for creating a part named rotary adapter which are complex shape products. The author also used UNIGRAPHICS software for modeling the part and the gating system. During simulations, different gating system has implemented for eliminating the defects. Simulation process repeated in the software repeatedly and the efficiency proved with defect free casting. Pressurized gating system used in these experiments. Different combinations of gating system designs and mold filling carried out for complete elimination of over filling related defects. Finally, the author decides as, casting simulation results certain advantages like that of substantial quality materials, saving time and cost required in shop floor trial [6]. Again also with another author **C. M. Choudhari et.al**, an attempt was made to redesign and develop casting defect free products in particular shrinkage defect. Therefore, through ought carrying various simulation trial optimum location of feeder was identified. The objective of this research work focused on caring

numerical simulation of casting solidification with experimental trials to minimize above-mentioned defects. Finally, the author decides as computer-aided casting design and simulation provides much better and faster insight for optimizing the feeder design of castings. However, placement of the feeder at the last solidifying regions did not shift the hot spot completely into the feeder [4]. **Ranjit et.al**, conducted a research on defect minimization of casting through process improvement [18].

Then **Uday A et.al**, analyzed a casting defect using design of experiments (DoE) and computer aided simulation technique. In first part of this paper, Taguchi based L18 orthogonal array used for the experimental purpose and analysis carried out using Minitab software for further analysis of variance (ANOVA) and analysis of mean (AOM) plot. ANOVA results indicate that the selected process parameters significantly affect the casting defects and rejection percentage. In the second part, shrinkage porosity analysis performed using casting simulation technique by introduction of a new gating system. Finally, with new gating and feeding system design reduction in shrinkage porosity about 15% and improvement in yield about 5% observed. With Taguchi, optimization method the percent rejection of castings due to sand related defects reduced from 10 % to a maximum up to 3.59 %. For analysis of defect like shrinkage porosities computer aided casting simulation technique is the most efficient and accurate method. The quality and yield of the casting efficiently improved by computer assisted casting simulation technique in shortest possible time and without carrying out the actual trials on foundry shop floor [12].

Sarath Paul et.al, conducted simulation and experimental validation of feeding efficiency in FG 260 grey cast iron castings. The entire casting process simulated by means of finite element simulation software and then the result compared with shop floor trials. Solidification simulation made with ANSYS software to compute solidification time and optimal riser combinations to obtain defect free castings in the shop floor. The experimental results revealed that the simulation performed using ANSYS holds good to produce defect free cast iron castings in the foundry. Finally, from simulation, cooling curve helps to find out the solidification time of casting and riser then experimental result compared with theoretical results for validation. It observed that there is a closeness of experimental values with the theoretical values [5].

Sumaiya Shahria et.al, focused on optimization of molding sand composition for casting aluminum alloy; the aim of this research is to reduce aluminum casting defects by optimizing proportion of water and bentonite added to a recycled sand mold. Aluminum 356 alloys was preferred for this research based on the traditional method of trial and error twelve castings were performed with the different proportion of sand, bentonite, and water. This study concluded that the data obtained can applied to set the parameters at optimum level to minimize defects and improve quality of aluminum alloy sand casting [2].

K.Pundari Kaksha et.al, performed research on minimization of casting defects in aluminum alloy wheels of grade A356.2. This project directly focused on identification of the casting defects in aluminum alloy wheels to reduce the losses due to scrap and rework. Through double filtration technique procedure, aluminum filter cloth bag used for purification of molten metal before pouring to the LPDC holding tank. Second filter cloth mesh instead of the traditional G.I MESH will reduce the iron content in the wheel therefore gas holes and pinholes will be decreased [1].

Hodbe G.A et.al, this author mainly focused on sand casting defect minimization of LM25 through design and simulation. The part taken for study is Contact wheel from one of casting company in Aurangabad, Maharashtra. On this study AlSi7Mg material used for the component, Auto Cast software for method design and simulation are used. Casting solidification simulated to view the progress of cooling from casting surface to interior, and to predict the location of shrinkage defects such as porosity and cracks. Then simulation and experimental trial result was compared and each comparison result listed as a good result [23].

2.8.1 Summary of mostly related researches on casting defect minimization

There is various literature, article and journals papers conducted on defect analysis of various casting processes as described on Table 2.5.

Table 2. 5:- Summary of various related researches works in the field of casting defects and analysis.

| Title of Paper | Author | Methodology used | Gaps to solve | Finding and solution |
|--|--|---|---|---|
| Casting Defect Analysis using Design of Experiments (DoE) and Computer Aided Casting Simulation Technique | Uday A. Dabade and Rahul C. Bhedasgaonkar [12] | (Taguchi method) used for analysis of sand and mold related defects and casting simulation technique is used for meth ding, filling and solidification related defects. | To reduce the % of rejection due to sand and molding related defects | The quality and yield of the casting efficiently improved. |
| Casting design and simulation of gating system in rotary adaptor using PROCAST software for defect minimization. | R. Kumar a , S. Madhu & et.all [6] | After parts modeled on UNIGRAPHICS software NX and Pro-cast software used to simulate. No any experimental done. | Minimize the rejection rate of casted part and save the energy and work force wasted. | Defects and hot spot locations easily identified. Finally, the product quality improved with increase in yield and less rejection. |
| A Review on Investigation of Casting Defects with Simulation | Akash A. Gaware, Dr. A. K. Mahalle [3] | Defects like shrinkage, blowhole, pinhole, sand inclusion and sand burning identified and simulated. | Identifying Cause of casting defect | They conclude as follows with ought experimental conduct "Simulation primarily helps to improve the superiority of product and its faster growth" |
| Minimization of Casting Defects | Achamyeleh A, Kassie , Samuel B, ,Assfa & et.all [24]. | They observe two steel casting defect, Gas defect and Shrinkage defect. Four process parameter are used in three level | Casting defect | After 9 experiments conducted using Taguchi's they concluded, as trail of experiment 6 is the better of all. |

| Title of Paper | Author | Methodology used | Gaps to solve | Finding and solution |
|---|---|--|--|---|
| A literature review on minimization of defects in casting through process improvement | Mr. Ranjit Suryakant Akiwate, Prof.Dr.G.R.Naik, Prof.R.R.Joshi [18] | Only Literature Review was Conducted. | Process improvement of casting system. | Various of brief review of a casting Simulation Techniques presented |
| Analysis of Different Sand Casting Defects in a Medium Scale Foundry Industry - A Review | Bhushan Shankar Kamble [14] | In this paper, only literature review done focusing various defects in casting process. | Different sand casting defect analysis. | Concludes, as foundry had not standardized their production processes in different areas. |
| Optimization of Casting Defects in Modern Alloy Wheel Casting With Quality Control Estimation | Mohit Kumar, Prof. Amit Kumar Tanwar, Prof. Bhagwan Das [22] | After data collection done, real time radiographic inspection (RTR) used to detect the micro defects. In addition, X-ray used to detect the fault. | Minimization of casting defects using 7 quality control tools. | The author concludes as the major rejections are due to shrinkages, cracks, inclusions. |
| A development of quality in casting by minimizing defects | Prasan kinagi, dr. r.g mench [25] | Design of experiment and FMEA techniques are combined to analyze casting defects, | Casting defect | Concludes as maximum rejection occurred due to sand inclusion, blowhole and cold shut. |

2.8.2 Summary of Aluminum casting defect related research

Certain literature, journal and article especially those who focused on aluminum alloy casting defect summarized in Table 2.6.

Table 2. 6:- Aluminum casting defect literature reviewed summary

| Title of Paper | Author | Methodology used | Gaps to solve | Finding and solution |
|---|--|--|---|---|
| Methoding and Simulation of LM 6 Sand Casting for Defect Minimization with its Experimental Validation. | C. M. Choudharia, B. E. Narkhedeb , S. K. Mahajanc [4] | Simulation was done by Gradient Vector Method (GVM), Optimum location of feeder has identified, | Identify the location and extent of internal defects. | Experimental result confirmed with simulation results, Then after location of hotspot identified, shifting the position of hotspot inside runner achieved successfully. |
| Minimization of Casting Defects In Aluminum Alloy Wheels of Grade A356.2 | K.PundarKaksha P.Satish Reddy N.Guru Murthy S.Siva Kuma [1] | Report prepared by taking consideration of 1000 alloy wheels by inspection. | Minimization of Casting Defect | Replace the GI mesh with the filter cloth mesh. Replace air leak machine with the ultrasonic air leak-testing machine. Using aluminum filter cloth bag for purification of molten metal |
| Optimization of Molding Sand Composition for Casting Al Alloy | Sumaiya Shahria, Md. Tariquzzaman, Md. Habibur Rahman, Md. Al Amin, Md. Abdur Rahman [2] | Analyzing the variance (ANOVA) by using Minitab 17.0 software was done. And also experimental process was done | Identify the optimum molding sand of A356 | Finally 90% sand, 5% bentonite, and 5% water presented as optimum mixture of molding sand. |
| Minimization of Shrinkage Porosity in Sand Casting Process By Simulation In AUTOCAST-X Software with Experimental Validation by Destructive testing | .K.Gajbhiye, C.M.Choudhar, D.N.Raut, B.E.Narkhede, B.M.Bhandarkar. [26] | Three casting trials was carried out without feeder, with feeder and feeder with exothermic sleeve | Shrinkage porosity are the main gap on this paper | Application of casting simulation software in the foundries not only minimizes the wastages of resources but also enhances the quality and yield of castings. |

- ✓ Only little researchers can conduct on aluminum casting defect minimization as shown on Table2.6. So further research on Aluminum A356 alloy needed.

2.9 Research Gap

From previous research works, article and journals were regiously reviewed and the following gaps were identified:-

- ✚ Majorities of studies were focused on product casted from plain carbon steel and ductile iron products rather than aluminum alloy. For that matter, this research was tried to solve these gaps through conducting study on aluminum A356.
- ✚ Most researchers also focus on surface defect rather than the defect happened internal to the products. Therefore, this paper can try to investigate on identification of various internal casting defects through using computer simulation before conducting an exact product in order to predict defect.
- ✚ From reviewed literatures, it was clearly showed that only a few researchers' studies related to rejection control of castings in foundry using different simulation models.
- ✚ Wide gap of researchers also visited especially on the percentage of defect result from the improper design of gating and feeding system. Because some paper concludes 90%, the other 94% and another 86%. Therefore, this paper can try to come up with clear analysis after simulation results.

Chapter Three

3 Research Materials and Methods

3.1 Research methodology

During this research in order to approach, a problem and resulting with better solution different method of analysis and data collection were followed.

Reviewing Literature: reviewing was done through collecting and studying different articles, journals, books concerning about sand casting defect, casting simulation software, aluminum alloy casted products in order to further understanding of casted product and coming up with best solution of problems.

Setting criteria for defect faced product selection: Identify the product that is more faced to casting defect from aluminum foundry shop of industries are the first task for these researches. The criteria were be drafted from the actual recorded certain products.

Assign severity and occurrence rate of defect for selected product: Descriptions of casting defect severity process through failure mode and effect analysis (FMEA) rule.

Identification of root cause of defect: Identification of currently available root because was done through Pro CAST simulation software with ought to changing any parameter.

Design improved casting process: after defect identified, currently available products it needs to redesign again in order to come up with less defect product.

Modeling, simulation and analysis of improved casting: - Until product with less casting defect achieved, Detail modelling of a product using Solid Work 2021 and then simulation tasked on Pro CAST casting simulation software with different attempt.

Experimental conduct: Depending on optimum simulation result, a product fabricated inside case factory foundry.

Scanning Electron Microscope (SEM) Testing: After sample preparation, task was conducted according to SEM standard for both currently existing model and a redesigned model six different specimen.

Result comparison and analysis: Finally, comparison of result presented through both qualitatively and quantitatively. During research analysis, two major tasks conducted alternatively as shown on Figure3.1.

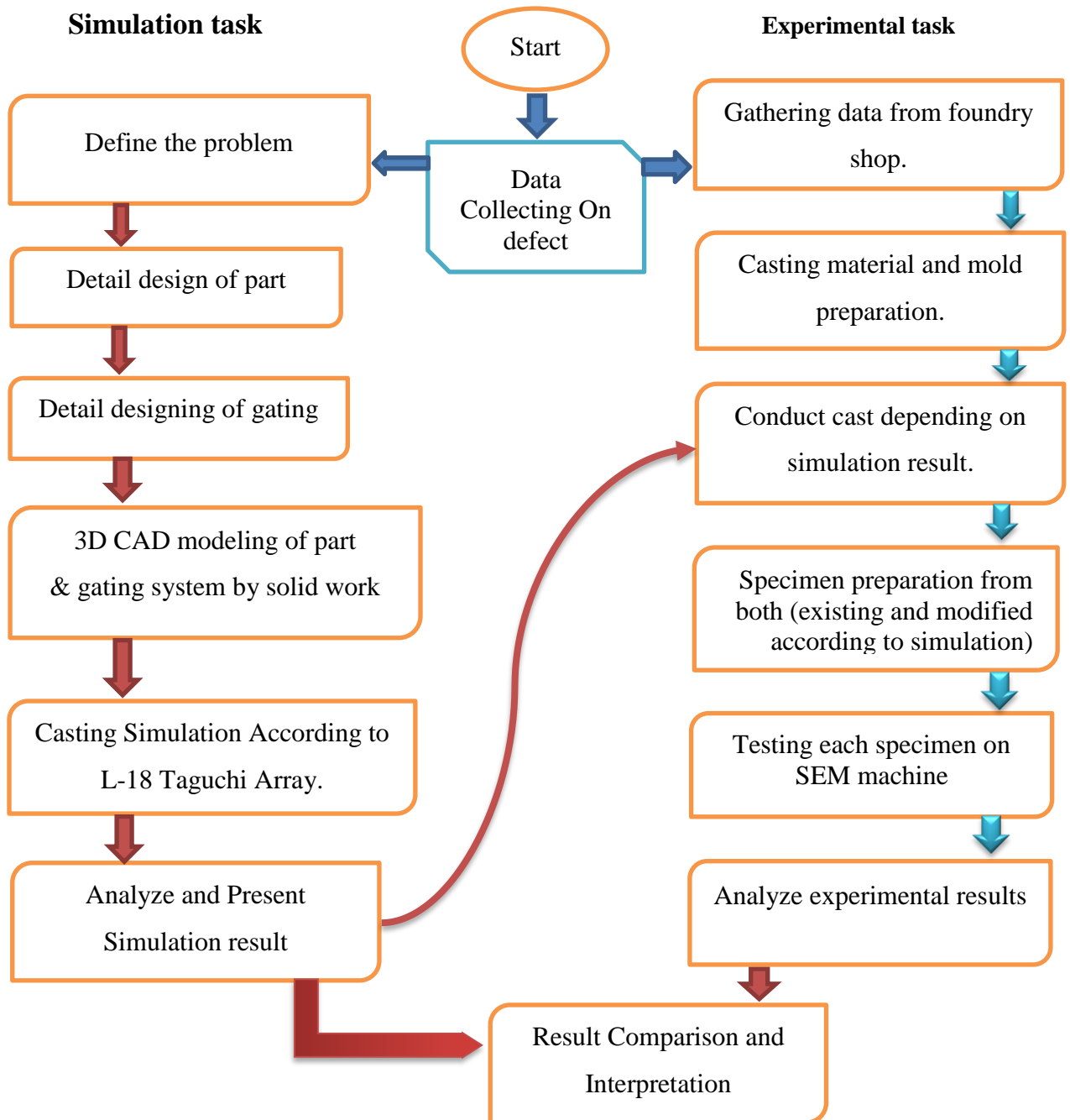


Figure 3.1:- Methodology and procedure of research study.

3.1.1 Data collection

The study was began with data acquisition about each of casting defects and components casted from aluminum A356 inside foundry. The following review was followed in order to collect maximum available data for this research purposes.

1. From different product fabricated inside case company the product which mostly influenced for defect, severity rate and percentage occurrence rate calculation was collected through questionnaire paper from three section of case company was conducted.
2. Registered data also revised regarding to demand rate for each product, to evaluate the quality of products regarding to fit for purpose designed effectively.
3. Published literature regarding to casting defect of aluminum A356 and simulation software is collected and all details relevant to this study summarized.
4. Types of defect and percentage of each defects data recorded from simulation result for currently available scenario as it is.

As mentioned below data gathering areas where different data was collected described on Figure 3.2.

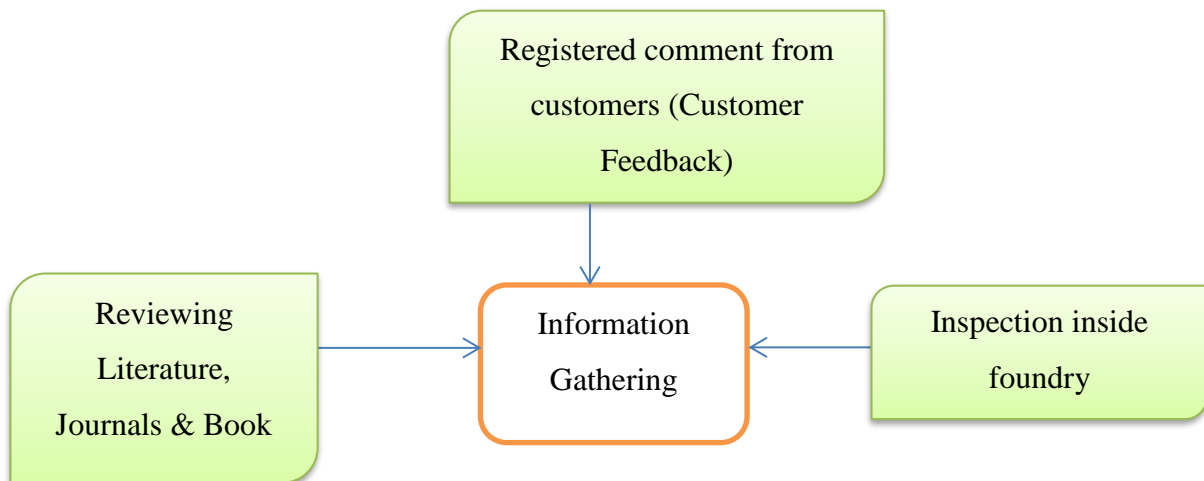


Figure 3.2:-Data collection area

3.2 Analysis of existing casting process and foundry

3.2.1 Tsehayi Roschili Industrial and Agricultural Engineering Case Company.

Tsehayi Roschili Industrial and Agricultural Engineering has having a foundry division that produces various aluminum alloy products such as sprocket, different pulley with nominal diameter varying from 80mm up to 600mm through different thickness, various wheel hubs, and different ornaments, bushing etc. Companies’ production type depends on job order so that it is difficult to determine the exact monthly and weekly production capacity.

3.2.1.1 Process flow diagram of existing casting process at Case Study Company

Currently inside Selam Children Village “Tsehayi Roschili Industrial and Agricultural Engineering Company (TRIAE)” there is no any computer integration testing of casting process. The process flow path of casting system at case company described on Figure 3.3.

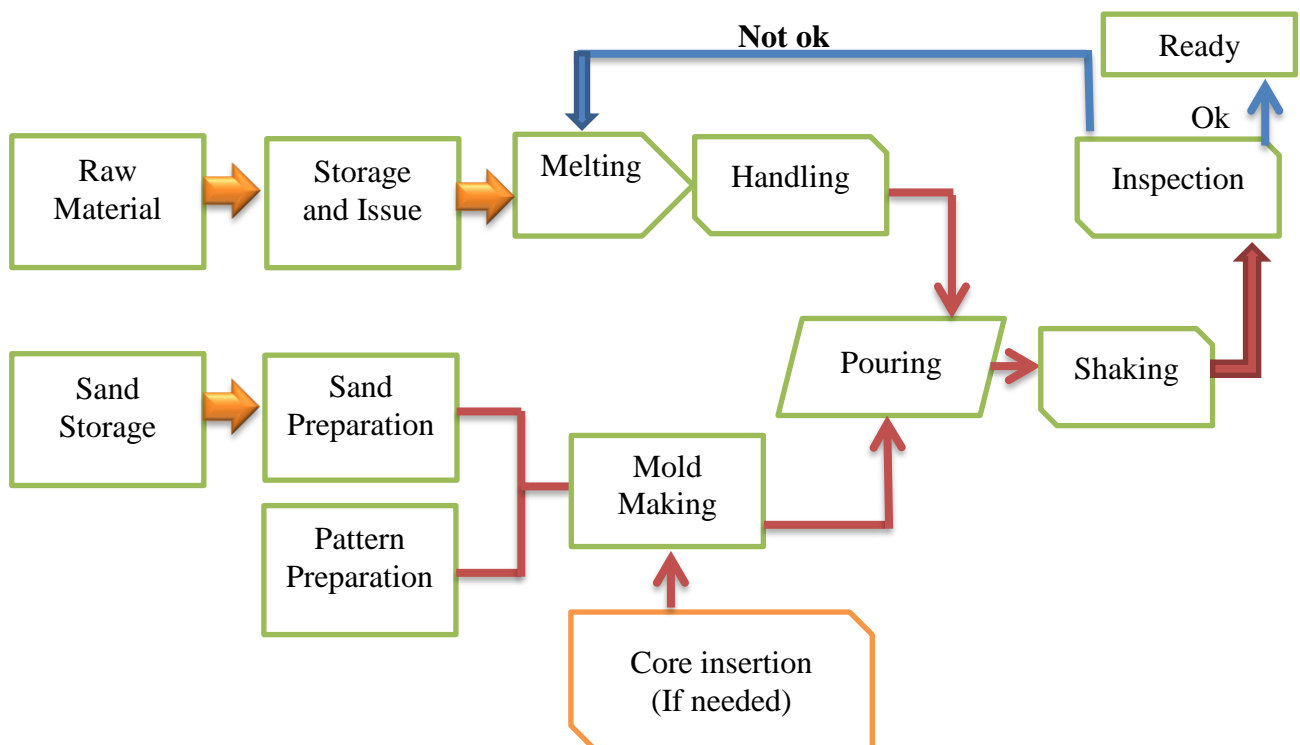


Figure 3.3:- Process flow chart of existing casting process

As shown on figure 3.3 the overall process path not fully modernized, due to that various parts are rejected and it takes much time on machining. So that after this research work a better quality products, less rejection, better resource utilization will be expected up on full implementation of the outcome of the current research.

3.2.1.2 Casting sand

Currently in Case Study Company silica sand are used. However, this sand can be brittle and can easily break down under the high temperatures of molten metal. They add some amount of black molasses in order to minimize the breakage capacity and have a better binder ability and mix effectively before molding preparation. Finally, with prepared plastic hammer effective sand ramming done manually.



Figure 3.4:- Silica sand [Photo taken from case company]

A: - Silica sand mixed with molasses B: - Mold preparation from silica sand

3.2.1.3 Pattern used during experiment

In Case Company, metal pattern made up of aluminum metal with different size used. However, the available pattern surface finish was not as smoother and has not sufficient draft angle used to dis-attach from the mold.

3.2.1.4 Mold making process

Drag and cope mold segment made from black steel metal was fully rammed with silica sand effectively as shown on Figure 3.5.



Figure 3.5:- Mold making process [Photo taken during experimental task at case company]

A: - Drag mold making process

B: - Cope mold-making process

C: - Pattern removal process

D: - Prepared and ready mold for pouring

3.2.1.4.1 Size and preparation of drag mold

Drag flask made up from metal was placed upside down on a wood board around a metal pattern of the pulley product to be cast. Then talcum powder was dusted over the pattern to aid in the removal of the pattern. Then little sand was sifted over the pattern until the model is covered by a few inches of sand. Again More sand is then dumped into the drag, and

rammed with a wooden wedge, or mechanically vibrated to pack the sand down. Regarding to size 500mm length 500mm width and 120mm height cope mold flask was used as shown with detail size and configuration on Figure 3.6.

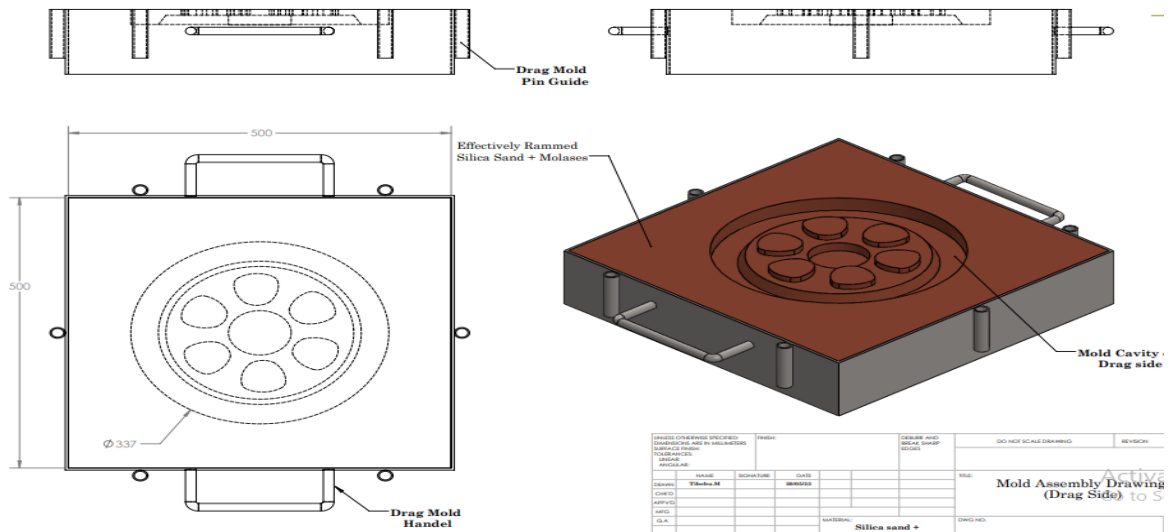


Figure 3.6:- Geometry and size of cope mold with dimension.

3.2.1.4.2 Size and preparation of drag mold

The cope flask was placed on the drag, and dowels (or pins) are put in the sand to make holes for the sprue and risers. Talcum powder and sand are sifted over the pattern and they effectively rammed to fill the cope. Then inserted pins are carefully pulled out of the sand. Again, 500mm length 500mm width and 120mm height drag mold flask was used as shown with detail size and configuration on Figure 3.7.

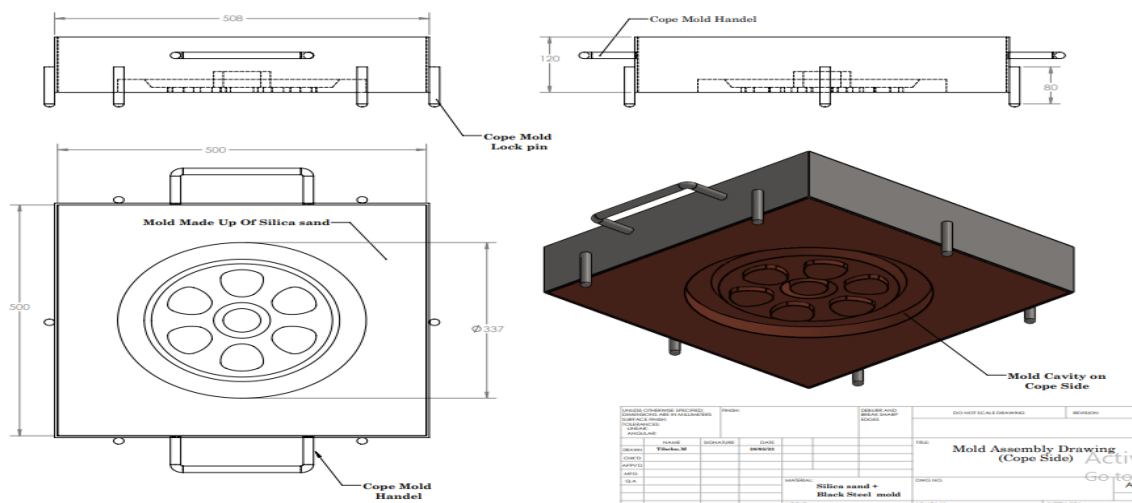


Figure 3.7:- Geometry and size of drag mold with dimension.

3.2.1.5 Melting and Pouring Mechanism

I. Melting temperature of aluminum

The melting temperature of metal depends on its purity. Aluminum alloys do not liquefy at a specific melting temperature but it comes in a range of temperatures that depending on the alloy composition.

Table 3.1:- The melting temperature range of some common cast aluminum alloys (AA designation).

| S. No | Aluminum types | Melting temperature range |
|-------|----------------|---------------------------|
| 1 | A380 | 566°C-580 °C |
| 2 | A356 | 557.2 – 612.8 °C |
| 3 | A413 | 649 – 760 °C |
| 4 | A360 | 577°C-612 °C |
| 5 | 319 | 516 – 604 °C |
| 6 | 390 | 507 – 649 °C |

In the research serial number two at ranges of melting temperature (557.2- 612.8°C) was used as shown on Table 3.1 for melting of aluminum A356.

II. Pouring temperature of aluminum

Aluminum pouring temperature, together with the melting temperature, is the aluminum casting temperature parameters that much influence the mechanical properties and casting-ability of aluminum alloys. Adding too high pouring temperature can cause shrinkage, mold wrapping and reduce the dimensional accuracy of the aluminum casting products. On the other hand, the too low aluminum pouring temperature can result in the mold cavity is not fully filled due to the rapid solidification of aluminum alloys, causing casting defects and inaccuracy.

From various different literature it has observed that the optimal pouring temperature range of aluminum alloys are **680°C to 750°C**. At this range, the aluminum casting parts are produced with good mechanical properties and casting quality.

3.3 Experimental task of current existing product

At case, company varieties of pulley products are being fabricated from A356 aluminum alloy through using silica sand mixed with molasses sands. During product fabrication there is no any casting simulation software was used in order to minimize a defect. Currently at case company after pulley product is casted it looks as shown on Figure3.8.



Figure 3.8:- Pulley product fabricated according to existing model

3.4 Identification of products mostly faced to defect

In order to identify the products mostly faced with defect the principles of failure mode and effect analysis (FMEA) for aluminum casting product was modeled. Through visiting the casting process each failure modes was identified and potential effects of failure was evaluated with their severity value. After that, the causes and their prevention was calculated along with their occurrence value. Detection value also assigned to the failure mode, and finally the R.P.N value was calculated for different four products. FMEA analysis was assisted in reducing down time of the machining process after casted product fabricated by improving its reliability.

3.4.1 Ranking severity of effect

Severity is the assessment of the seriousness of the effect of the potential failure mode [27]. Criteria for ranking of severity occurrence and detection were selected suitably by analyzing the past defect records of the casted product. There are various criteria listed with its own ranking based on the history of previous defect recorded data on Table 3.2.

Table 3.2:- Severity of effect [28] [27]

| <i>Effect</i> | <i>Criteria: Severity of effect</i> | <i>Example</i> | <i>Ranking</i> |
|---------------------------|---|-------------------------------|----------------|
| Hazardous without warning | Failure mode affects safe operation of product and occur without warning. | May cause injury or death | 10 |
| Hazardous with warning | Very high severity ranking. Failure will occur without warning. | Regulatory non-compliance | 9 |
| Very high | Major disruption to machining line. 100% of product may have to be scrapped | In-effective service | 8 |
| High | Minor disruption to machining line apportion of the product have to be scrapped. Item operable but reduced level | High Customer Dissatisfaction | 7 |
| Moderate | Minor disruption to machining and operation line. A portion of product may have to be scrapped (no sorting) | Potential in-effectiveness | 6 |
| Low | Minor disruption to machining line .100% of product may have to rework. item operable | Customer Complaints | 5 |
| Very low | Minor disruption to machine line. Product may have to be sorted and a portion reworked. Minor adjustment do not conform. Defect noticed by customer. | Lowered effectiveness | 4 |
| Minor | Minor disruption to production line. A portion of product may have to be reworked on-line, but out of station. Minor adjustments do not conform | A nuisance to the customer | 3 |
| Very minor | Minor disruption to production line. A portion of product may have to be reworked on-line, but out of station. Minor adjustments do not conform. Defect noticed by discriminating customer. | Not apparent; minor effect | 2 |
| None | No effect | Not apparent; no effect | 1 |

3.4.2 Ranking for possible failure rates (Occurrence)

Occurrence is the chance that one of the specific cause/mechanism will occur. In this step, it is necessary to look at the cause of a failure and times it occurs [27] [30]. Occurrence also described as probability of the failure mode and cause [29]. Looking at similar products or processes the failures that has documented for selected pulley product are registered depends on the information mentioned at Table 3.3.

Table 3.3:- Example of occurrence table

| Rank | Occurrence | Rank | Occurrence |
|------|---------------------------|------|----------------------------|
| 1 | Extremely Unlikely | 6 | Medium likelihood |
| 2 | Remote Likelihood | 7 | Moderately high likelihood |
| 3 | Very Low Likelihood | 8 | Very High Likelihood |
| 4 | Low Likelihood | 9 | Extreme Likelihood |
| 5 | Moderately Low Likelihood | 10 | Maximum Likelihood |

3.4.3 Assign detection rating

Detection rankings evaluate the current process controls in place [28]. To assign detection rankings, identify the process or products related controls in place for each failure mode and then assign a detection ranking to each control. In simple words it can said that detection ranking is done based on prevention failure modes from occurring or which detect the failure before it reaches to the customer [30]. An example for ranking of the detection are listed on Table 3.4.

Table 3.4:- Likely detection of failures and corresponding ranking

| Rank | Detection | Rank | Detection |
|------|----------------------------|------|---------------------------|
| 1 | Extremely Likely | 6 | Moderately Low Likelihood |
| 2 | Very High Likelihood | 7 | Low Likelihood |
| 3 | High Likelihood | 8 | Very Low Likelihood |
| 4 | Moderately High Likelihood | 9 | Very Low Likelihood |
| 5 | Medium Likelihood | 10 | Extremely Unlikely |

3.4.4 Calculation of risk priority number (RPN) for listed product

Using values of severity occurrence and detection numbers risk priority number (RPN) calculated for selected defects. The RPN gives us a relative risk ranking. The RPN was calculated by multiplying the three rankings together.

$$\text{Risk Priority Number (RPN)} = (\text{Severity}) \times (\text{Occurrence}) \times (\text{Detection}) \dots (3.1)$$

RPN was calculated for certain failure mode with corresponding effect for different selected products. It will always be between 1 and 1000. The higher the RPN product will be the relative risk. Risk priority number (RPN) also shows us an excellent way to prioritize focused improvement efforts for certain casted products. Therefore, on Table 3.5 shows the risk priority numbers of different products registered.

Table 3.5:- Risk priority number calculation for listed product

| Product | Failure mode | Severity S | Occurrence O | Detection D | RPN | |
|-------------------|-----------------------------|---------------|-----------------|----------------|-----|-----|
| Coupling (Hub) | Surface Void | 6 | 6 | 1 | 36 | 240 |
| | Blow hole on surface | 6 | 3 | 5 | 90 | |
| | Hot spot on product surface | 8 | 1 | 2 | 16 | |
| | Underweight in mass | 5 | 2 | 2 | 20 | |
| | Shape lose | 7 | 2 | 1 | 14 | |
| | Shrinkage porosity | 4 | 8 | 2 | 64 | |
| Sprocket | Surface Void | 8 | 5 | 1 | 40 | 229 |
| | Blow hole on surface | 7 | 2 | 1 | 14 | |
| | Hot spot on product surface | 4 | 4 | 2 | 32 | |
| | Underweight in mass | 3 | 3 | 1 | 9 | |
| | Shape lose | 7 | 2 | 1 | 14 | |
| | Shrinkage porosity | 3 | 5 | 8 | 120 | |
| Pulley | Surface Void | 8 | 7 | 2 | 112 | 450 |
| | Blow hole on surface | 5 | 5 | 2 | 50 | |
| | Hot spot on product surface | 7 | 6 | 1 | 42 | |
| | Underweight in mass | 9 | 3 | 2 | 54 | |
| | Shape lose | 6 | 7 | 2 | 84 | |

| | | | | | | |
|------|-----------------------------|---|---|---|-----|-----|
| | Shrinkage Porosity | 2 | 6 | 9 | 108 | |
| Gear | Surface Void | 8 | 6 | 2 | 96 | 409 |
| | Blow hole on surface | 5 | 4 | 1 | 20 | |
| | Hot spot on product surface | 9 | 7 | 1 | 63 | |
| | Underweight in mass | 4 | 6 | 3 | 72 | |
| | Shape lose | 8 | 2 | 2 | 32 | |
| | Shrinkage porosity | 2 | 9 | 7 | 126 | |

As shown on Table 3.5 higher value of risk priority number obtained for pulley products, gear products, coupling and sprockets respectively. Therefore, pulley product selected for this research. To minimize those defect and severity effects a Pro CAST simulation software used for detail design and simulation of process enhanced before actual casting process conducted.

3.5 Identification of major defect cause a product to be reject

3.5.1 Identification Method

I. Based on documented data

First data collection on the amount of product rejection data, information about casted product was conducted inside foundry. Then product rejection data of one months was gathered from quality check (QC) reports and the most common problems due to which products rejected listed before the start of the study. Table 3.6 lists the major problem that cause the product to be reject areas with the percentage of rejection.

Table 3.6:- Major casting defect with resulted percent rejection

| <i>Sr. No</i> | <i>Major problem (Defect) cause product to be reject</i> | <i>% rejection for pulley products</i> | <i>Rank</i> |
|---------------|--|--|-----------------|
| 1 | Surface void | 24.9 | 1st |
| 2 | Blow hole on surface | 11.1 | 5 th |
| 3 | Hot spot on product surface | 9.3 | 6 th |
| 4 | Underweight in mass | 12 | 4 th |
| 5 | Shape lose | 18.7 | 3 rd |
| 6 | Shrinkage Porosity | 24 | 2 nd |

II. Based on RPN number

According to calculated RPN (Risk priority number) on Table 3.5, a pulley product has a maximum RPN than other products. Additionally from RPN result shrinkage porosity registered shrinkage porosity value was maximum than other.

III. Depending on simulation result of currently existing model

On the result of currently available model (scenario number one) different defect was visited. On total volume of product 5.56% volume was affected by shrinkage porosity. Open type shrinkage defect on different node of surface of castings and closed type shrinkage defects on the interior node of a product were also visited. Additionally there is a hotspot defect, which visited on more than 35 points of pulley product and low percentage of void visited on products indicated at Figure3.8.

3.6 Research materials used

During this research aluminum, alloyA356 was used as cast material. Aluminum alloy was chosen due to the fact that it was used widely in common engineering application of various products like that of pulley, rivets, bolts, structural members, water-cooled cylinder blocks, plants among other applications ... etc.

3.6.1 Mechanical properties of Aluminum A356 Alloy

From various properties of aluminum A356 excellent cast ability, good weld-ability, pressure tightness, and good resistance to corrosion are the major reason that made to use this material inside the foundry of Case Study Company. On Table 3.7, mechanical properties of aluminum A356 alloy are described [1].

Table 3.7:- Mechanical properties of Aluminum A356

| Properties | Value |
|---|----------------------|
| Proof Stress (N/mm ²) | 185 |
| Tensile stress (N/mm ²) | 230 |
| Elongation (%) | 2 |
| Brinell Hardness | 75 |
| Endurance Limit | 56 |
| Modulus of Elasticity (N/m ²) | 7.24e ⁺¹⁰ |
| Shear Modulus (N/m ²) | 2.72e ⁺¹⁰ |
| Poisson Ratio(N/A) | 0.33 |

3.6.2 Thermal and mass properties of Aluminum A356

Lightweight is the other properties that made aluminum for various purposes as listed [17].

Table 3.8 shows thermal and mass properties of aluminum A356 Alloy.

Table 3.8:- Aluminum A356 thermal and mass properties

| Properties | Unit | Amount |
|-------------------------------|--------------------|---------------------|
| Density | g/cm | 2.685 |
| Liquids temperature | °C, °F | 615,1135 |
| Solidus temperature | °C, °F | 555,1035 |
| Specific Heat at 100 °C | J/Kg.K, Btu/lb. °F | 963, 0.230 |
| Latent heat of fusion | KJ/Kg | 389 |
| Thermal conductivity | °C, °F | 25,77 |
| Thermal expansion coefficient | /k | 2.14e ⁻⁵ |

3.6.3 Chemical Composition of Aluminum A356

Aluminum A356 is alloy composed from various compositions with capacity described [1] [17]. Table 3.9 shows a clear chemical composition aluminum A356 alloy composed.

Table 3.9:- Chemical composition of aluminum A356 alloy

| Composition | Measurement | Amount |
|--------------------|--------------------|---------------|
| Aluminum | % | 92.4 |
| Silicon | % | 6.5-7.5 |
| Magnesium | % | 0.25-0.45 |
| Tin | % | 0.2 |
| Iron | % | 0.12 |
| Manganese and Zink | % | 0.02 |

3.7 Design of improved casting system

3.7.1 Gating system design

Gating system design using Caine’s method, as Caine’s rule both the height of riser and riser neck was assumed first. Then after that other parameter are designed depending on the size of riser neck and height of risers. Optimum gating design can determines the optimal pouring time. Mold filling simulation performed to determine the actual filling time, and to identify gating related defects. The gating design analyzed in terms of yield, ease of fettling and other criteria based on which suggestions for design improvement presented. Depending on the gating ratio types of gating systems on the choke, area categorized as **Non-pressurized** and **pressurized**. For this study aluminium alloys with non-pressurized gating system ratio **$A_s: A_r: A_g = 1:4:4$** (Non- pressurized gating ratio) will be used [27].

Where A_s = the cross sectional area of the sprue exit,

A_r = the cross sectional area of the Runner(s) and

A_g = the cross sectional area of the ingate(s)

The choke (the smallest cross sectional area) is at the sprue base exit therefore $A_s=A_c$.

Table 3.10:- Gating ratio for several of materials [27].

| Materials | Gating ratio |
|-----------------|--|
| Aluminum | 1:2:1 1:1.2:2 1:2:4 1:3:3 1:4:4 1:6:6 |
| Aluminum bronze | 1:2.88:4.8 |
| Brass | 1:1:1 1:2:3 1.6:1.3:1 |
| Copper | 2:8:1 3:9:1 |
| Ductile iron | 1.15:1.1:1 1.25:1.13:1 1.33:2.67:1 |

For this research Aluminum material with 1:4:4 Gating Ratio was selected from Table 3.10.

3.7.2 Types of gate selected

In this research, middle and top parting line gate was selected. Because this gate type solves the disadvantages of both bottom and top gate. During parting line, gate system the compartment below the parting line filled with liquid metal through top gating, while the compartment above the parting line filled with the bottom gating.

3.7.3 Calculate the total weight of castings

$$W = \rho \times V \dots \dots \dots (3.2)$$

Where: - W = total weight of casting,

ρ = density (2705 kg/m³)

V = total volume of casting = 2915740.88mm³ = 0.0029157409m³

W = 2705Kg/m³ x 0.00291574m³

= 7.88Kg

3.7.4 Pouring rate and pouring time calculation

Pouring rate formula for non-ferrous gating becomes $=R(b\sqrt{w})$ (3.3)

Where:- R = pouring rate

b = constant depends on wall thickness. Typical values of b is shown on Table 3.11.

Table 3.11:- Values of constant (b) for different casting thickness [27]

| Wall thickness (mm) | Below 6 mm | 6-12 mm | Above 12 mm |
|---------------------|------------|---------|-------------|
| b -constant | 0.99 | 0.87 | 0.47 |

$$R = 0.47 \times \sqrt{7.89} = 1.3193 \text{Kg/sec}$$

$$\text{Then } Ra = \frac{R}{K.c} \text{ (3.4)}$$

Where:- Ra = adjusted pouring rate,

K = metal fluidity,

C = the effect of friction with values of 0.85-0.90 for tapered sprues in the gating system.

$$Ra = \frac{1.3193}{1 \times 0.87} = 1.516 \text{Kg/sec}$$

$$\text{And also } t = \frac{W}{Ra} = 7.88 \text{Kg} / 1.516 \text{Kg/sec}$$

$$t = 5.21 \text{sec,}$$

Where: t = pouring time

3.7.5 Calculate the effective sprue height:

The design of the down sprue is critical in order to avoid start of turbulent flow in the system. Turbulent metal flow might cause an increased area, which exposed to air and thus an increased oxidation of the metal. Those oxides may rise to the top of the casting to form a rough surface for the casting or they may be trapped in the casting and create imperfections. Turbulent flow may also cause erosion of the sand mold. To avoid turbulence flow, oxides formed, erosion proper design of sprue is necessary [27].

$$\text{Effective sprue height (H}_p\text{)} = h - 0.5 \times (H_1^2/H_2) \dots\dots\dots (3.5)$$

Where:- Sprue height (h) = 140 mm

Height of casting in the cope H₁=30mm

Total height(Cope + Drag Casting Height) H₂ =76mm

$$H_p = 140 - 0.5 \times \left(\frac{30^2}{76}\right) = 140 - 0.5 (11.84) = \mathbf{134.8mm}$$

3.7.6 Calculate the choke cross sectional area

Choke cross sectional area is the smallest cross sectional area in the gating system, which is sprue exit area, used to calculate sprue height and sprue inlet and exit radius.

$$\text{Cross sectional area of choke } A_c = \frac{W}{\rho t c \sqrt{2gH_p}} \dots\dots\dots (3.6)$$

Where:- A_c = choke area (mm²)

W = Casting weight (Kg)

ρ = Density of molten metal ($\frac{Kg}{m^3}$)

H_p = effective sprue height (m)

c = discharge coefficient (0.8)

g = acceleration due to gravity (9.81m/s²)

Ra = adjusted pouring rate (Kg/s)

t = Pouring time(s)

$$A_c = \frac{7.88}{2685 \times 5.21 \times 0.8 \times \sqrt{2 \times 9.81 \times 0.1348}} = \mathbf{427mm^2}$$

3.7.7 Calculation of the sprue inlet area

Since sprue exit area $A_{\text{sprue exit}} = \text{Choke area } (A_c)$, From continuity equation 3.8:-

$$A_{\text{sprue inlet}} = \frac{A_{\text{sprue exit}} \sqrt{H_{\text{Sprue exit}}}}{\sqrt{H_{\text{sprue Inlet}}}} \dots\dots\dots (3.8)$$

$$= 427 \times \frac{\sqrt{195}}{\sqrt{35}} = 935.83 \text{mm}^2$$

Where: - $A_{\text{sprue inlet}} = \text{Sprue inlet cross sectional area.}$

$$A_{\text{sprue exit}} = \text{Sprue exit cross sectional area} = 404 \text{mm}^2$$

$$H_{\text{Sprue exit}} = \text{Distance between the ladle and sprue exit} = 160 + 35$$

$$= 195 \text{mm}$$

$$H_{\text{Sprue inlet}} = \text{Distance between the ladle and sprue top} = 35 \text{mm}$$

- ✓ Height between ladle & sprue-inlet or height of the sprue inlet = 35 mm its assumption.

Diameter of the sprue inlet, $A_{\text{sprue inlet}} = \pi r^2 = \frac{\pi D^2}{4} \dots\dots\dots (3.9)$

$$D^2 = \frac{A \times 4}{\pi} = \frac{935.83 \times 4}{\pi} = 1191.53, \text{ Diameter of sprue inlet } (D) = 34.5 \text{mm}$$

Diameter of the sprue exit, $A_{\text{sprue exit}} = \pi r^2 = \frac{\pi D^2}{4}$

$$D^2 = \frac{A \times 4}{\pi} = \frac{404 \times 4}{\pi} = 514.4, \text{ Diameter of sprue exit } (D) = 23 \text{mm}$$

3.7.8 Design of the in gate and runner cross-sectional area

Runners are the passages that carry the molten metal from the sprue well to the gates through which metal enters the mold cavity. Gates are the passages between the runners and the part. Both gate and runner cross-sectional area designed based on gating ratio of **1:4:4**. So according to gate ratio runner cross-sectional area = $4 \times 404 \text{mm}^2 = \mathbf{1616 \text{mm}^2}$. Since for a square,

$$\text{Area} = L \times B \dots\dots\dots(3.10)$$

Where:- L = length,

B = breath. But during ingate case Length = Breath,

$$\text{So that Length} = \sqrt{\text{Area}} = \sqrt{1616} = \mathbf{40.2 \text{mm}} = \text{Breath}$$

Total number of in gate used is 2 means is divided into two will be divided in to two equal areas. Therefore area for each in gate is **808mm²**

3.7.9 Design of Sprue well

Sprue well is the passage of transferring molten metal from sprue exit to runner.

$$\text{Sprue well cross-sectional area} = 5 \times \text{sprue exit area} \dots\dots\dots(3.11)$$

$$= 5 \times 404 \text{ mm}^2 = \mathbf{2020 \text{ mm}^2}, \text{ When } A = \pi r^2, r=25.35 \text{mm}$$

$$\text{Sprue well depth} = 2 \times \text{runner depth} \dots\dots\dots (3.12)$$

$$= 2 \times 28.5 = \mathbf{57 \text{ mm}}$$

3.8 Feeder design

Feeders designed to compensate the solidification shrinkage of a casting, and make it free of shrinkage porosity. Feeder design parameter includes shape, and dimensions of feeder, circular section requires higher gradient than flat rectangular sections. It also depends upon the quality improvement. The temperature and gradient at any point along the feed path influence the type of feeding at that location [31]. In this research for the greatest efficiency, for small casting, riser should be cylindrical.

According to Chvirino’s rule: $\frac{V}{A} \text{Riser} > \frac{V}{A} \text{Casting} \dots\dots\dots(3.13) [31]$

$$\text{Volume of riser} = 0.47 \times \text{Volume of casting} \dots\dots\dots (3.14)$$

$$= 0.47 * 2915740.88\text{mm}^3 = 1370397.8\text{mm}^3$$

$$Volume = \frac{\pi D^2 H}{4} = 1370397.8\text{mm}^3$$

But for Top riser $H = D/2$ and

For Side Riser $H = D$

$$\frac{\pi}{8} D^3 = 1370397.88, \quad D^3 = 1370397.88 * 8/\pi \quad \frac{\pi}{4} D^3 = 1370397.88$$

$$D = 151.68\text{mm}$$

$$D = 75.84\text{mm}$$

After detail calculation three different scenario designed with a size of sprue, runner, riser and in gate summarized on Table 3.12.

Table 3.12:- Summary of conventional and revised gating and feeding system size.

| Types | Sprue (mm) | | | Runner (mm) | | | Riser (mm) | | In gate (mm) | | |
|--|------------|---------|-----|-------------|-----|----|------------|-----|--------------|----|----|
| | Base Dim | Top Dim | H | W | L | H | D | H | W | L | H |
| Convectional Gating and Feeding System | 30 | 38 | 140 | - | - | - | 25 | 120 | 40 | 40 | 15 |
| Revised Scenario Number Two | 30 | 46 | 140 | - | - | - | 25 | 120 | 25 | 40 | 20 |
| Revised Scenario Number Three | 30 | 46 | 174 | 20 | 120 | 20 | 37.5 | 135 | 20 | 35 | 20 |

3.9 Design of pattern

A pattern of pulley part fabricated from aluminum metal with cope and drag section, having a good surface finish. During design shrinkage, allowance for Aluminum alloys is 16mm/m. **Pattern Dimension = Actual Dimension + Shrinkage allowance...** (3.15).

Table 3.13 shows a detail size of product and detail size of pattern.

Table 3.13:- Parameters with product and pattern size of pulley .

| No | Parameters | Product size (mm) | Pattern size(mm) |
|----|----------------------------|-------------------|------------------|
| 1 | Pulley outer diameter (D1) | 330 | 335.28 |
| 2 | Pulley middle diameter D2 | 260 | 264.16 |
| 3 | Pulley Center diameter D3 | 240 | 243.85 |
| 4 | Inside hole diameter | 50 | 49.2 |
| 5 | Flange diameter (F1) | 75 | 76.12 |
| 6 | Pulley + Hub width (H1) | 33.5 | 34 |
| 7 | Pulley width (H2) | 17.5 | 14.46 |

| | | | |
|---|-----------------|----|--------------|
| 8 | Hub length (H3) | 17 | 18.26 |
| 9 | Hub width (H4) | 17 | 18.26 |

According to all three designed senario the size of selected product becomes the same and detail dimensions are shown on figure3.9.

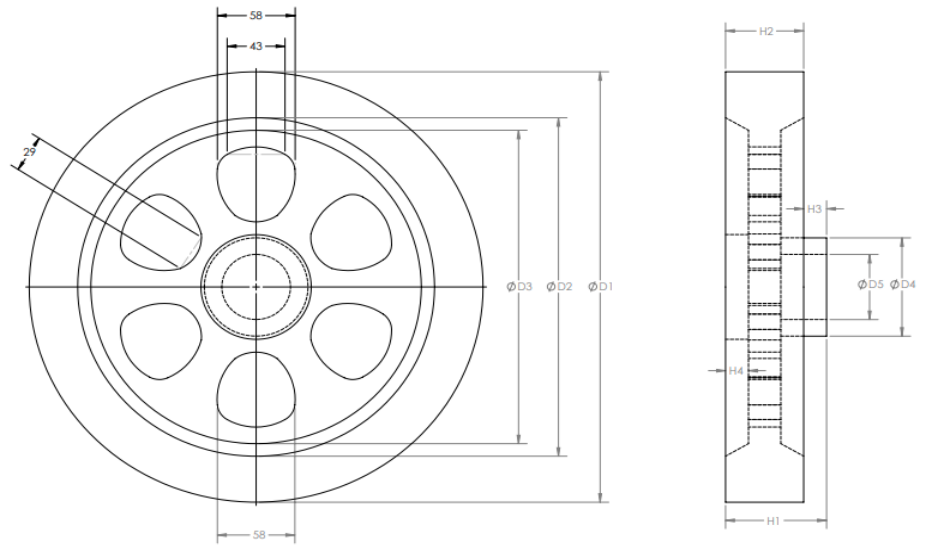


Figure 3.9:- Pulley pattern detail size drawing (Solid Work 2022)

Original dimension of pulley D=300 and t=60

- Pattern diameter = $300 + 0.30 \times 16 = 304.8$ mm
- Pattern height = $60 + 0.060 \times 16 = 60.96$ mm

3.10 Computer simulation of casting process

Simulation is the process of imitating a real phenomenon using a set of mathematical equations implemented in a computer program. During casting simulation the mold filling and solidification analysis conducted by using an algorithm or program based on finite volume method, to identify the hot spots and hence defects like shrinkage porosities, hot tears, cracks, etc. Product model (with feeders and gates) of a pulley part was designed on SOLID WORK 2022. Then after converting model to stl format, it was imported into the casting simulation software (PROCAST).

3.10.1 Software used

Pro cast and 3D flow simulation software were used to perform various tasks associated with casting simulation process. Each program comprises a set of modules for design, solid modeling, simulation, analysis and improvement. The major software listed with its purpose on Table 3.14.

Table 3.14:- List of used software

| <i>S.No</i> | <i>Software used</i> | <i>Purpose</i> |
|-------------|----------------------|---|
| 1 | Solid work 2022 | Design and 3D modelling of pulley parts with three different scenario. Design and modeling of the whole gating system of parts. Modeling of silica sand mold. Weight and volume ratio calculation. Conversion of 3D Model to step file. |
| 2 | Pro Cast | To design feed module. To indicate optimum gating system Feeding optimization Hot defect visualization Shrinkage porosity defect visualization Void place indication |
| 3 | Minitab 21.2 | To calculate the influence of process parameters on rejection rate |

3.10.2 Casting simulation procedure

The main target of simulation was to minimize the amount of rejection rate inside foundry through conducting a computer-aided detection of defect before conducting actual casting processes. During this simulation, it has its own flow path as shown on Figure 3.10.

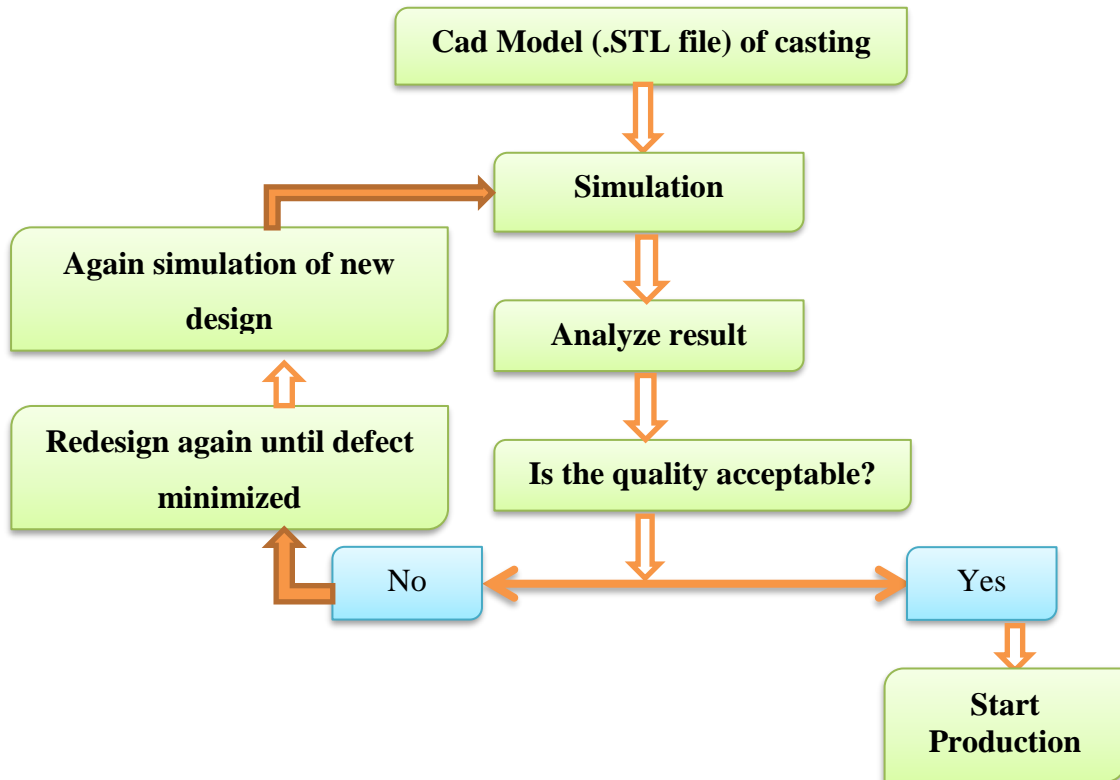


Figure 3.10:- Procedure for casting simulation

During simulation case, number of iteration were conducted and from these iterations, the best one was selected before conducting actual casting. Depending on best simulation result, casting was conducted and result comparison prepared was conducted.

3.10.3 Modelling Process

Generally, the simulation software has three main parts: **Pre-processing: the program reads which mean the CAD geometry and generates the mesh**, Main processing adding of boundary conditions and material data, filling and temperature calculations, Post processing: presentation, evaluation. Casting simulation package requires three-dimensional CAD model for the simulation purpose. CAD model designed with gating and risering system. Computer simulation based on the design procedures described above has implemented with one case study.

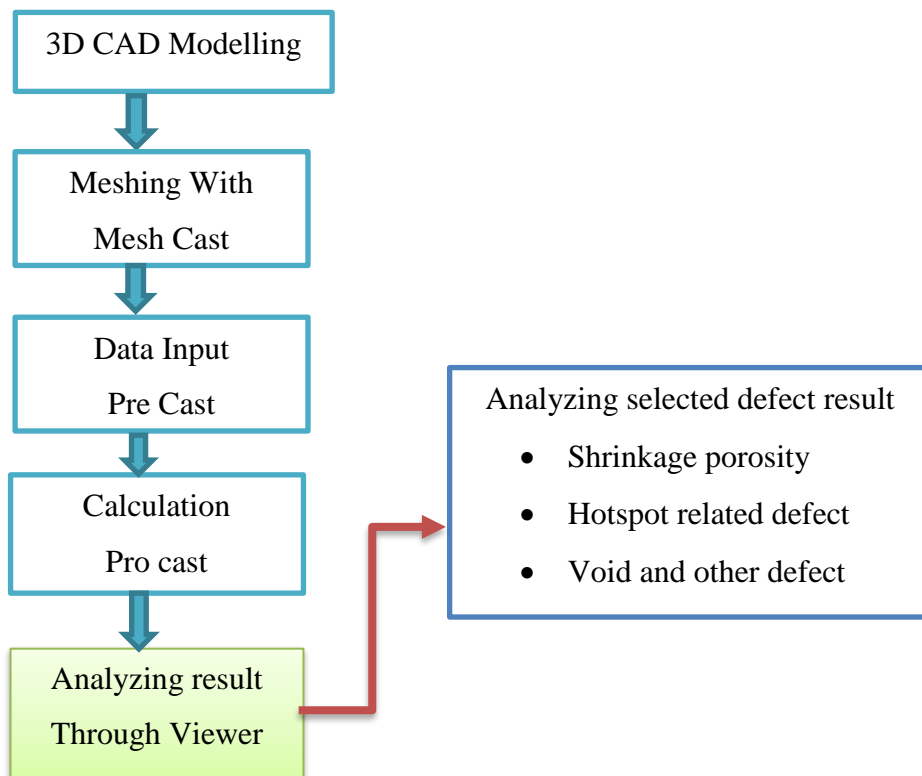


Figure 3.11:- Pro-CAST Simulation Work Flow

The purpose of this stage was to generate a finite element model, to setup the calculation, to run the analysis and to interpret the results. The primary working flow of Pro CAST casting simulation divided into three main parts: -

- ✚ It begins with Pre-Processing.
- ✚ Next step it solves various input parameters which used to run the analysis and
- ✚ Finally was it interpret the results and each step includes several sub-steps.

3.10.4 Input parameters for casting simulations

The parameters that have the greatest influence on the sand casting selected as input parameters. In this research, Table 3.15 describes the following parameter, which selected as input parameters:-

Table 3.15:- Main input Process Parameter

| Input Process parameters | Values |
|---------------------------------|------------------------|
| Casting Materials | Aluminum, A356 |
| Molding Material | Silica Sand |
| Pouring Temperature | 660°C, 680°C and 700°C |
| Pouring Rate | 1.2,1.5 and 2 Kg/s |
| Mold Temperature | 20°C,25°C and 30°C |
| Solidification Time | - |
| Heat Co-efficient | Different |

3.10.5 Simulation process parameters

During simulation on PRO CAST casting simulation software there are certain process parameters, which given as input for the program. From those the following are the major parameters.

3.10.5.1 Thermal related simulation parameter

Under Table 3.16, list of thermal related process parameter used during simulation and further description of parameter with stated values mentioned separately.

Table 3.16:- Thermal related simulation process parameter.

| Process parameters | Description on Parameters | Used |
|---------------------------|---|-------------------|
| POROS | Specifies the porosity calculations to be performed Choose from: 0 - for no porosity calculation. 1 - Most advanced porosity model. 8 - Evolution of the POROS=8 model, which allows to handle multiple free surfaces. 4 - Old porosity model from version 3.2.0. In order to disable the porosity calculation, one should set POROS = 0. | On 1 is activated |

| | | |
|----------|--|---|
| | | |
| MACROFS | Parameter used for the macro porosity calculation. It sets the limiting fraction of solid between the macro porosity and the micro porosity formation. The value should be set between 0 and 1. | 0.7 is default value for aluminum alloy casting |
| FEEDLEN | "Feeding length" (distance), at which macro porosity can occur, beyond the MACROFS ISO surface. | |
| NIYAMA | Is widely used criterion in metal casting, Value are evaluated at a specified temperature (or fraction solid) near the end of solidification. Simulation parameter NIYAMA [0, 1] corresponding to the fraction of solid where regular Niyama is calculated. | Recommended and default value is 0.9. |
| GATEFEED | Allows specifying whether liquid fed at the in-gate or not. In the case of injection (i.e. HPDC or LPDC), the shrinkage at the gate is compensated by the liquid pushed by the piston (for HPDC). On the other hand, in gravity casting, there is no feeding at the top of the risers and piping will occur. GATEFEED=1 will automatically activate the "Active feeding" where inlet velocities or pressures are set. | GATEFEED=1 activated which tells the software to activate the feeding at the in gate, thus leading to no piping at this location. |
| GATENODE | GATENODE is an alternative to GATEFEED. When a gate feeding should applied, but there is no external surface of the model where an inlet surface or a pressure can applied. | Set to constant value 0 |
| MOLDRIG | The rigidity of the mold has an influence on the amount of porosity in the case of expanding alloys. If the mold is very rigid, the casting cannot expand and thus the alloy expansion will be "available" for the "refill" of the existing porosity. On the other hand, if the mold is very soft (or weak), the casting will expand and thus there will be no "refill" of the porosity (of course, the reality is more complex as the solid shell is thick enough it will act as a "rigid" mold, even if the sand mold is weak. For real situations, the value of MOLDRIG should be set somewhere between 0 and 1 depending upon the casting processes. The default value is 1. | Default Value 1 activated |
| HOTSPOT | Allow specifying whether the user wants the hot spots to compute or not. Choose from: 0 - for no hot spots calculation. 1 - To perform hot spots calculation. | 1 is activated to calculate hotspot |

3.10.5.2 Flow related simulation parameter

Under table 3.15, there is detail list of process parameter used during simulation and further description of parameter with stated values mentioned separately.

Table 3.17:- List of flow related simulation parameter used for controls the use of molten metal (fluid)equations.

| Process parameters | Description on Parameters | Sated Value |
|--------------------|--|--|
| GAS | Specifies whether to consider the trapped gas effects. If the option to consider trapped gas effects chosen, trapped gas effects will considered even when the model contains no vents, gas injection, or gas diffusion through the mold. Choose from: 0 - not consider trapped gas effects. 1 - Consider trapped gas effects, but gas pressure does not change. The mass associated with the lost volume becomes air entrainment in castings. | ON With back gas pressure was used |
| VFREQ | Specifies the time step interval for writing velocity and pressure results to the unformatted files. This parameter can used to reduce the size of these results files, which can become quite large for problems with many nodes and time steps. | 10 interval value was sated |
| PREF | Specifies the pressure, which be subtracted from any boundary condition pressure in order to convert an absolute pressure into a gauge pressure. This parameter comes into play when: (1) there is trapped gas, (2) a pressure boundary condition drives the flow, (3) there are vents, and/or (4) there is gas injected. For example, if the pressure boundary condition drives the flow at a gauge of 1 atmosphere, the boundary condition is set to 2 atm. | Should be set to 1atm as rule of PROCAST |
| LVMASS | Specifies list of casting volumes considered for LVMASS calculation. If this parameter not defined, LVMASS is applicable on all casting volumes. If this parameter (and LVMASS of course) defined, LVMASS is applicable on selected volumes. | LVMASS was defined |
| WSHEAR | Wall shear algorithm that allows take into account a velocity boundary layer along mold wall. It allows non-zero velocities at the mold walls, which is more representative of the reality (slip of the liquid along walls). This is valid at all liquid-mold interfaces and not only at the free surface | ON “ turbulence was |

| | | |
|-----------|---|--|
| | <p>whereas the WALLF algorithm is valid only at the free surface.</p> <p>For HPDC and Gravity casting, a value of WSHEAR = 2 is recommended (however, for large gravity casting a value of WSHEAR = 0 should be used). For LPDC, a value of WSHEAR = 0 must be used.</p> | <p>activated Because of "Gravity Sand cast</p> |
| WALLF | <p>Used to compute the velocity of the free surface at the mold wall (not used away from the free surface). In order to compute the velocity of the free surface at the mold wall, one takes the core velocity of the closest core node (i.e. closest node in the volume). The surface velocity at the free surface is equal to the core velocity of this closest node multiplied by WALLF. This algorithm applied for any value of WSHEAR.</p> <p>A value of 0.99 corresponds to more slip along the wall, whereas a value of 0.8 will act as if the mold surface is rougher (more friction). It advised to use a value of 0.9 for sand gravity casting, GDC and LPDC casting, and a value of 0.99 for high-pressure die-casting (HPDC). The default value is 0.9.</p> | <p>0.9 Value used because of Sand Gravity casting</p> |
| OXIDATION | <p>Specifies whether the flow model has to take into account sedimentation of particles or not. Sedimentation of particles (impurities, oxides...) tracked and the model accounts for size of particles drag force and sedimentation under gravity.</p> <p>Choose from: 0 - to indicate no sedimentation of particles. 1 - To indicate with sedimentation of particles.</p> | <p>0 is activated because of no particle sedimentation</p> |
| JUNCTION | <p>Is activating different algorithm for the calculation of the "metal front tracking" and metal movement during the filling. This allows to track where the particles and impurities mostly accumulated and to view the flow junction lines. As this algorithm is taking an amount of CPU time which may not be negligible, by default this calculation is not activated (JUNCTION = 0). To activate it, one should set JUNCTION to 1, 2, 4, 8, 1025, 1026, 1028, 1032 or any combination of those values in the p.dat file.</p> | <p>Default value was activated</p> |
| PFREQ | <p>Specifies the "Particle tracing" launch frequency in the solver. Particles are launched at each node of the inlet (defined by a velocity BC, an inlet pressure BC or an Inlet BC), every PFREQ steps. A value of 50 recommended.</p> | <p>Recommended value was used</p> |

3.10.5.3 Microstructure related simulation parameter

Microstructure module was activated with a value of one. The micro parameters should be activated with a value of 1024. Table 3.18 describes the microstructure related simulation process parameter with activated one.

Table 3.18:- Microstructure related simulation process parameters.

| Process parameters (Designation) | Description on Parameters | Activated |
|---|--|------------------------|
| PERGROW | Defines the pre-factor of the pearlite growth kinetics. The default value is 0.0168. This value changed in order to calibrate the calculated amount of pearlite (respectively of ferrite) with experimental observations. If the value decreased, the amount of pearlite will also decrease, as the growth kinetics will be slower. | Default value was used |
| PERNUCL | Nucleation parameter of the pearlite. Pre-factor of the Nucleation model of the pearlite. The default value is 5e6. This value changed in order to calibrate the calculated amount of pearlite (respectively of ferrite) with experimental observations. If the value decreased, the amount of pearlite will also decrease, as the number of pearlite nodules will be lower. | Default value was used |

3.11 Taguchi Method

Taguchi method is an application of experimental design, control factors. Factors that cannot be controlled (uncontrollable factor) or noise factors always considered as variation. The influence caused by these variables cannot eliminated. Therefore, the main function of the Taguchi method is to reduce product variation [32].

3.11.1 Taguchi orthogonal array

On these research four factors, with mixed level, one factor having 2 levels and another three factor having three level. L-18 ($2^1, 3^3$) Orthogonal arrays (OAs) were used in the simulation analysis as shown on Table 13.7.

Table 3.19:- List of varied factor used and their level.

| Factor | | Range | Level | | |
|----------|-------------------------------|---------|------------|------------|------------|
| | | | 1 | 2 | 3 |
| A | Mold initial Temperature (°C) | 20 -25 | 20 | 25 | - |
| B | Designed Scenario (Model) | 1-3 | Scenario 1 | Scenario 2 | Scenario 3 |
| C | Pouring temperature (°C) | 660-700 | 660 | 670 | 680 |
| D | Flow rate (kg/s) | 1.2-2 | 1.2 | 1.5 | 2 |

Therefore, the simulation performed on 18 runs with different model and the total iteration of 18 simulation with 18 trial sequence was conducted using PROCAST software (Visual cast 17.5). The number of trials depending on the level of the given factors are also shown in Table 3.20.

Table 3.20:- L-18 (2¹, 3³) Orthogonal arrays

| Trial Order | Factor | | | | Recorded Defect Value | | |
|-------------|--------|-------|-----|-----|------------------------|------------------------|-------------------------------------|
| | A | B | C | D | Shrinkage Porosity (%) | Maximum Hot Spot (Sec) | Defect distance on ISO surface (Cm) |
| 1 | 20 | S.N 1 | 660 | 1.2 | - | - | - |
| 2 | 20 | S.N 1 | 670 | 1.5 | - | - | - |
| 3 | 20 | S.N 1 | 680 | 2 | - | - | - |
| 4 | 20 | S.N 2 | 660 | 1.2 | - | - | - |
| 5 | 20 | S.N 2 | 670 | 1.5 | - | - | - |
| 6 | 20 | S.N 2 | 680 | 2 | - | - | - |
| 7 | 20 | S.N 3 | 660 | 1.2 | - | - | - |
| 8 | 20 | S.N 3 | 670 | 1.5 | - | - | - |
| 9 | 20 | S.N 3 | 680 | 2 | - | - | - |
| 10 | 25 | S.N 1 | 660 | 1.2 | - | - | - |
| 11 | 25 | S.N 1 | 670 | 1.5 | - | - | - |
| 12 | 25 | S.N 1 | 680 | 2 | - | - | - |
| 13 | 25 | S.N 2 | 660 | 1.2 | - | - | - |
| 14 | 25 | S.N 2 | 670 | 1.5 | - | - | - |
| 15 | 25 | S.N 2 | 680 | 2 | - | - | - |
| 16 | 25 | S.N 3 | 660 | 1.2 | - | - | - |
| 17 | 25 | S.N 3 | 670 | 1.5 | - | - | - |
| 18 | 25 | S.N 3 | 680 | 2 | - | - | - |

When: - **A:** - Mold initial temperature

B: - Scenario number (designed model)

C: - Pouring temperature

D: - Flow rate

S.N.1:- Stands for Scenario number one **S.N.2:-** Stands for Scenario number one

S.N.3: Stands for Scenario number three

The sequence, which designed with four factors versus three different level, applied to Minitab statistical software as calculation aid shown on Table3.21.

Table 3.21:- Designed Taguchi Orthogonal Array

| Trial order | Factor | | | |
|-------------|--------|---|---|---|
| | A | B | C | D |
| 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 2 | 2 |
| 3 | 1 | 1 | 3 | 3 |
| 4 | 1 | 2 | 1 | 1 |
| 5 | 1 | 2 | 2 | 2 |
| 6 | 1 | 2 | 3 | 3 |
| 7 | 1 | 3 | 1 | 1 |
| 8 | 1 | 3 | 2 | 2 |
| 9 | 1 | 3 | 3 | 3 |
| 10 | 2 | 1 | 1 | 1 |
| 11 | 2 | 1 | 2 | 2 |
| 12 | 2 | 1 | 3 | 3 |
| 13 | 2 | 2 | 1 | 1 |
| 14 | 2 | 2 | 2 | 2 |
| 15 | 2 | 2 | 3 | 3 |
| 16 | 2 | 3 | 1 | 1 |
| 17 | 2 | 3 | 2 | 2 |
| 18 | 2 | 3 | 3 | 3 |

Depending on designed Taguchi array eighteen different simulations runs were conducted and their result of shrinkage porosity, hotspot and other defects were recorded separately. After that, selection of optimum process parameter conducted with a Grey analysis method using Minitab software.

3.11.2 Considered Casting Factor

On this research four different major factor were considered and included on Taguchi L-18 to conduct casting simulation task. Here below description of those considered factor are mentioned below.

3.11.2.1 Mold initial temperature

In a casting process, the material is first heated to completely melt and then poured into a cavity of the mold. As soon as the molten metal is in the mold, it begins to cool. When the temperature drops below the freezing point (melting point) of the material, solidification starts. Solidification involves a change of phase of the material and also a reason of defect initiation. A pure metal solidifies at a constant temperature, which is its melting point

(freezing point) [33] [17]. Here after consideration from various literature mold initial temperature was determined at 20°C and 25°C.

3.11.2.2 Designed Scenario

Three different scenario was introduced for this research. The first scenario was directly developed from currently existing model at case company. Then the second and the third scenario was designed depending on the simulation result of first scenario and with other expected hypothesis.

a) Scenario Number One

Through conducting a simulation on PRO Cast simulation software for scenario number by changing a process parameters according to L-18 Taguchi analysis different defect was observed. Then after only process parameter, variation does not come more than 3.5% defect minimization. Then after adding, another scenario was included as described below.

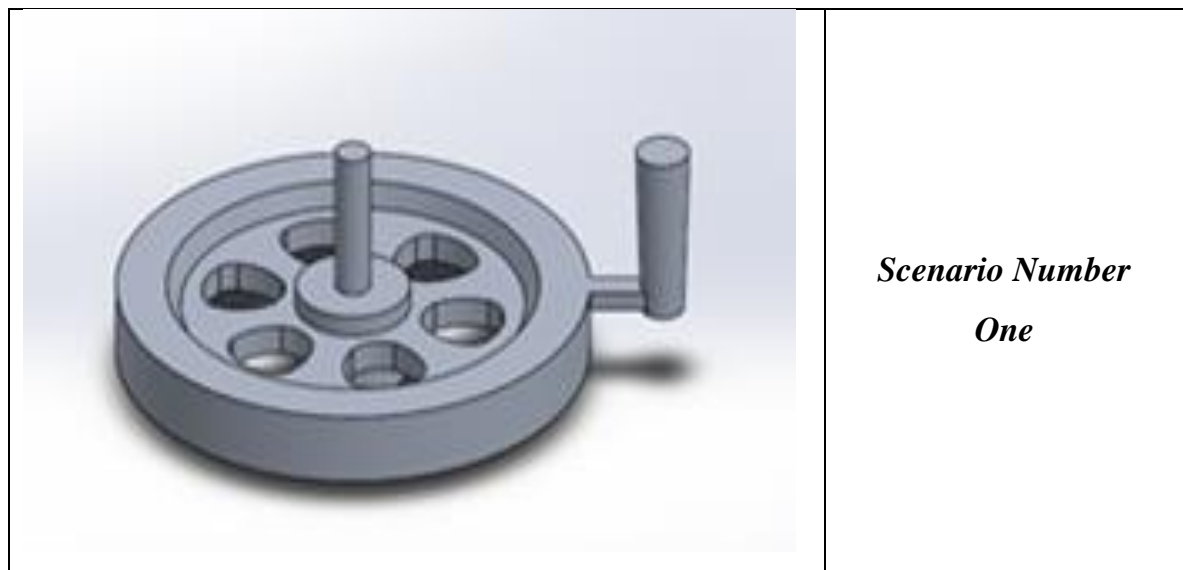


Figure 3.12:- Currently existing model as Scenario number one

b) Scenario Number Two

In case cold-shots are detected or the fine details of the casting are not filled properly, the sprue cross-sectional area should be increased [34]. Sprue wells are built with a different material than the one used in the mold for higher resistance to erosion: e.g., clay brick, sand with high proportion silica flour, cement-bonded alumina [34].

As visited from simulation result of scenario number one because of limited size of sprue needed volume of feeder metal to the thicker section of the products (At section of pulley

products with 60mm height) was not reached effectively. So that the number of riser was changed from one to two. Again also, the position of riser was completely shifter from middle of the product to the thicker section of products (At section of pulley products with 60mm height, which visited with high volume of shrinkage porosity region). Additional diameter of sprue also scaled up with 1.15 range and bottom sprue basin was added according to reviewed certain literature.

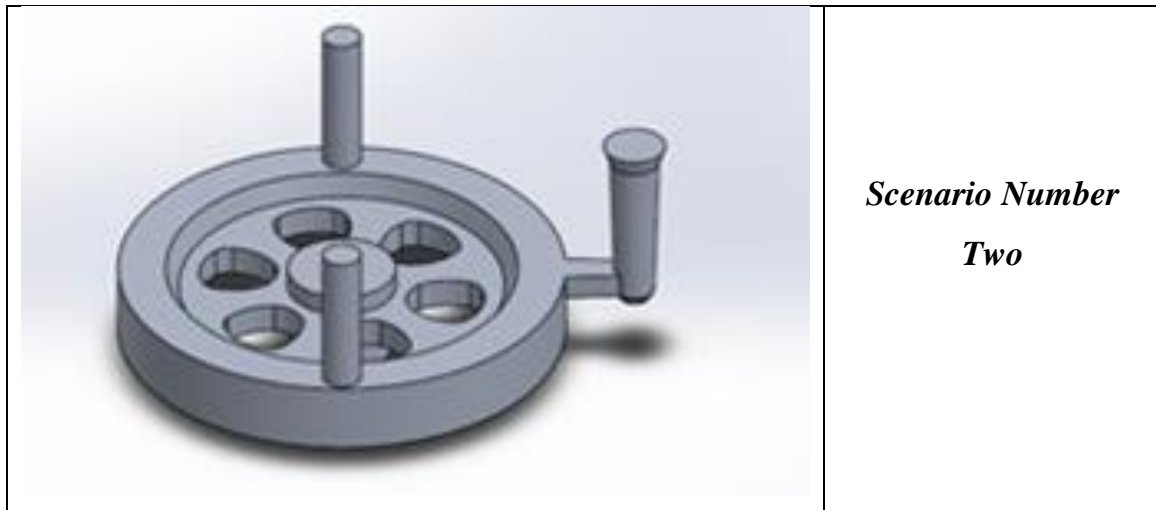


Figure 3.13:- Newly designed model as Scenario number two

c) Scenario Number Three

More than 86% sand casting defect was happened due to improper gating system design. Again also other literature concludes as improper gating system design and improper location can result more than 94% casting defect. The gating system design is a critical factor in the sand casting process, which not only directly influences the molten metal flow, heat transfer, and alloy solidification but allows better casting quality . Improper gating system design causes an increased liquid metal flow rate. That results in more turbulence on the surface, which promotes oxide film entrapment inside the liquid metal [34].

So depending on different literature conclusion and also depending on simulation result of scenario number two another scenario (Scenario number three) with different feature was designed. Here length of sprue was increased with additional 30mm; Because of indicated higher solidification time at middle section of product, gating system was completely changed from upper position to the middle section to come with effective feed. Again the number of ingate also changed from one to two to compensate sufficient molten metal for visited shrinkage and hotspot at middle section as shown on Figure 3.14.

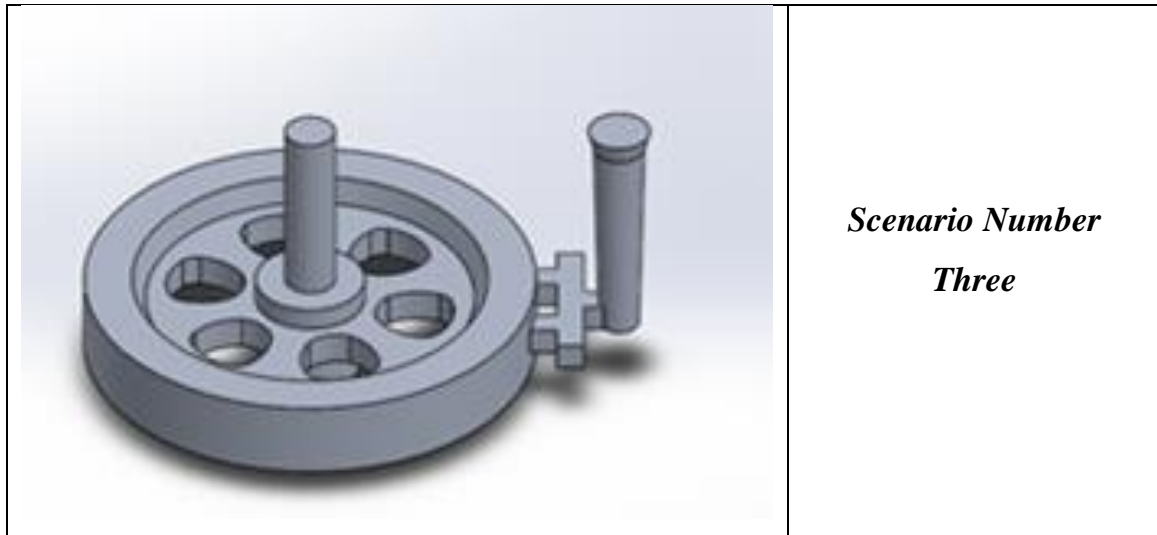


Figure 3.14:- Newly designed model as Scenario number three

3.11.2.3 Pouring temperature

Poring temperature was another factor which included on this research. Because from different literature pouring temperature has its own impact for casting defect. On this research three different pouring temperature (660°C,670°C and 680°C) was used.

3.11.2.4 Molten metal flow rate

Again, as fourth factor the flow rate of molten metal was considered through making little up and down value from calculated one as (1.2Kg/sec, 1.5kg/sec and 2kg/sec).

3.12 Gray relational analysis (GRA)

The Taguchi method is very popular for solving optimization problems in the field of production engineering. The method utilizes a well-balanced experimental design (allows a limited number of experimental runs) called orthogonal array design, and signal to-noise ratio (S/N ratio) which serve the objective function to be optimized (maximized) within experimental. However, traditional Taguchi method cannot solve multi-objective optimization problem. To overcome this, the Taguchi method coupled with Grey relational analysis has a wide area of application in manufacturing processes. This approach can solve multi-response optimization problem simultaneously. In recent years, grey relational analysis becomes a powerful tool to analyze the processes with multiple performance characteristics. Grey relational analysis (GRA) utilizes a specific concept of information [32].

3.13 Experimental casted product according to selected trial order.

According to simulation analysis, “Scenario number three with trial number seven” was the one that resulted with less defect than other. Depending on casting simulation result experiments were conducted in case study foundry. After casting of selected product, a sample preparation was made for Scanning Electron Microscope (SEM) examination of microstructure. Figure 3.12 shows product fabricated according to PROCAST casting simulation result of scenario three with trial number seven.



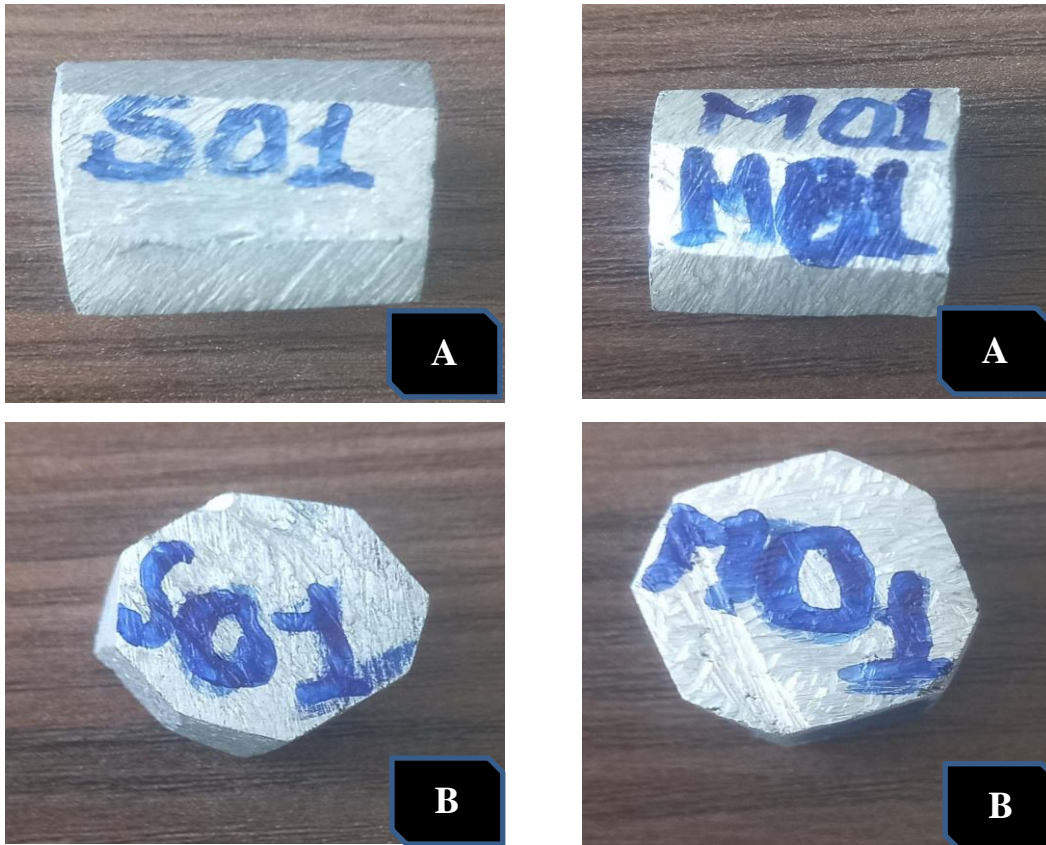
**Figure 3.15:- Fabricated pulley product according to selected simulation result
(Trial Order seven)**

3.13.1 Specimen preparation for Scanning Electron Microscope (SEM) machine test

Scanning Electron Microscope (SEM) is a type of electron microscope that scans surfaces of microorganisms that uses a beam of electrons moving at low energy to focus and scan specimens. The development of electron microscopes was due to the inefficiency of the wavelength of light microscopes. During this, research six different samples for testing were prepared. From six specimens three specimen were prepared from existing fabricated product and three specimen were are prepared from selected product fabricated according to simulation result.

3.13.1.1 Sample prepared from existing pulley product (Product made with ought casting simulation software).

From existing product (product shown on Figure 3.8) three sample were prepared and visited under Scanning Electron Microscope Machine for identification of certain defect and further microstructure examination.



Sample size:-20x20x20mm
Sample Code:- SO1
Material :- Aluminum

Sample size:-20x20x20mm
Sample Code:- MO1
Material :- Aluminum

Figure 3.16:- Sample prepared from currently existing product

A: - Sample photo from side view

B: - Sample photo from top view

3.13.1.2 Sample prepared from re designed pulley product (Product made with casting simulation software).

Again, according to re- designed casting simulation software casted product (product shown on Figure 3.12) three different samples from different section of parts were prepared for further identification of certain defect and grain structure on it. During identification process Scanning Electron Microscope Machine were used.

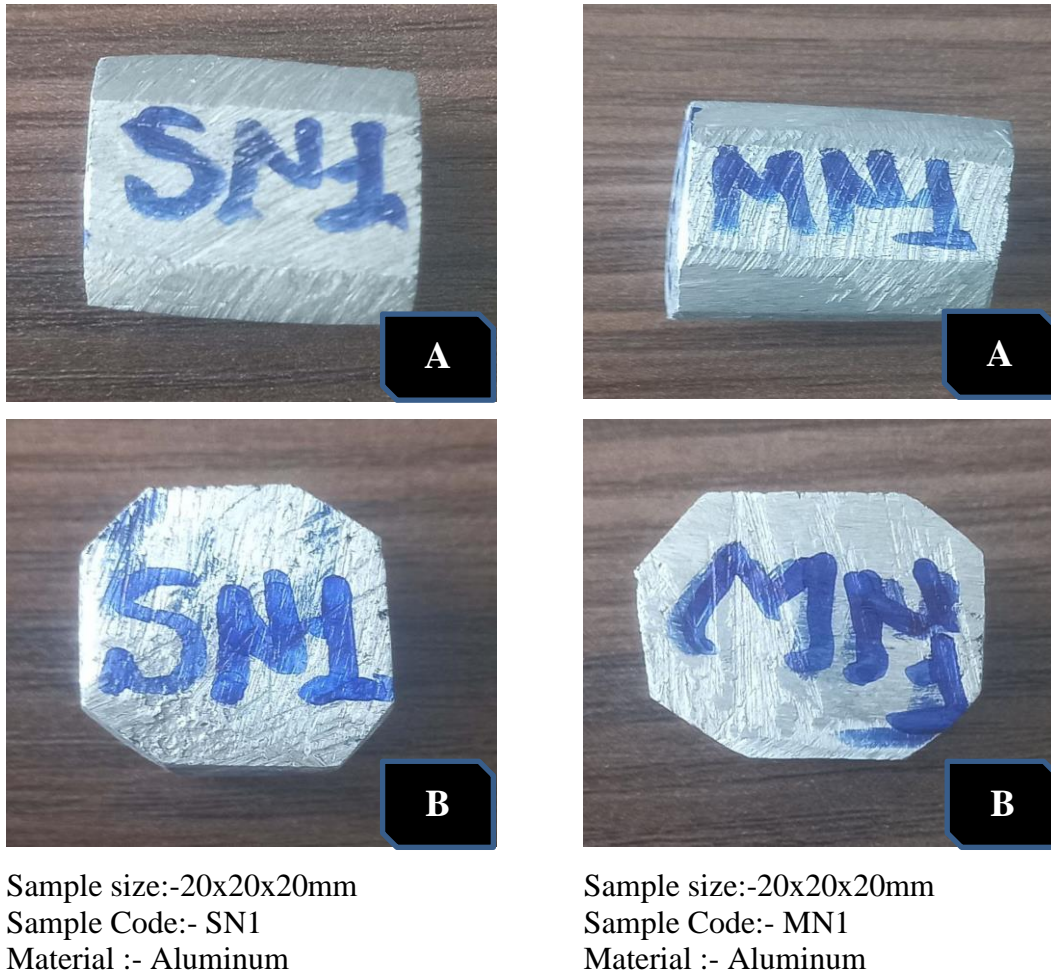


Figure 3.17:- Sample prepared from newly casted product.

A: - Sample photo from side view

B: - Sample photo from top view

3.14 Sample configuration under Scanning Electron Microscope (SEM) Machine.

The scanning electron microscope allows to obtain a magnified image of the surface of thick sample and analysis their composition. It consists in an electron source, electromagnetic lenses and an electron detector. It uses an electron beam instead of light based on wave particle duality. The electron accelerated and focused on the sample using the lenses. The sample emits secondary electrons, which are then detected. The number of detected electrons depends on the variation of samples surface. The electron beam can also ionize the atom and make them emit the X-ray. The rays energy also depends on elementary composition of the sample. By scanning ones again the beam and detecting the x-rays energy, once can deduce the chemical nature of the material and its statically variations.

After the specimen were prepared each sample placed on SEM chamber and screened separately for defect and sample microstructural observation as shown on Figure 3.15.

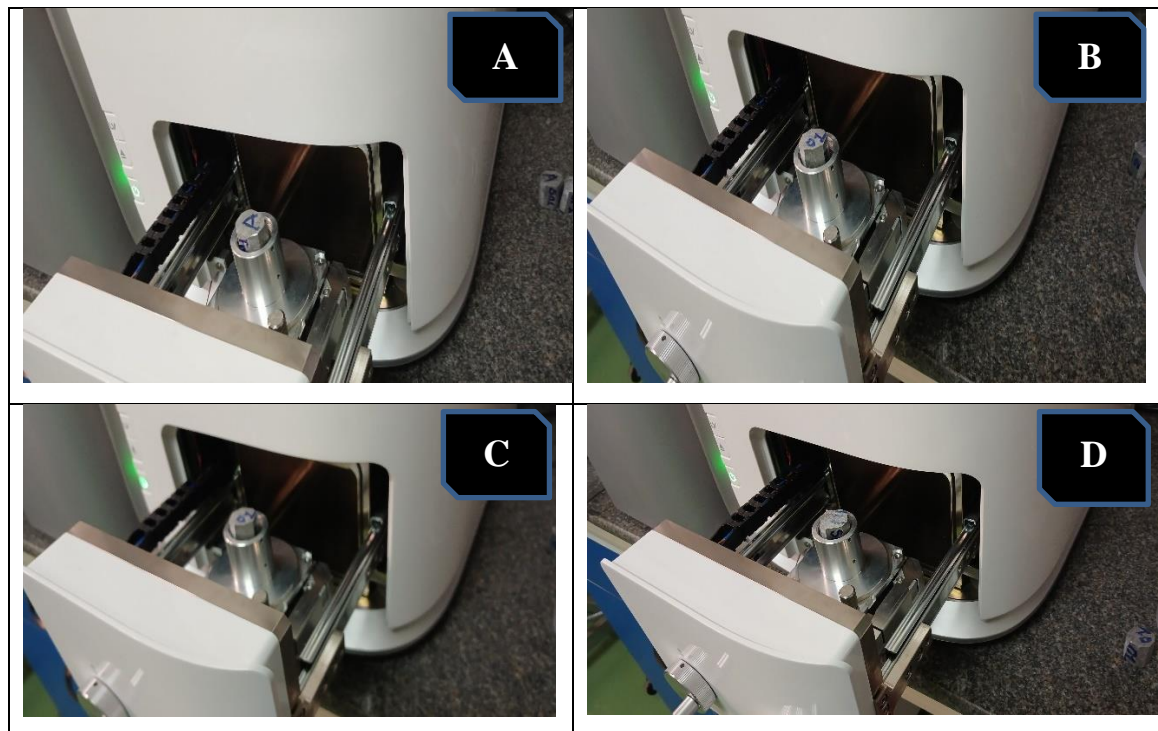


Figure 3.18:- Sample configuration for testing under scanning electron microscope machine

A) Sample MN1 B) Sample SO1 C) Sample MO1 D) Sample SN1

Chapter Four

4 Result and Discussion

On this research the result were presented in two main sections, the first result presented was mainly focused on the outcomes of different PROCAST simulations showing defects with their location and consequence, next to that experimental result of selected product are presented. Finally, the relation between simulation result and experimental result was presented.

4.1 Simulation results of various casting defects

Casting simulation was run on eighty models with three different scenarios. Each simulation was conducted according with L18 Taguchi orthogonal array with different process parameters and designed three scenario as shown on Table 3.20.

4.1.1 Result of defect during scenario number one

Scenario number one directly modeled from currently existing model (Conventional) inside the foundry of Case Study Company. From the simulation result of PROCAST (Visual Cast 17.5), high level of shrinkage porosity, hot spot defect and minor void defect were found on different section of the model. From those defects, the result of selected defect was presented.

4.1.1.1 Shrinkage porosity defect

As shown, clearly on Figure 4.1 from the total volume of pulley product 5.56% volume affected by shrinkage porosity. Both open shrinkage defect on the node of surface of castings and closed shrinkage defects on the interior node of a product were also observed. According to L-18 with mixed level of (L18 ($2^1 3^3$)) Taguchi array after running of six different model as (trial number one, trial number two, trial number three, trial number ten, trial number eleven and trial number twelve) the results of these three defects were presented on Table 4.2 in terms of figurative and numerical values.

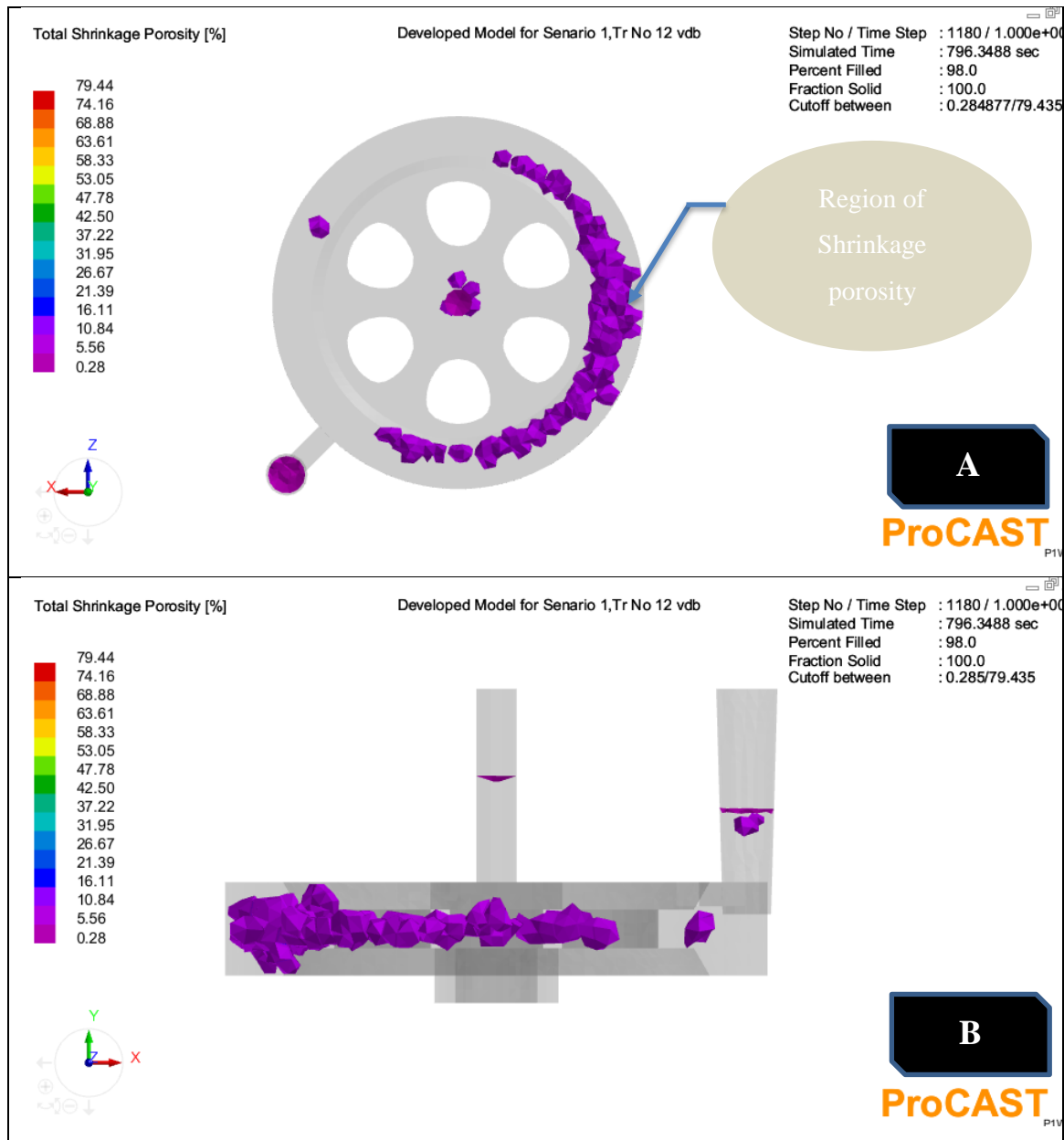


Figure 4.1:- Result of shrinkage porosity defect on scenario number one

(Currently existing scenario)

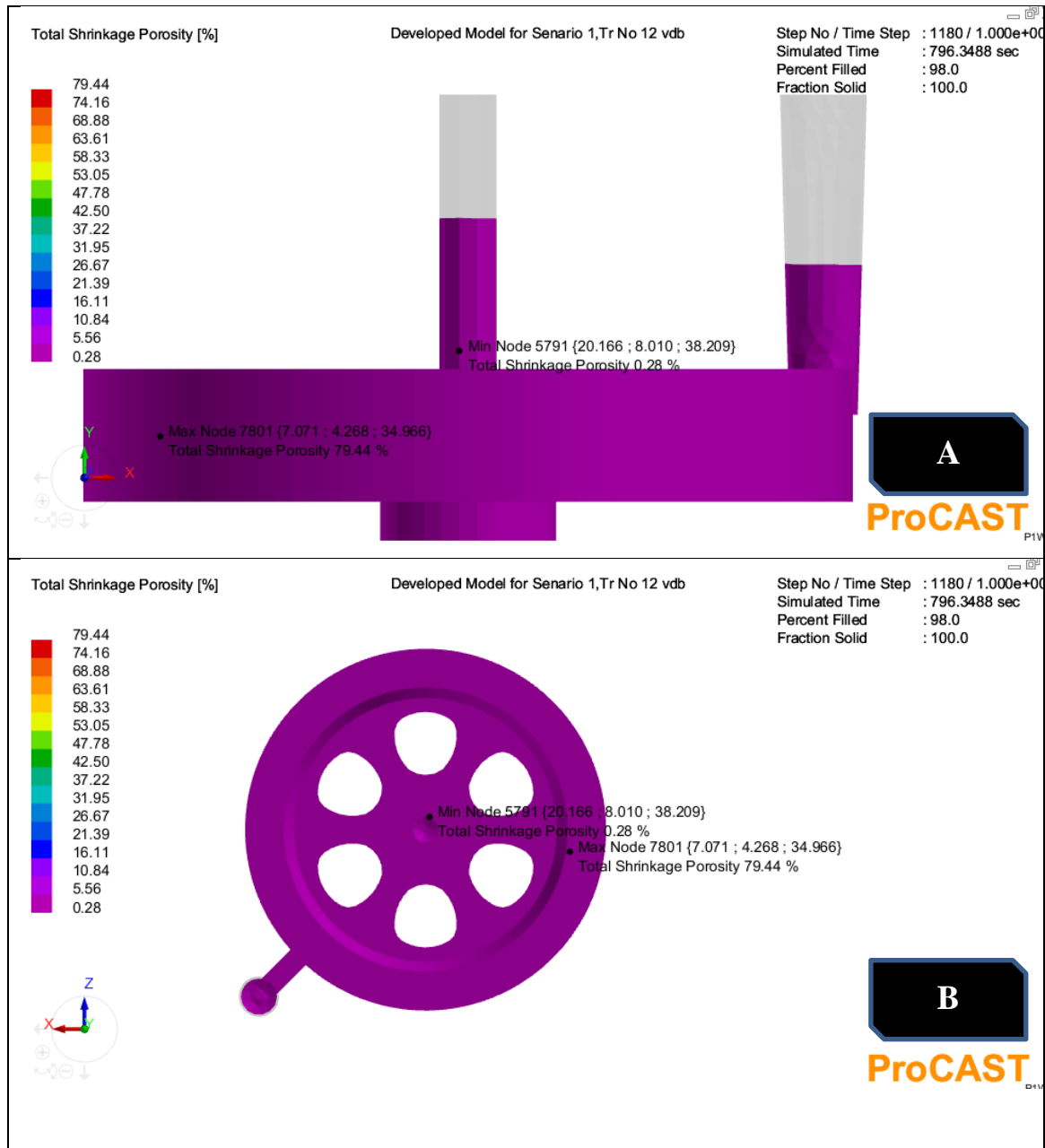
A: - Total volume of shrinkage porosity defect (Top view)

B: - Total volume of shrinkage porosity defect (Side view)

As shown clearly almost thin section of the product (nearest to the center point) are free from shrinkage. However, the thick section of the pulley product, which is far from the center observed with high-level shrinkage porosity defect. Additionally open shrinkage porosity at the surface of product also observed at far position to the sprue location, but on the surface, which nearest to the sprue location there is no any shrinkage on the surface of products.

4.1.1.1.1 Exact location at which maximum shrinkage defect visited

Maximum shrinkage porosity was observed at node level 7801 {7.071; 4.268; 34.966} with total 74.99% and minimum shrinkage porosity at node 5791 {20.166; 8.010; 38.209} with total 0.28% were observed. Additionally the range of shrinkage porosity was increased from surface section of the product to the medium section of the products. Therefore, middle section of the product was found as the region with high level of shrinkage porosity.



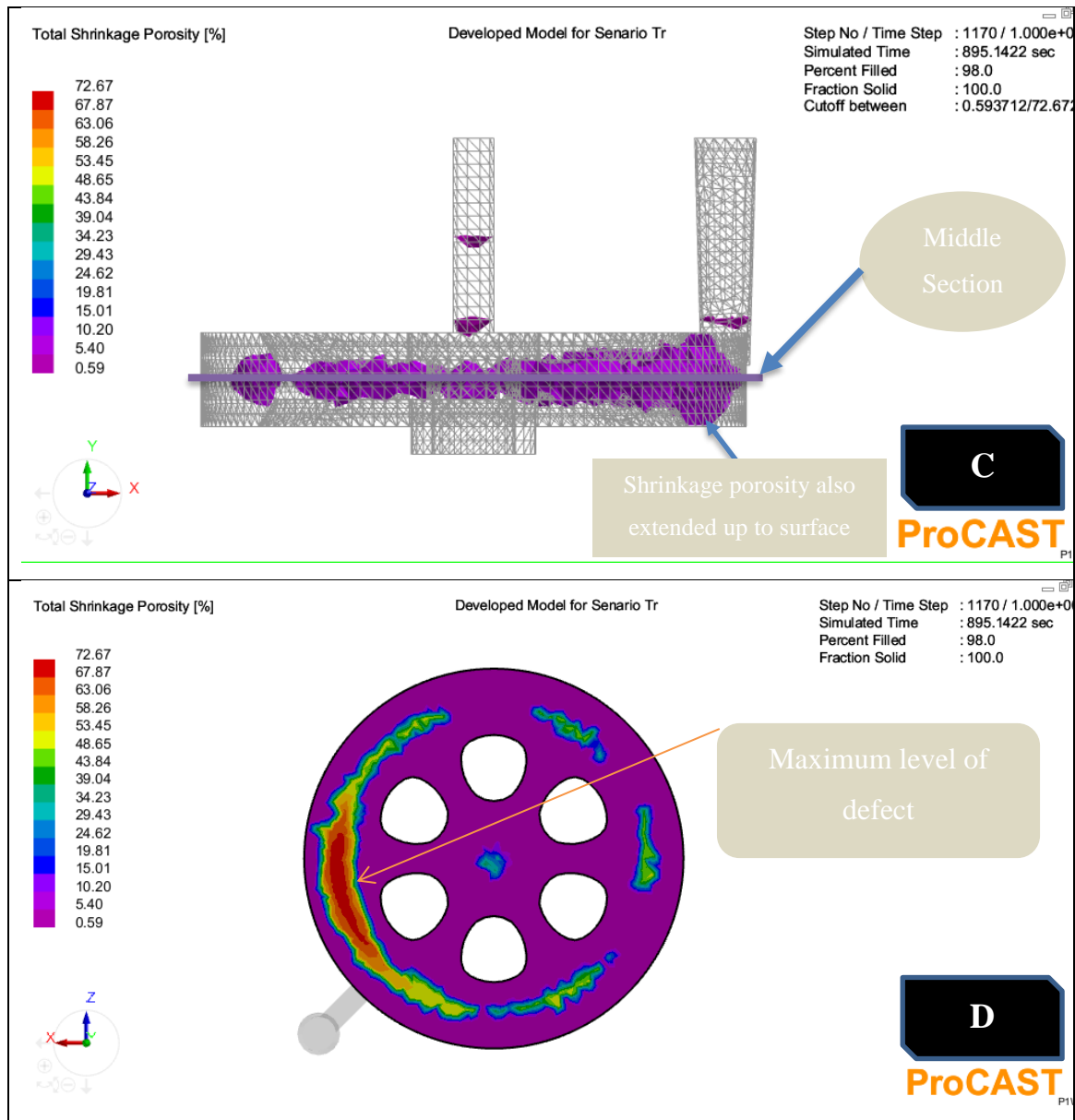


Figure 4.2:- Exact location at which high level of shrinkage porosity is visited

(Scenario number one)

- A: - Exact location of maximum and minimum shrinkage porosity (Side view)
- B: - Exact location of maximum and minimum shrinkage porosity (Top view)
- C: - Region at which high percentage of shrinkage porosity visited (Side view)
- D: - Region at which high percentage of shrinkage porosity visited (Top view)

4.1.1.1.2 Taguchi analysis result of shrinkage porosity

If the shrinkage porosity is small in diameter and confined to the very center of thick sections it will usually cause no problems. However, if it is larger or joined, it can severely weaken a casting [32]. Nevertheless, in scenario number one, the diameter of visited shrinkage porosity becomes not small and the visited defect becomes larger. Therefore according Taguchi array through varying only a process parameters (mold initial temperature, pouring temperature and flow rate of molten metal) of six different model with scenario number one the result of shrinkage porosity defect at **middle section** (maximum point) recorded as shown on Figure 4.3.

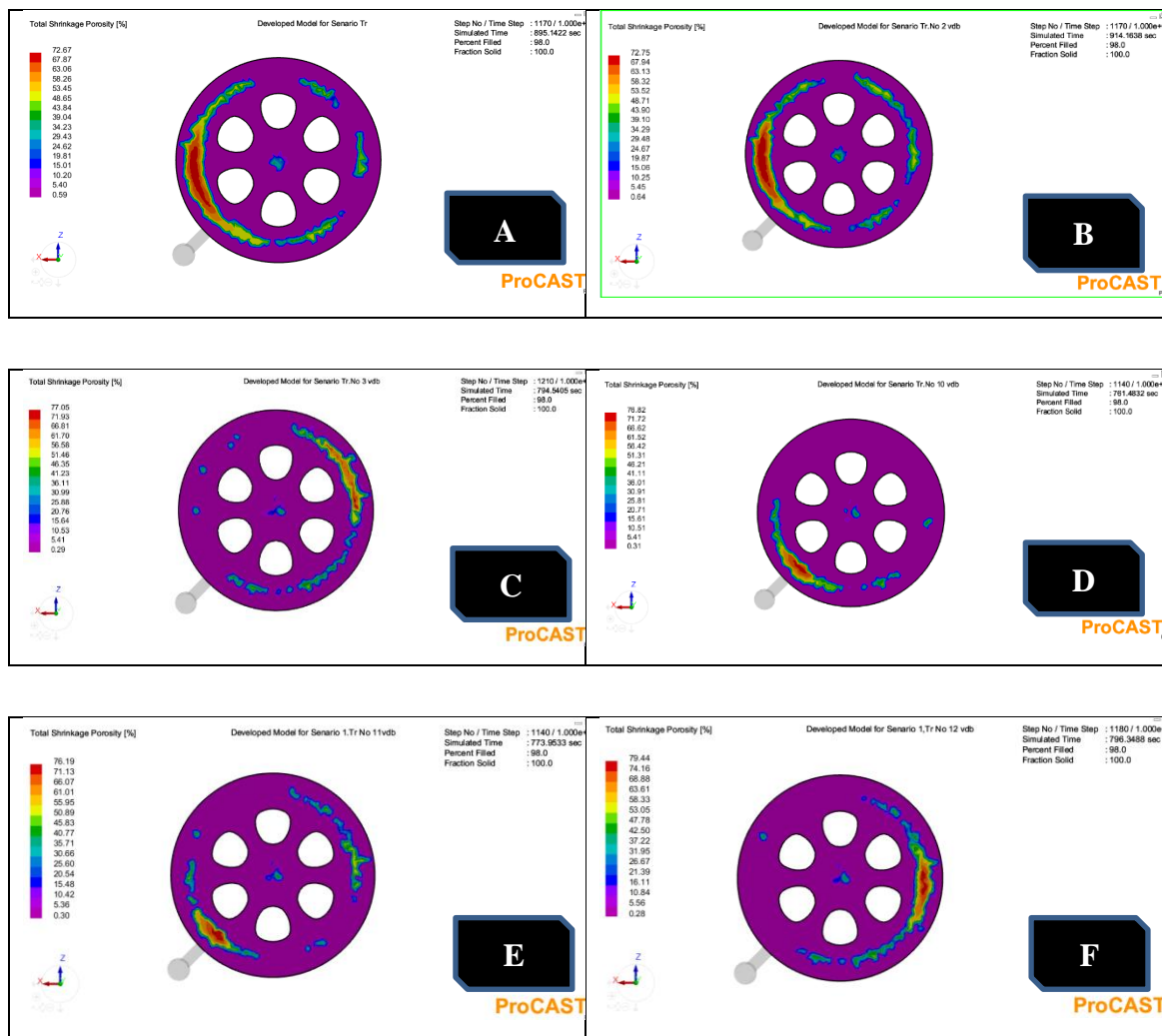


Figure 4.3:- Maximum shrinkage porosity result of scenario number one.

- A/ Shrinkage porosity of trial number one
- B/ Shrinkage porosity of trial number two
- C/ Shrinkage porosity of trial number three
- D/ Shrinkage porosity of trial number ten
- E/ Shrinkage porosity of trial number eleven
- F/ Shrinkage porosity of trial number twelve

4.1.1.2 Summary of shrinkage porosity result of scenario number one

Only through varying a process parameter (Mold initial temperature, Pouring temperature and Flow rate of molten metal), the location and yield volume of shrinkage porosity is varied. Therefore as shown, on Table 4.1 the volume of shrinkage porosity on six different trial of scenario number one presented.

Table 4.1:- Result of total shrinkage porosity defect (Scenario one)

| <i>Trial order</i> | <i>Total volume of shrinkage porosity by %</i> |
|--------------------|--|
| 1 | 5.40 |
| 2 | 5.45 |
| 3 | 5.41 |
| 10 | 5.41 |
| 11 | 5.36 |
| 12 | 5.56 |

4.1.1.3 Hot spot defect

A hotspot defect is a type of casting defect that occurs when a region of the metal cools faster than the surrounding metal, creating a hard spot on the surface of the casting. This can affect the mechanical properties and appearance of the casting [24]. As shown on Figure 4.4 more than 35 points of pulley product observed with hotspot defect. Nevertheless, span width of the hotspot defect did not extend up to the surface age of products. The range of hotspot defect along the width of product was limited only at 28mm (from total 58mm width of product). Therefore aligned on some straight line with only limited 28mm section of the products was affected with hotspot.

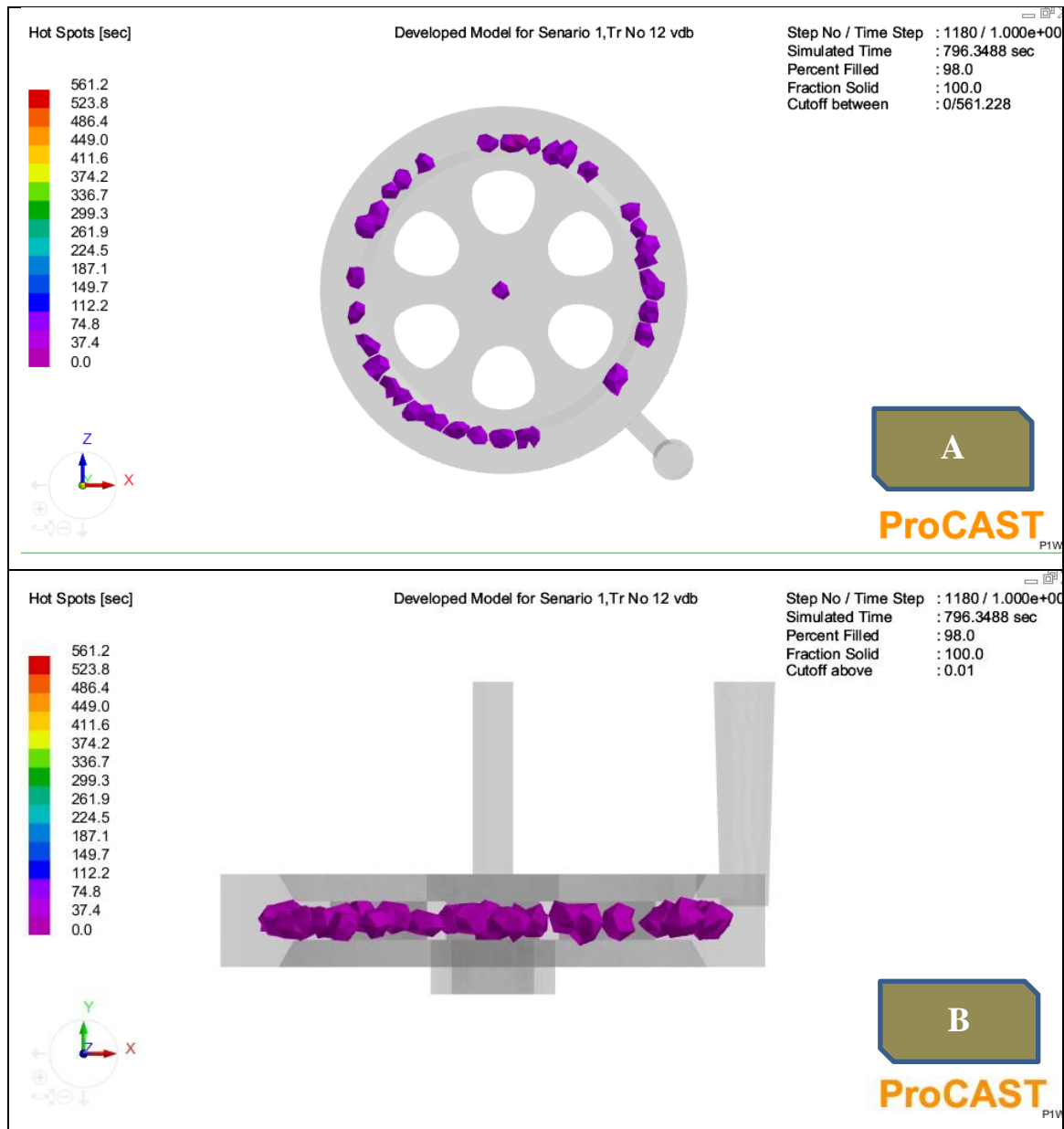


Figure 4.4:- Result of hotspot defect (scenario number one)

A: - Result of hotspot defect visited (Top view)

B: - Result of hotspot defect visited (Side view)

4.1.1.3.1 Location at which maximum hotspot defect observed.

Figure 4.5 shows as there was hotspot defect on the middle section at node 7801{7.071; 4.268; 34.966} and minimum hotspot defect at node 1{23.638; 0.215; 38.483} on products.

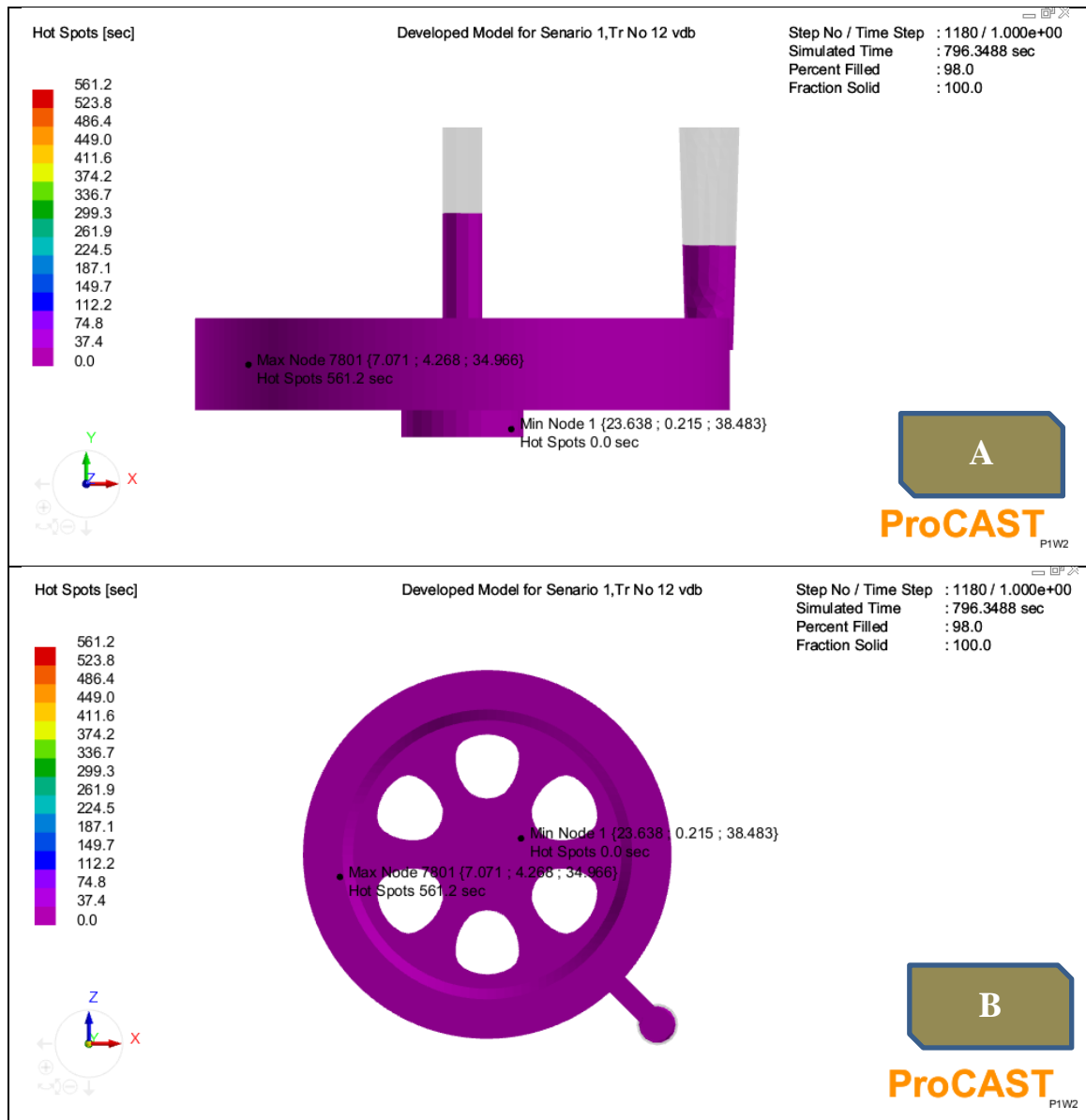


Figure 4.5:- Exact location of maximum and minimum hotspot defect

(Scenario Number One)

A: - Exact location of maximum and minimum hotspot defect (Side view)

B: - Exact location of maximum and minimum hotspot defect (Top view)

4.1.1.3.2 Taguchi analysis result on hotspot defect

After running six-trial model through varying process parameter (mold initial temperature, pouring temperature and flow rate), the result of maximum hotspot defect recorded was indicated on Figure 4.6.

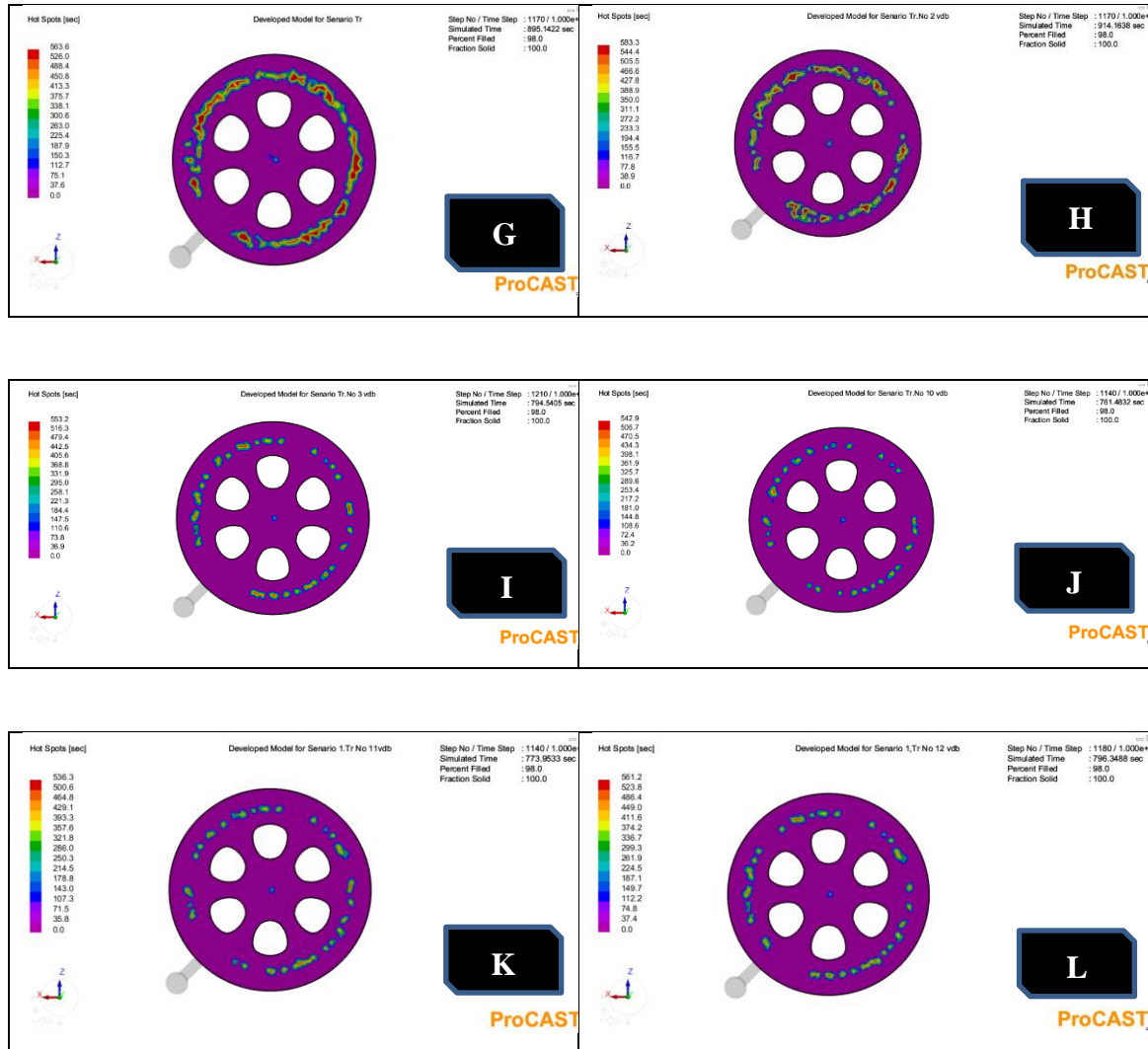


Figure 4.6:- Different result of hotspot defect on scenario number one.

G/ Hotspot result of trial number one

H/ Hotspot result of trial number two

I/ Hotspot result of trial number three

J/ Hotspot result of trial number ten

K/ Hotspot result of trial number eleven

L/ Hotspot result of trial number twelve

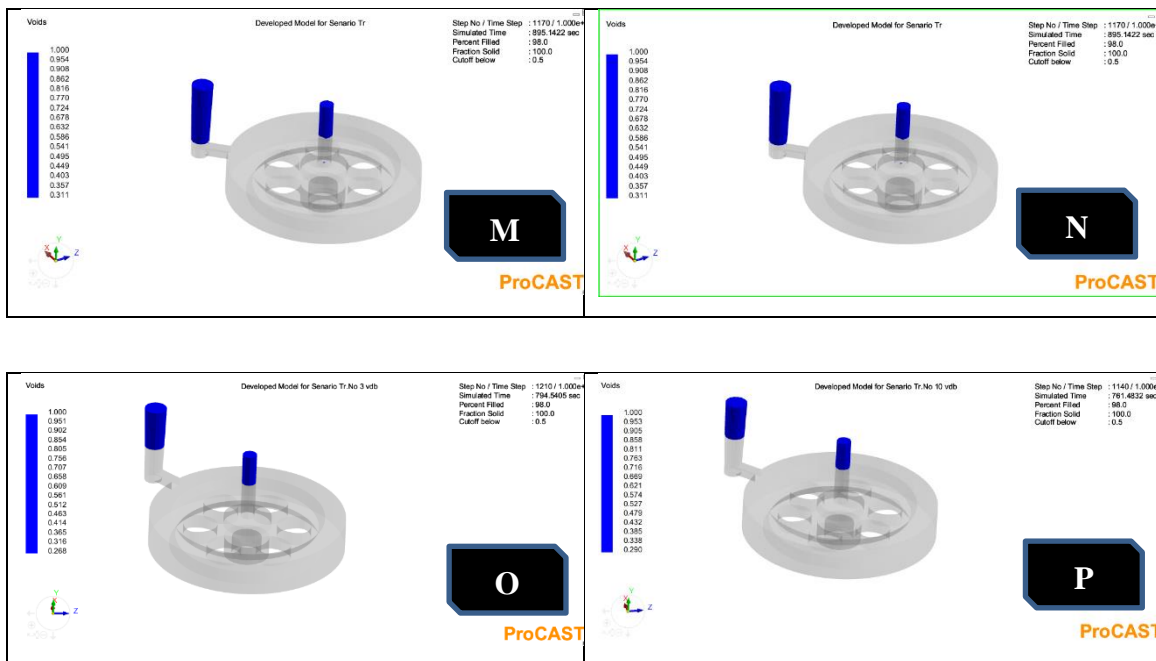
As shown on the Figure 4.6 the diameter of hotspot becomes enlarged at some trial and again becomes less on another trial. Additionally in all trial the exact time at which hotspot start becomes vary. Then the result of time at which hotspot initiated and node at which maximum and minimum hotspot happen was tabulated on Table 4.2.

Table 4.2:- Summary of maximum hotspot defect (Scenario Number One)

| Trial order | Maximum hotspot defect | | Minimum hotspot defect | |
|-------------|------------------------|---------------------------|------------------------|---------------------|
| | Sec | Node | Sec | Node |
| 1 | 563.6 | 8286 {34.36;4.52;36.87} | 0.0 | 1{23.63;0.21;38.48} |
| 2 | 583.3 | 5229{33.86;4.26;37.91} | 0.0 | 1{23.63;0.21;38.48} |
| 3 | 553.2 | 4819{7.05;4.31;38.18} | 0.0 | 1{23.63;0.21;38.48} |
| 10 | 542.9 | 9527{24.80;4.24;24.29} | 0.0 | 1{23.63;0.21;38.48} |
| 11 | 536.3 | 4819{7.05;4.31;38.18} | 0.0 | 1{23.63;0.21;38.48} |
| 12 | 561.2 | 7801 (7.071;4.268;34.966) | 0.0 | 1{23.63;0.21;38.48} |

4.1.1.4 Result of void defect (scenario number one)

The ratio of void visited was not as much percentage to other types of defect. The void can was observed only on upper side of the product on two different trial as shown on Figure 4.7.



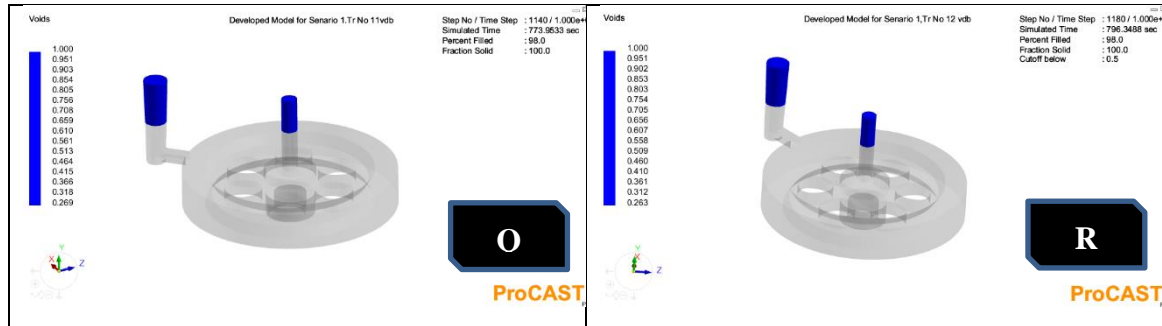


Figure 4.7:- Different result of void defect on scenario number one.

- | | |
|--|--|
| M/ Result of void defect for trial number one | N/ Result of void defect for trial number two |
| O/ Result of void defect for trial number three | P/ Result of void defect for trial number ten |
| Q/ Result of void defect for trial number eleven | R/ Result of void defect for trial number twelve |

4.1.2 Result of defect during scenario number two

During the second scenario, the number and position of riser changed with ought changing gating system. Number of riser changed from one to two and the position was also shifted at the thicker position of the product. Additionally sprue size was made to scale up and new pouring basin and choke were designed.

4.1.2.1 Shrinkage porosity defect

During second scenario again also, there were both open and closed shrinkage defects found casting product. Maximum volume of 5.56% shrinkage porosity defect on scenario number one become minimized to 5.05% shrinkage porosity defect on scenario number two. Increasing riser number from one two, scaling up the sprue size and additionally shifting its position toward thicker section of product can result only achievement of 9.17% shrinkage porosity minimization.

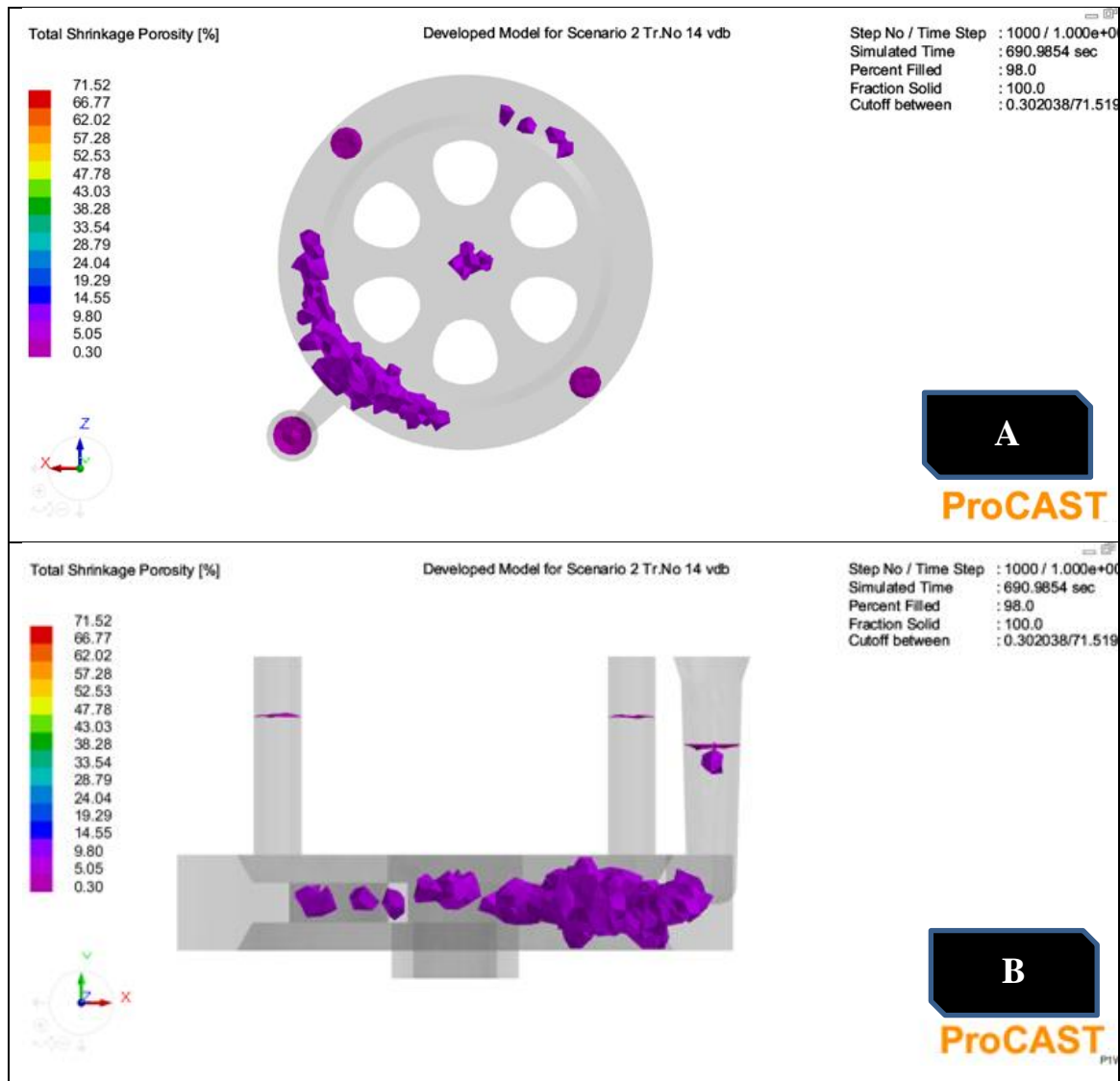


Figure 4.8:- Total volume of shrinkage porosity defect on scenario number two

A: - Total volume of shrinkage porosity defect (Side view)

B: - Total volume of shrinkage porosity defect (Top view)

4.1.2.1.1 Exact location at which maximum shrinkage porosity observed

Maximum shrinkage porosity was visited at node 2993 {24.960; 19.242; 18.341} with total shrinkage porosity 71.52% and minimum shrinkage porosity at node 6584 {27.878; 22.137; 38.457} with total 0.30% are visited. The range of shrinkage porosity level again increased from surface section of the product to the middle section. Therefore, middle section of the product was observed as the region with high level of a shrinkage porosity.

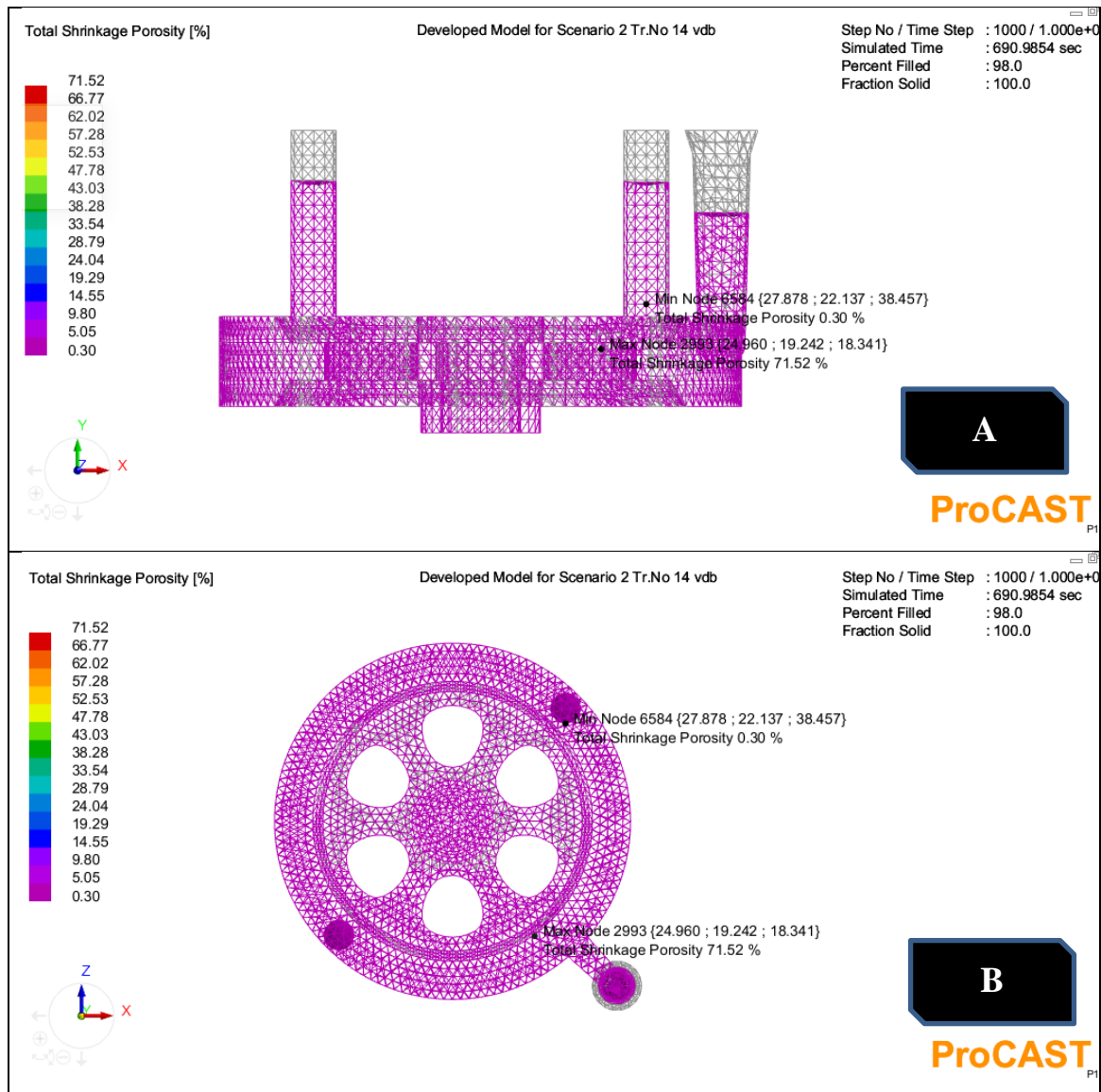


Figure 4.9:- Exact location at which high level of shrinkage porosity is observed (Scenario number two)

A: - Exact location of maximum and minimum shrinkage porosity (Side view)

B: - Exact location of maximum and minimum shrinkage porosity (Top view)

4.1.2.1.2 Taguchi analysis result on shrinkage porosity

Totally according to mixed level Taguchi L-18 ($2^1 3^3$) orthogonal array through varying process parameters (mold initial temperature, pouring temperature and flow rate of molten metal) of six different model are simulated. Totally, under scenario number two six model were developed and there simulation results presented in terms of both figurative and numerical values. Again, the range of maximum shrinkage porosity visited at middle section of thicker parts of product as shown on Figure 4.10.

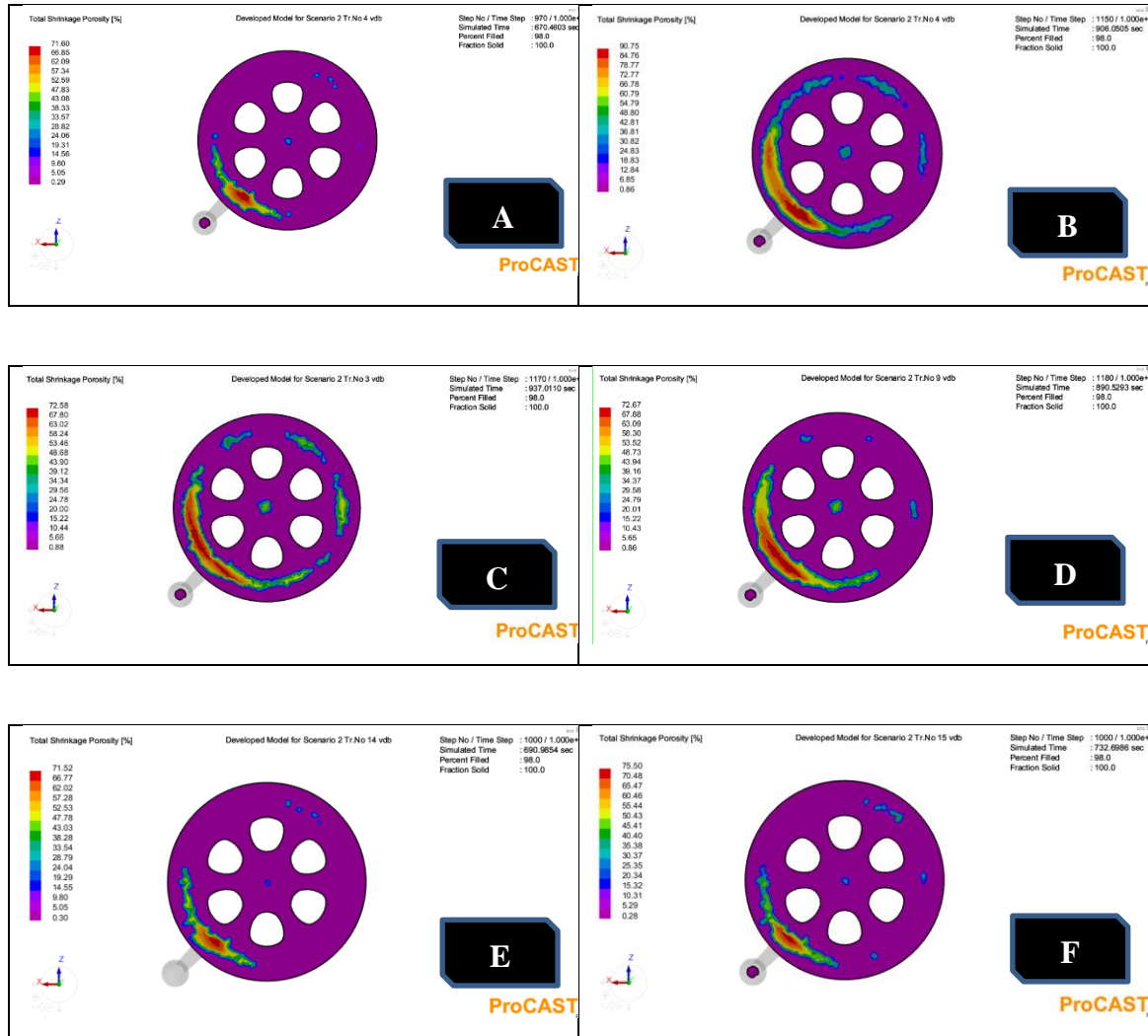


Figure 4.10:- Maximum shrinkage porosity result of scenario two.

A/ Shrinkage porosity of trial number four

B/ Shrinkage porosity of trial number five

C/ Shrinkage porosity of trial number six

D/ Shrinkage porosity of trial number thirteen

E/ Shrinkage porosity of trial number fourteen

F/ Shrinkage porosity of trial number fifteen

4.1.2.1.3 *Summary of shrinkage porosity result of scenario number two*

At second scenario only through varying a process parameter (Mold initial temperature, Pouring temperature and Flow rate of molten metal), the location and yield volume of shrinkage porosity is varied. Therefore as shown, on Table 4.3 the volume of shrinkage porosity observed from total product volume on six different trial of scenario number two was presented.

Table 4.3:- Result of total volume of shrinkage porosity (Scenario Two)

| <i>Trial order</i> | <i>Total volume of shrinkage porosity by %</i> |
|--------------------|--|
| 4 | 5.05 |
| 5 | 6.58 |
| 6 | 5.66 |
| 13 | 5.65 |
| 14 | 5.05 |
| 15 | 5.29 |

4.1.2.1.4 *Comparison of shrinkage porosity result between scenario one and scenario number two*

In both case the maximum shrinkage porosity visited at the middle section of product. However, during comparison of maximum shrinkage porosity at node level on scenario number two becomes more than that of scenario number one. Because maximum level of shrinkage porosity 79.44percent at scenario number one changed into 90.75 percent at scenario number two. Therefore, the second scenario resulted 11.31 percent more shrinkage porosity at node level than first scenario. Additionally according to total volume of shrinkage porosity minimization from

4.1.2.2 Hot spot defect

Again, there is hotspot defect shown on the middle section of the products. However, regarding to arrangement of observed hotspot on scenario number one was little different from that of scenario number two. Figure 4.11 shows observed hotspot defect on more than 19 point of the products.

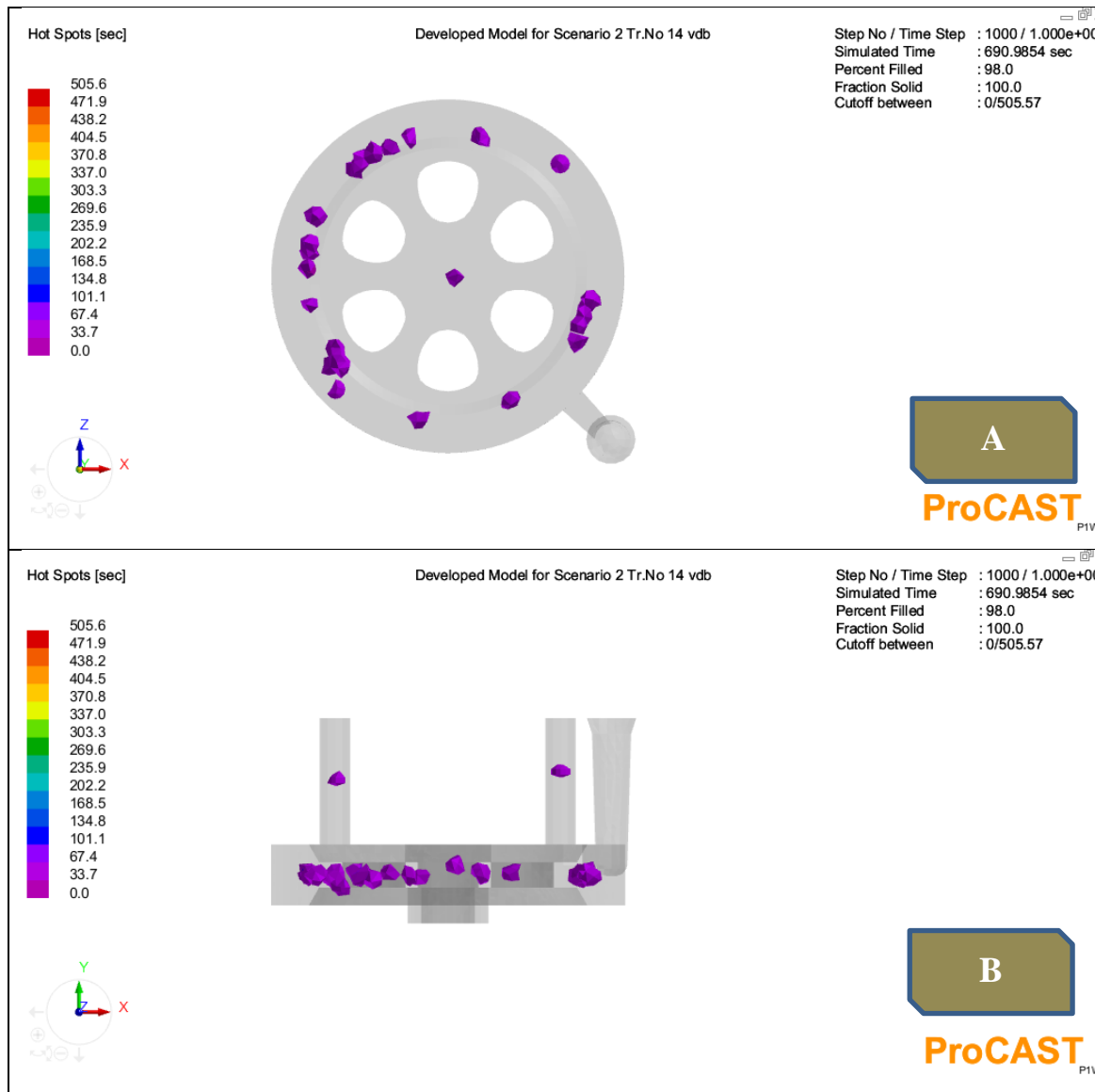


Figure 4.11:- Result of hotspot defect (Scenario Two)

A: - Result of hotspot defect visited (Top view)

B: - Result of hotspot defect visited (Side view)

4.1.2.2.1 Location at which maximum hotspot defect observed.

As shown on Figure 4.12 maximum hotspot defect are observed on the middle section at node 7801 {7.071; 4.268; 34.966} and minimum hotspot defect observed at node 1 {23.638; 0.215; 38.483} of product.

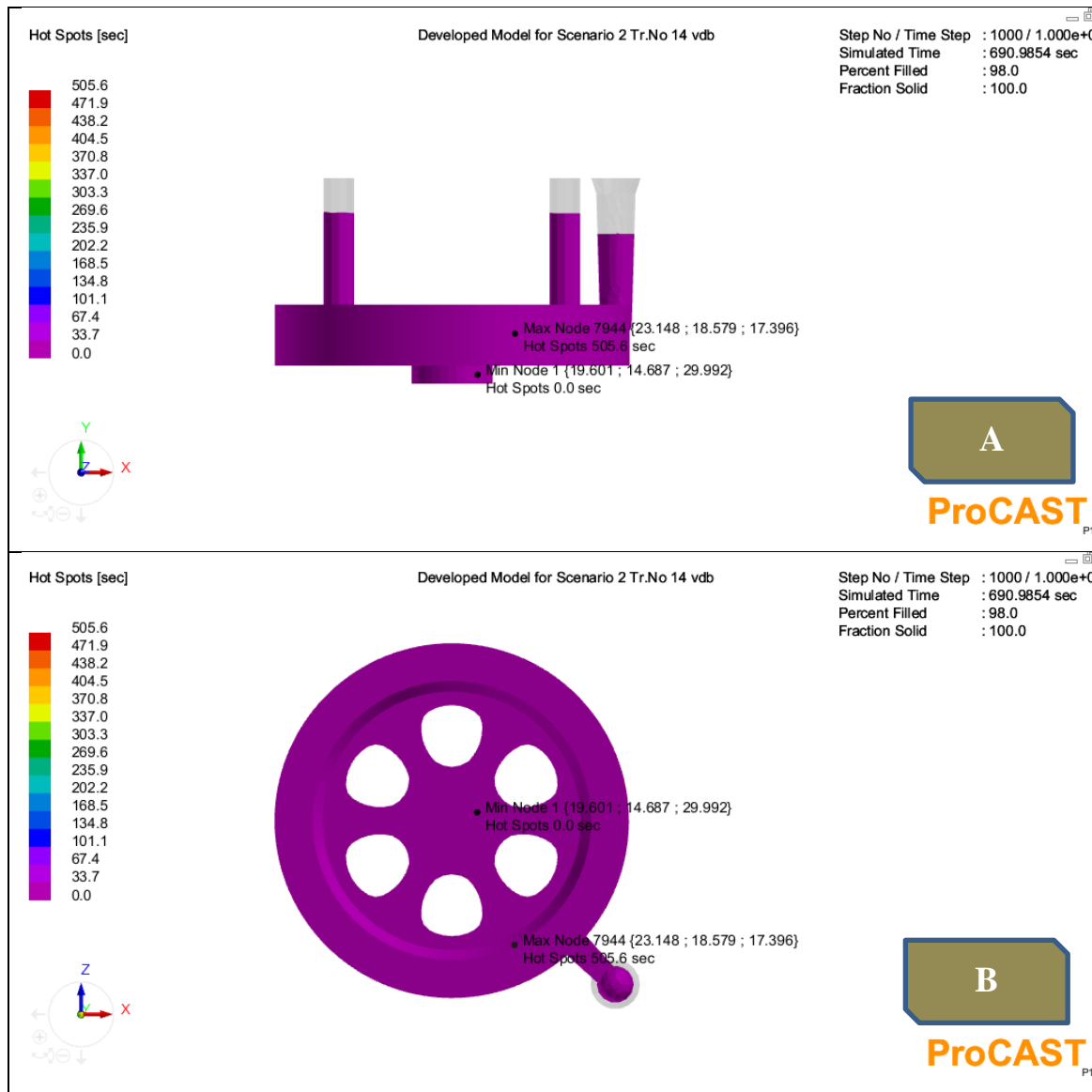


Figure 4.12:- Exact location of maximum and minimum hotspot defect (Scenario Two)

- A: - Exact location of maximum and minimum hotspot defect (Side view)
- B: - Exact location of maximum and minimum hotspot defect (Top view)

4.1.2.2.2 Taguchi array analysis result on hotspot defect

Again also on the second scenario there is hotspot defect observed but the number of point at which hotspot defect observed was more less than that of scenario one. Totally, the result of six different trial presented below in forms of numerical and figurative on figure 4.13.

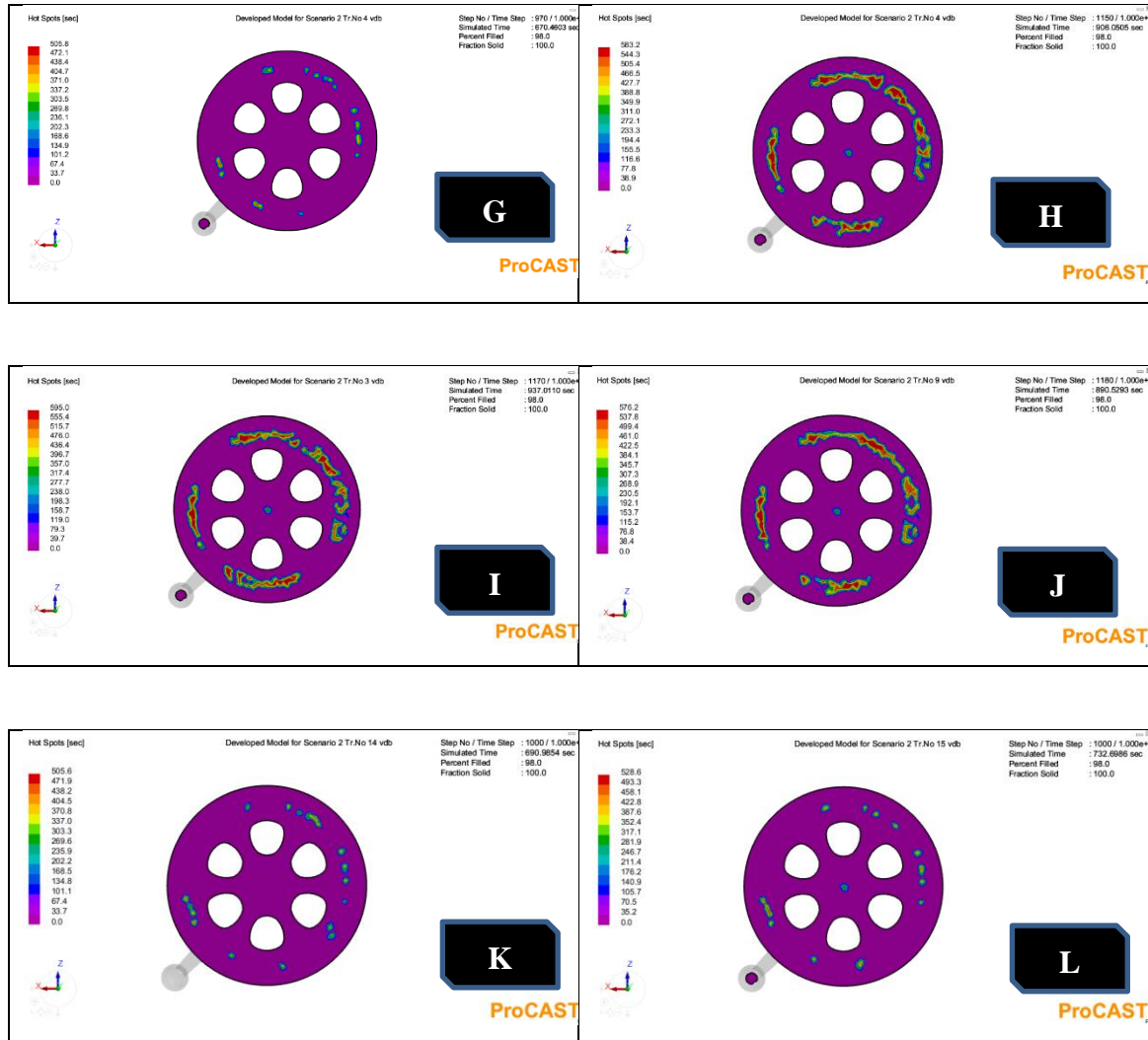


Figure 4.13:- Hot spot defect result of scenario number two

G/ Hotspot result of trial number four

H/ Hotspot result of trial number five

I/ Hotspot result of trial number six

J/ Hotspot result of trial number thirteen

K/ Hotspot result of trial number fourteen

L/ Hotspot result of trial number fifteen

4.1.2.2.3 Summary on hotspot result (Scenario number two)

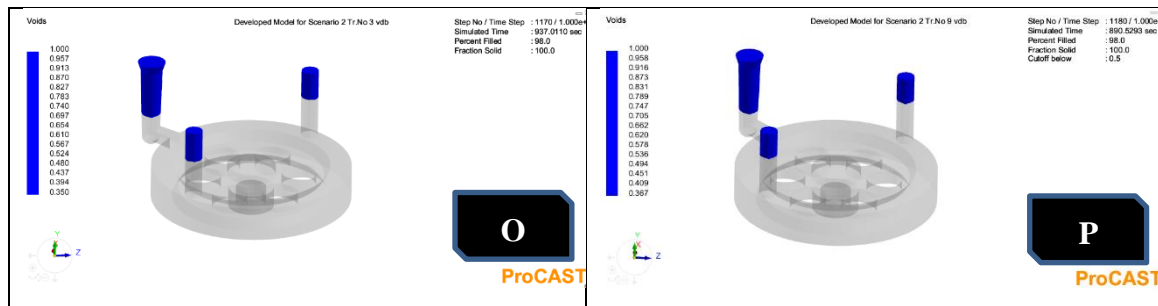
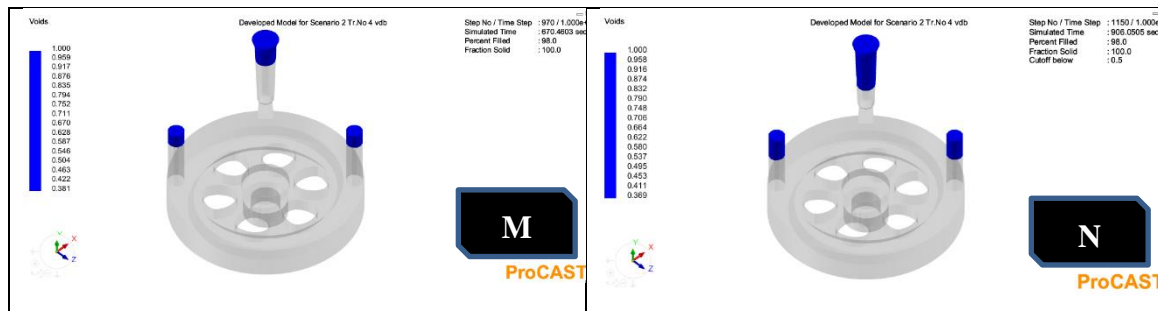
Again as shown on the Figure 4.13 the diameter of hotspot becomes enlarged at some trial and again becomes less on another trial. Also defect was not only limited to the middle section of the products it was also extended toward the external surface in both direction. Additionally in all trial the exact time at which hotspot start becomes vary. Then the result of time at which hotspot initiated and node at which maximum and minimum hotspot happen were given on Table 4.4.

Table 4.4:- Summary of maximum hotspot defect (Scenario two)

| Trial order | Maximum hotspot defect | | Minimum hotspot defect | |
|-------------|------------------------|--------------------------|------------------------|----------------------|
| | Sec | Node | Sec | Node |
| 4 | 505.8 | 7944{23.14;18.57;18.57} | 0.0 | 1{19.60;14.68;29.99} |
| 5 | 583.2 | 5162{30.74;18.21;30.00} | 0.0 | 1{19.60;14.68;29.99} |
| 6 | 595 | 5162{30.74;18.21;30.00} | 0.0 | 1{19.60;14.68;29.99} |
| 13 | 576.2 | 5187{30.36;18.24;29.18} | 0.0 | 1{19.60;14.68;29.99} |
| 14 | 505.6 | 7944{23.14;18.57;17.39} | 0.0 | 1{19.60;14.68;29.99} |
| 15 | 528.6 | 9535 (22.18;18.33;16.91) | 0.0 | 1{19.60;14.68;29.99} |

4.1.2.3 Result related to void on scenario two

A void can reduce the strength and performance of the casting. On this second scenario also almost void completely removed from the main products as visited on Figure 4.14.



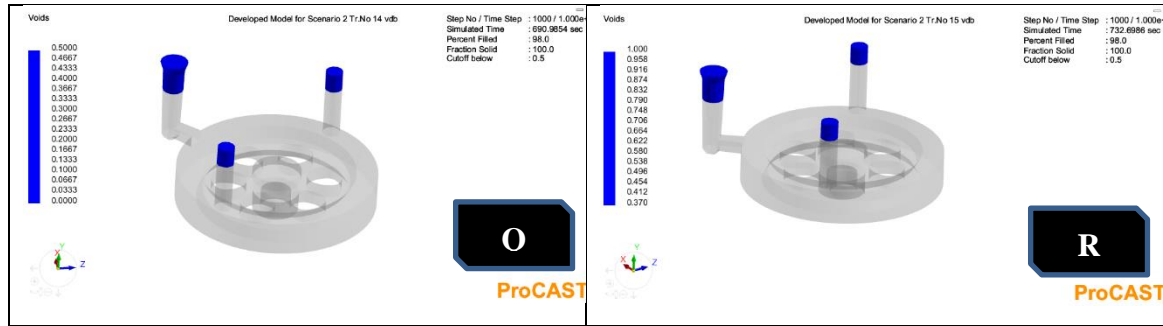


Figure 4.14:- Result of void defect of scenario number two.

- | | |
|--|--|
| M/ Result of void defect for trial number four | N/ Result of void defect for trial number five |
| O/ Result of void defect for trial number six | P/ Result of void defect for trial number thirteen |
| Q/ Result of void defect for trial number fourteen | R/ Result of void defect for trial number fifteen |

4.1.3 Result of defect during scenario number three

During scenario number three, the type of gating system was completely changed from top type to middle type gating system. New gating system with two in gates and runner was also designed. However, the position and number of riser during the third scenario not changed from currently existed scenario (Scenario one). After running simulations, the result of various observed defects was presented.

4.1.3.1 Shrinkage porosity defect

Again also closed shrinkage defects was still not eliminated completely. The total volume of 5.05% shrinkage porosity defect on scenario number two minimized to 4.77% shrinkage porosity defect on scenario number three. Through changing, a gating system from top type to middle type gating system and with additional runner and one more in gates model at third scenario another additional 5.54% shrinkage porosity minimization was achieved.

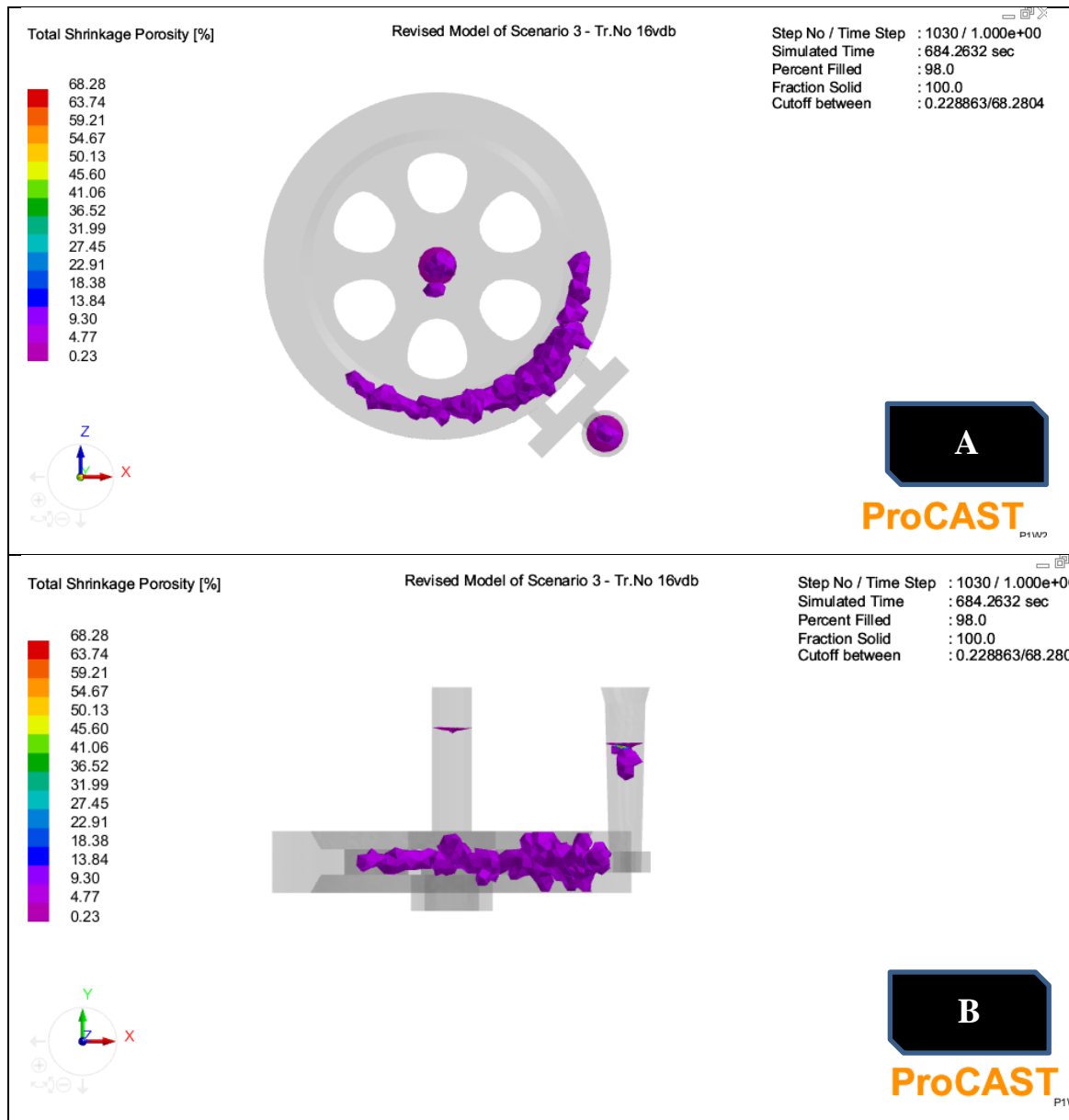


Figure 4.15:- Total volume of shrinkage porosity defect on scenario number two

A: - Total volume of shrinkage porosity defect (Top view)

B: - Total volume of shrinkage porosity defect (Side view)

4.1.3.1.1 Exact location at which maximum shrinkage porosity observed

Both maximum and minimum shrinkage porosity at the node level was observed on the point out of main product. Maximum shrinkage porosity visited on center of sprue at node 6606 {24.631; 24.900; 28.990} with total shrinkage porosity 68.28% and minimum shrinkage porosity on the corner end of runner at node 4063 {16.850; 16.111; 28.191} with

total 0.23% are visited. So certain observed result on scenario number three becomes a best achievement indication.

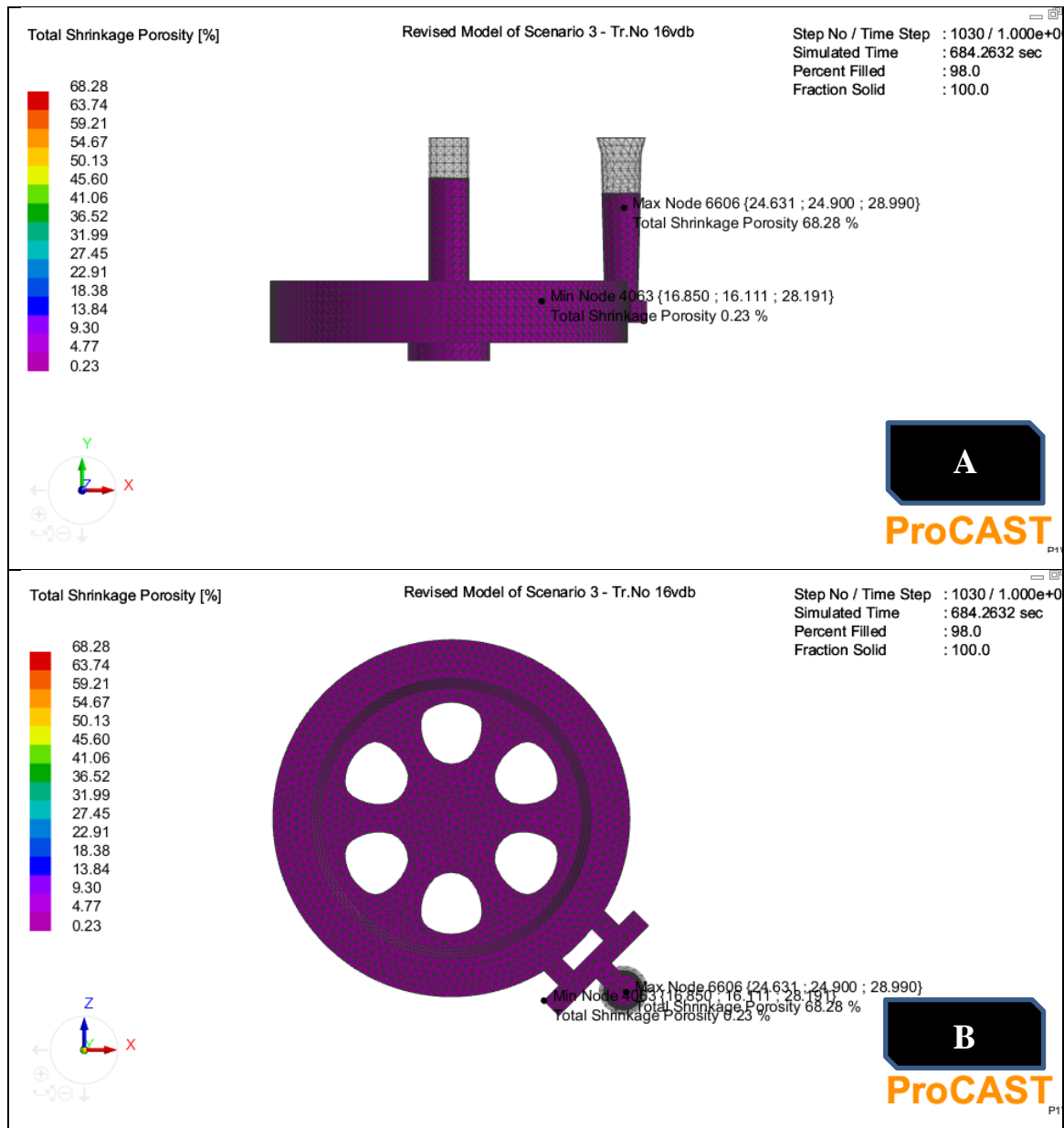


Figure 4.16:- Exact location at which high level of shrinkage porosity is visited (Scenario number two)

A: - Exact location of maximum and minimum shrinkage porosity (Side view)

B: - Exact location of maximum and minimum shrinkage porosity (Top view)

4.1.3.1.2 Taguchi analysis result on shrinkage porosity

After running six deferent trial, the result of maximum shrinkage porosity again also existed at the middle section of product and the range of defect extension was minor than currently existing. As shown clearly on all trial almost the position of shrinkage porosity are located nearest to in-gate. The area which covered by this defect almost minimized by half.

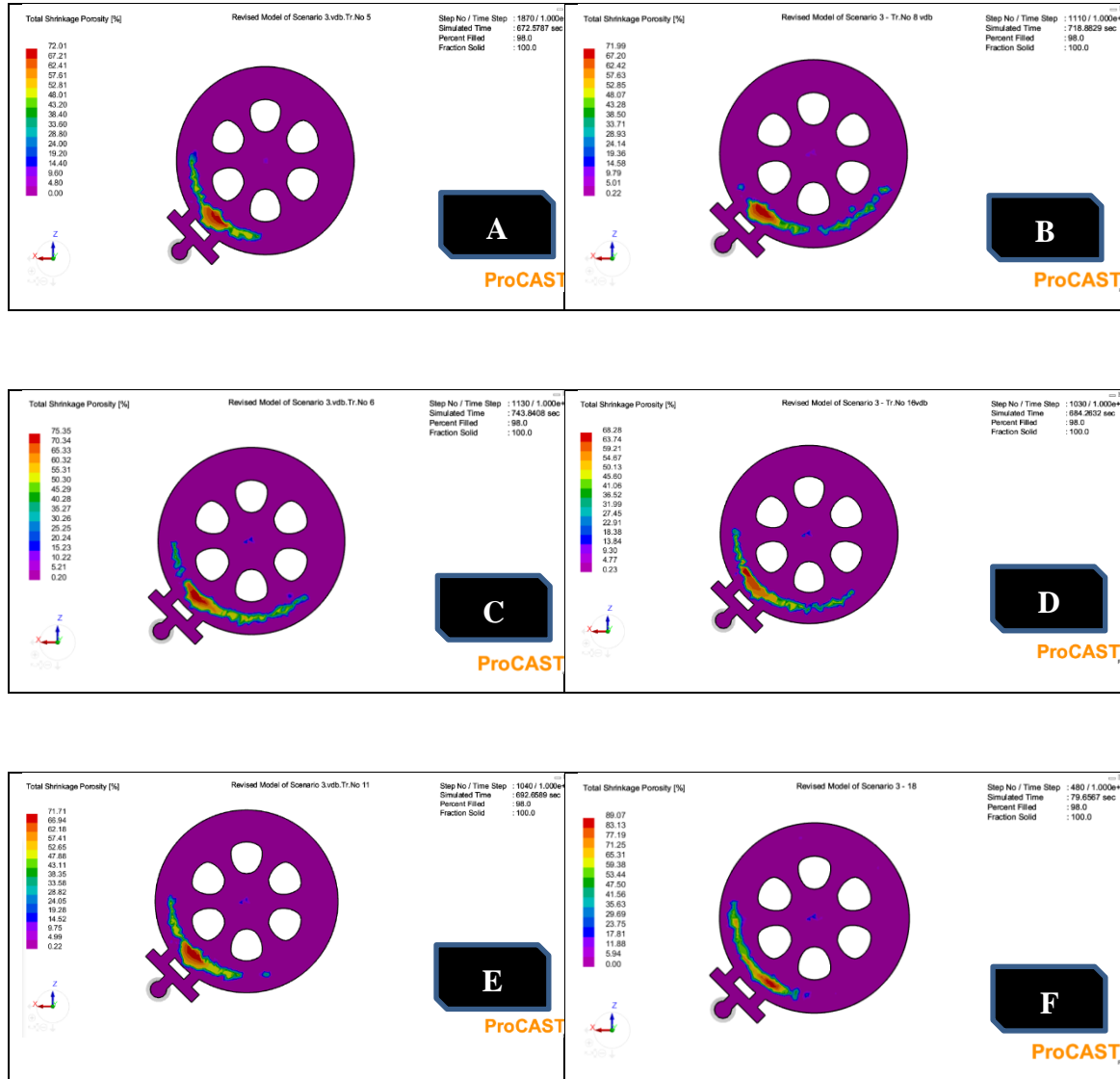


Figure 4.17:- Maximum shrinkage porosity result of scenario three.

- A/ Shrinkage porosity of trial number seven
- B/ Shrinkage porosity of trial number eight
- C/ Shrinkage porosity of trial number nine
- D/ Shrinkage porosity of trial number sixteen
- E/ Shrinkage porosity of trial number seventeen
- F/ Shrinkage porosity of trial number eighteen

During the third scenario, almost 75% of the thicker section of product were free from shrinkage defect as shown on Figure 4.18. During first scenario shrinkage, porosity defect can wide almost around 360degree at the thicker section, but on the third scenario spread minimization of shrinkage porosity defect achieved effectively.

4.1.3.1.3 Summary of shrinkage porosity result of scenario three

Again, at third scenario only through varying a process parameter (Mold initial temperature, Pouring temperature and Flow rate of molten metal), the location and yield volume of shrinkage porosity is varied. Therefore as shown, on Table 4.5 the volume of shrinkage porosity observed from total product volume on six different trial of scenario number two was presented.

Table 4.5:- Result of total volume of shrinkage porosity (Scenario Three)

| <i>Trial order</i> | <i>Total volume of shrinkage porosity by %</i> |
|---------------------------|---|
| 7 | 4.80 |
| 8 | 5.01 |
| 9 | 5.21 |
| 16 | 4.77 |
| 17 | 4.99 |
| 18 | 5.94 |

4.1.3.1.4 Comparison of shrinkage porosity result between scenario two and scenario number three

Again, on third scenario there was shrinkage porosity observed at the middle section of product. However, during comparison of maximum shrinkage porosity at node level on scenario number two becomes more than that of scenario number three. Because maximum level of shrinkage porosity 90.75percent at scenario number two changed into 75.35 percent at scenario number three. Therefore, the third scenario resulted 15.4% less shrinkage porosity at node level than scenario number two.

4.1.3.2 Hot spot defect

On the third scenario, the point at which hotspot visited is almost similar to that of scenario number two but it was completely different regarding to their arrangement as shown on Figure 4.18. Regarding too hotspot alignment straight type alignment are visited on scenario three. Nevertheless, the main drawback of PROCAST simulation software does not indicate the exact size of hotspots.

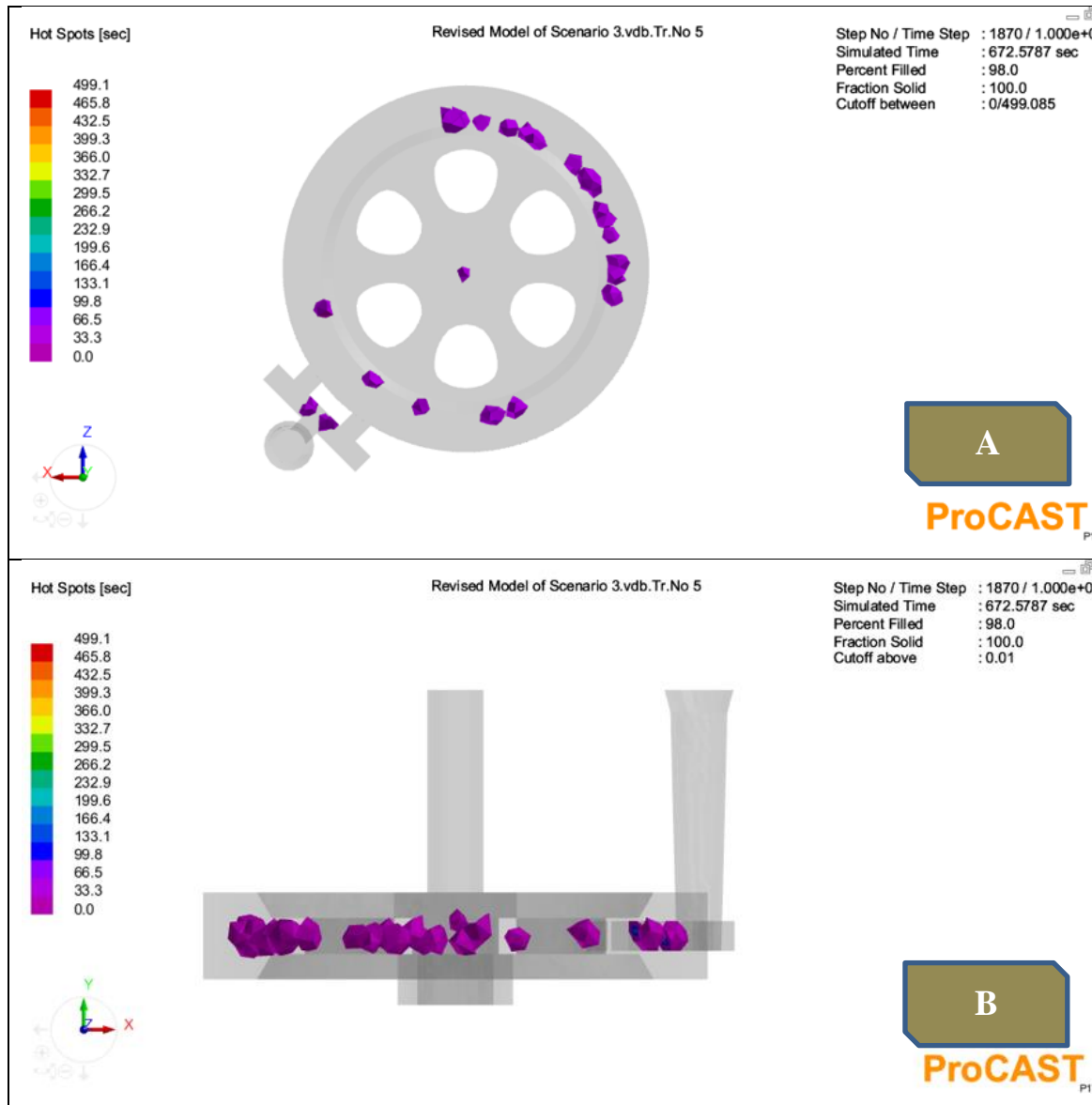


Figure 4.18:- Result of hotspot defect (Scenario three)

A: - Result of hotspot defect visited (Top view)

B: - Result of hotspot defect visited (Side view)

4.1.3.2.1 Location at which maximum hotspot defect observed.

Maximum hotspot defect was observed on the middle section at node 7801 {7.071; 4.268; 34.966} on 561.2sec and minimum hotspot defect at node 1 {23.638; 0.215; 38.483} on 0sec as shown on Figure 4.19.

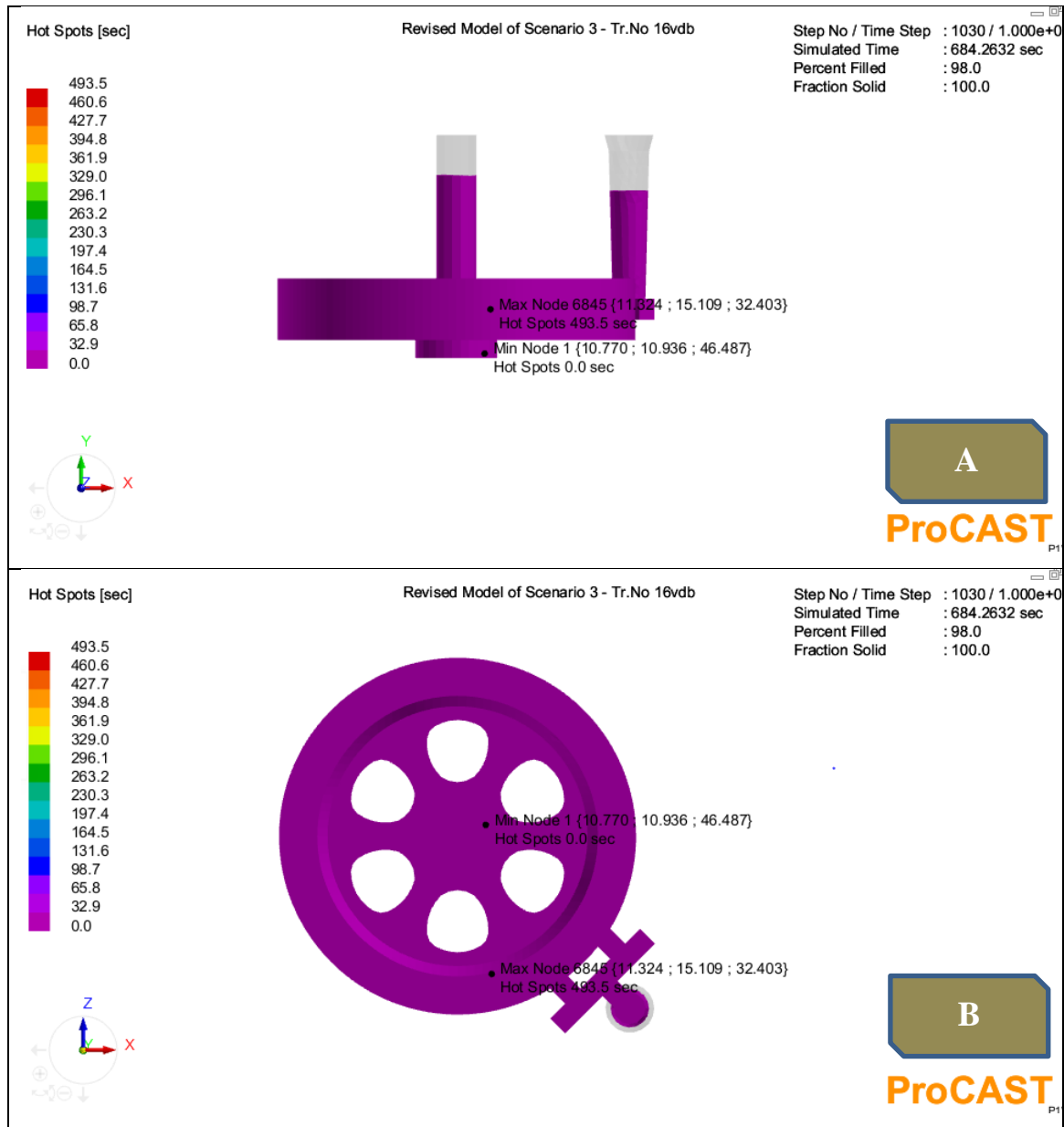


Figure 4.19:- Exact location of maximum and minimum hotspot defect (Scenario Three)

A: - Exact location of maximum and minimum hotspot defect (Side view)

B: - Exact location of maximum and minimum hotspot defect (Top view)

4.1.3.2.2 Taguchi array analysis result on hotspot defect

On this third scenario, again hotspot defect visited but the range of distance it covers is less than that of scenario one and two. Totally, the result of six different trial presented below in forms of numerical and figurative on Figure 4.20.

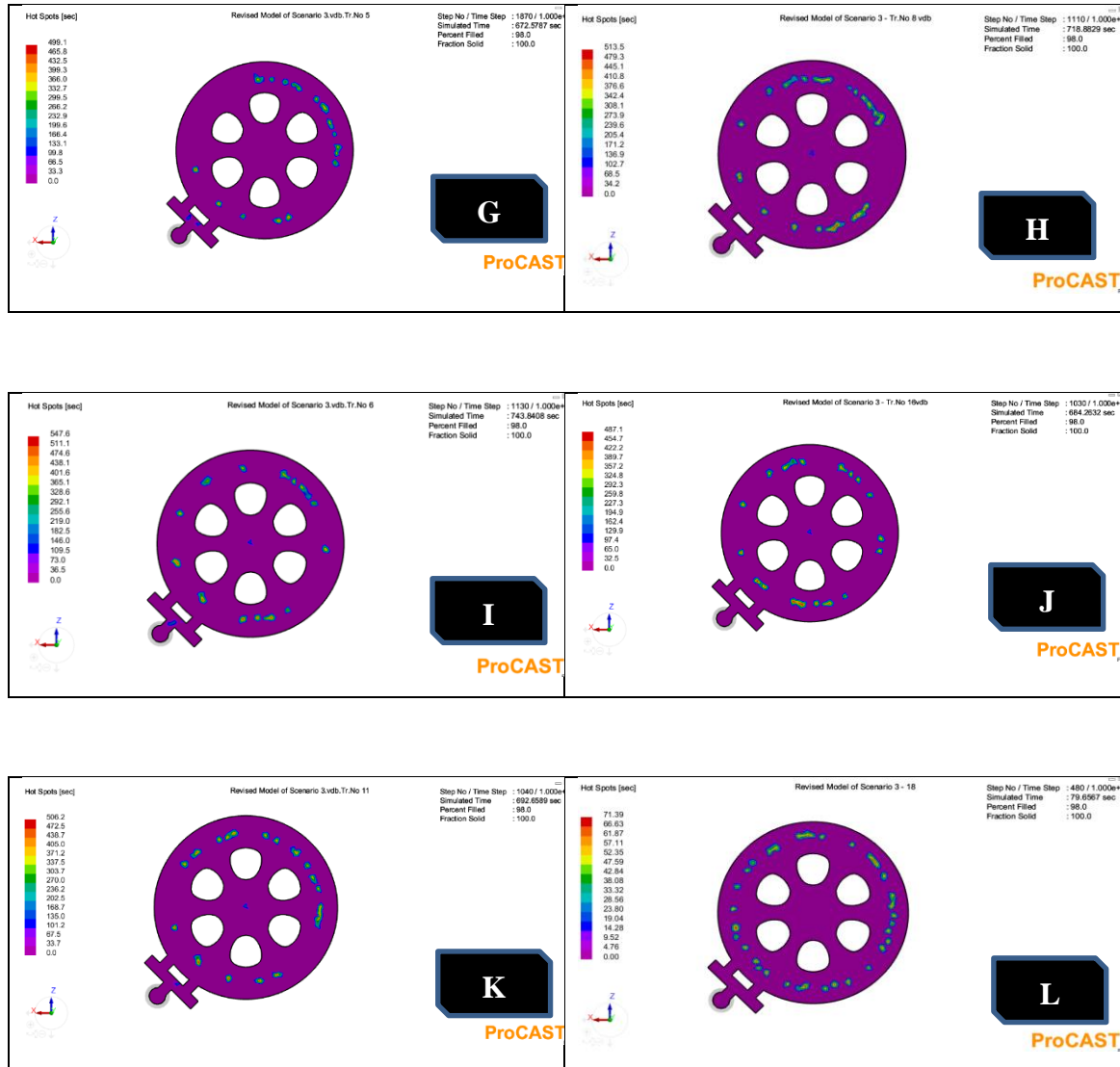


Figure 4.20:- Hot spot defect result of scenario three.

G/ Hotspot result of trial number seven

H/ Hotspot result of trial number eight

I/ Hotspot result of trial number nine

J/ Hotspot result of trial number sixteen

K/ Hotspot result of trial number seventeen

L/ Hotspot result of trial number eighteen

4.1.3.2.3 Summary on hotspot result (Scenario number three)

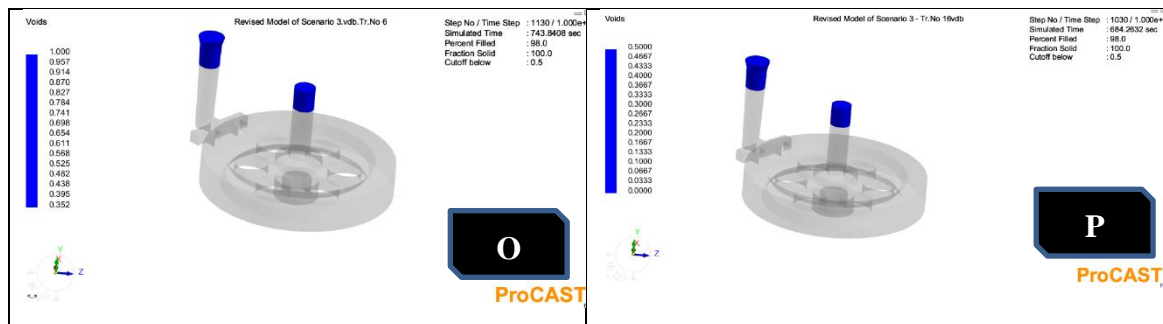
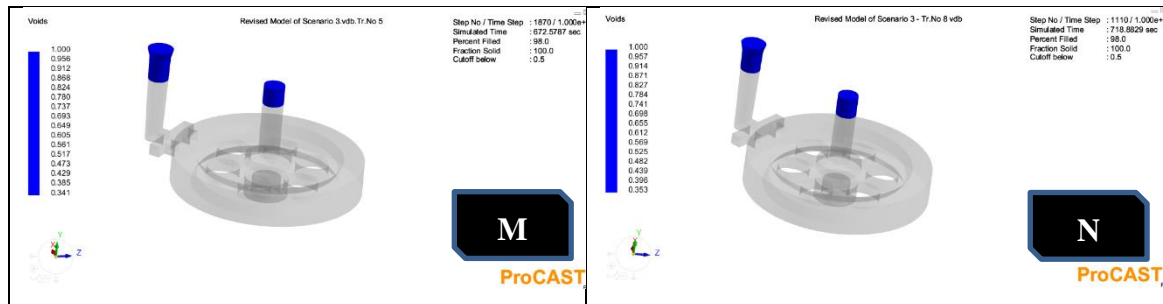
Here as shown on the Figure 4.20 the hotspot defect was not only limited to the middle section of the products it also extended toward the external surface in both direction. Finally, the numerical result of maximum hotspot and its exact location listed on Table 4.6.

Table 4.6:- Summary of maximum hotspot defect (Scenario number three)

| Trial order | Maximum hotspot defect | | Minimum hotspot defect | |
|-------------|------------------------|-------------------------|------------------------|----------------------|
| | Sec | Node | Sec | Node |
| 7 | 499.1 | 8737{12.25;14.85;32.78} | 0.0 | 1{10.77;10.93;46.48} |
| 8 | 513.5 | 6845{11.32;15.10;32.40} | 0.0 | 1{10.77;10.93;46.48} |
| 9 | 547.6 | 5919{9.46;15.11;31.80} | 0.0 | 1{10.77;10.93;46.48} |
| 16 | 493.5 | 6845{11.32;15.10;32.40} | 0.0 | 1{10.77;10.93;46.48} |
| 17 | 506.2 | 7376{11.31;15.11;32.41} | 0.0 | 1{9.60;11.36;47.48} |
| 18 | 71.39 | 6782{21.90;14.86;42.99} | 0.0 | 1{10.77;10.93;46.48} |

4.1.3.3 Result related to void defect

A void can reduce the strength and performance of the casting. On this third scenario almost void eliminated from the main product section completely as visited on figure 4.21.



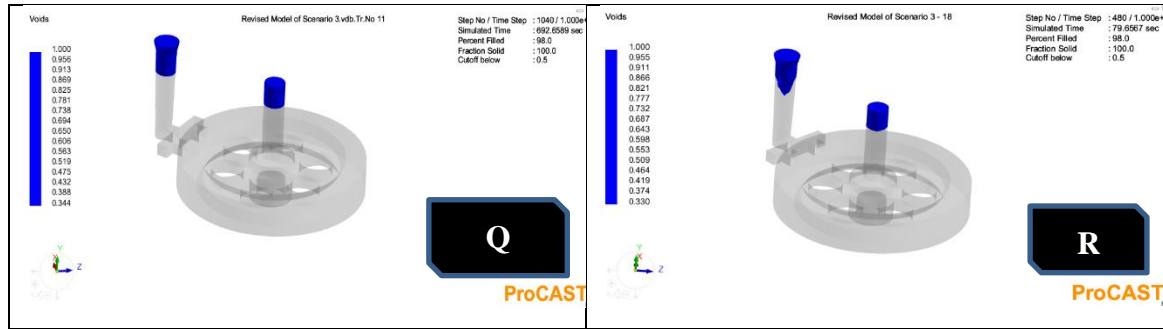


Figure 4.21:- Result of void defect of scenario one.

M/ Result of void defect for trial number seven

N/ Result of void defect for trial number eight

O/ Result of void defect for trial number nine

P/ Result of void defect for trial number sixteen

Q/ Result of void defect for trial number seventeen

R/ Result of void defect for trial number eighteen

4.2 Process parameter optimization result

4.2.1 Taguchi method analysis results

At first simulation was performed on PROCAST (Visual cast 17.5) according to L18 orthogonal array of Taguchi approach. PROCAST simulation software result of mean shrinkage porosity visited in percent; maximum hotspot observed and total ISO surface defect distance by cm is depicted in Table 4.7.

Table 4.7:- Simulational layout of L18 orthogonal array Input process parameters and output characteristics of L18 orthogonal array.

| Trial | A | B | C | D | Recorded Defect Value | | |
|-------|----|-------|-----|-----|----------------------------------|-------------------------------|----------------------------------|
| | | | | | Volume of Shrinkage Porosity (%) | Hot Spot Startup Period (Sec) | ISO surface Defect distance (Cm) |
| 1 | 20 | S.N 1 | 660 | 1.2 | 5.4 | 37.6 | 55.62 |
| 2 | 20 | S.N 1 | 670 | 1.5 | 5.45 | 38.9 | 49.68 |
| 3 | 20 | S.N 1 | 680 | 2 | 5.41 | 36.9 | 36.85 |
| 4 | 20 | S.N 2 | 660 | 1.2 | 5.05 | 33.7 | 25.01 |
| 5 | 20 | S.N 2 | 670 | 1.5 | 6.58 | 38.9 | 48.27 |
| 6 | 20 | S.N 2 | 680 | 2 | 5.66 | 39.7 | 43.5 |
| 7 | 20 | S.N 3 | 660 | 1.2 | 4.8 | 33.3 | 25.59 |
| 8 | 20 | S.N 3 | 670 | 1.5 | 5.01 | 34.2 | 23.84 |
| 9 | 20 | S.N 3 | 680 | 2 | 5.21 | 36.5 | 26.91 |
| 10 | 25 | S.N 1 | 660 | 1.2 | 5.41 | 36.2 | 35.12 |
| 11 | 25 | S.N 1 | 670 | 1.5 | 5.36 | 33.7 | 38.90 |
| 12 | 25 | S.N 1 | 680 | 2 | 5.56 | 35.2 | 37.41 |
| 13 | 25 | S.N 2 | 660 | 1.2 | 5.65 | 38.4 | 49.26 |
| 14 | 25 | S.N 2 | 670 | 1.5 | 5.05 | 33.7 | 26.58 |
| 15 | 25 | S.N 2 | 680 | 2 | 5.29 | 35.2 | 25.5 |
| 16 | 25 | S.N 3 | 660 | 1.2 | 4.77 | 32.5 | 26.45 |
| 17 | 25 | S.N 3 | 670 | 1.5 | 4.99 | 33.7 | 28.15 |
| 18 | 25 | S.N 3 | 680 | 2 | 5.94 | 4.76 | 20.6 |

A: - Mold initial Temperature

C: - Pouring Temperature

B: - Scenario (Designed model)

D: - Flow rate

4.2.1.1 Signal-to-noise [S/N] ratio and normalization result

In this study, rejection rate due to casting defect was considered as the main characteristic. The MINITAB®21.2 software was used to calculate the influence of process parameters on rejection rate due to simulation defects response. In order to assess the influence of factors on the response, the mean and the Signal-to-noise ratio for each control factor were calculated. The decisive factor ‘smaller is better’ used for choosing the S/N ratio. The response table for normalization and S/N ratio shown in the Tables 4.8.

Table 4.8:- Response table for S/N ratios of rejection rate and normalization for casting simulation defects at various levels of input parameters

| S/N Ratio | | | Normalization | | |
|--------------------------------|----------------|-----------------------------|--------------------------------|----------------|----------------------------------|
| Volume of shrinkage porosity % | Hot Spot (Sec) | Total defect on ISO surface | Volume of shrinkage porosity % | Hot Spot (Sec) | Total defect on ISO surface (Cm) |
| -14.648 | 31.504 | -34.905 | 0.386 | 0.026 | 1.000 |
| -14.728 | 31.799 | -33.924 | 1.085 | 0.994 | 0.586 |
| -14.664 | 31.341 | -31.329 | 0.391 | 0.034 | 0.586 |
| -14.066 | 30.553 | -27.962 | 1.037 | 0.955 | 1.064 |
| -16.365 | 31.799 | -33.674 | 1.000 | 0.010 | 0.857 |
| -15.056 | 31.976 | -32.770 | 1.110 | 1.000 | 1.247 |
| -13.625 | 30.449 | -28.161 | 0.019 | 0.083 | 0.218 |
| -13.997 | 30.681 | -27.546 | 1.031 | 0.959 | 1.048 |
| -14.337 | 31.246 | -28.598 | 0.274 | 0.040 | 0.269 |
| -14.664 | 31.174 | -30.911 | 1.081 | 0.975 | 1.176 |
| -14.583 | 30.553 | -31.799 | 0.363 | 0.077 | 0.640 |
| -14.901 | 30.931 | -31.460 | 1.098 | 0.967 | 1.197 |
| -15.041 | 31.687 | -33.850 | 0.526 | 0.016 | 0.878 |
| -14.066 | 30.553 | -28.491 | 1.037 | 0.955 | 1.084 |
| -14.469 | 30.931 | -28.131 | 0.322 | 0.057 | 0.215 |
| -13.570 | 30.238 | -28.449 | 1.000 | 0.946 | 1.083 |
| -13.962 | 30.553 | -28.990 | 0.140 | 0.077 | 0.314 |
| -15.476 | 13.552 | -26.277 | 1.140 | 0.424 | 1.000 |

4.2.1.2 Delta Oj, Grey relational Coefficient and grade

Grey relation analysis has wide applications in analyzing complex problems. Grey relation analysis approach is based on similar or dissimilar relation between various variables of process. The method also provides information for prediction and decision making. The method can also be applied in multi criteria decision making.

Table 4.9:- Grey relational coefficient and grade result

| Delta Oj | | | Grey Relational Coefficient | | | Grade | Rank |
|-------------------------------|----------------|-----------------------------|----------------------------------|----------------|----------------------------------|--------------|-----------|
| Shrinkage porosity Volume (%) | Hot Spot (Sec) | Total defect on ISO surface | Volume of shrinkage porosity (%) | Hot Spot (Sec) | Total defect on ISO surface (Cm) | | |
| 0.614 | 0.974 | 0.000 | 0.317 | 0.337 | 0.371 | 0.341 | 11 |
| -0.085 | 0.006 | 0.414 | 0.864 | 0.989 | 0.180 | 0.678 | 8 |
| 0.609 | 0.966 | 0.414 | 0.318 | 0.339 | 0.180 | 0.279 | 14 |
| -0.037 | 0.045 | -0.064 | 0.771 | 0.918 | 0.443 | 0.711 | 5 |
| 0.000 | 0.990 | 0.143 | 0.714 | 0.333 | 0.272 | 0.440 | 10 |
| -0.110 | 0.000 | -0.247 | 0.919 | 0.351 | 1.000 | 0.756 | 3 |
| 0.981 | 0.917 | 0.782 | 0.238 | 0.351 | 0.124 | 0.237 | 18 |
| -0.031 | 0.041 | -0.048 | 0.762 | 0.924 | 0.423 | 0.703 | 6 |
| 0.726 | 0.960 | 0.731 | 0.288 | 0.340 | 0.130 | 0.252 | 16 |
| -0.081 | 0.025 | -0.176 | 0.854 | 0.952 | 0.673 | 0.826 | 2 |
| 0.637 | 0.923 | 0.360 | 0.310 | 0.349 | 0.193 | 0.284 | 13 |
| -0.098 | 0.033 | -0.197 | 0.892 | 0.938 | 0.745 | 0.858 | 1 |
| 0.474 | 0.984 | 0.122 | 0.363 | 0.335 | 0.283 | 0.327 | 12 |
| -0.037 | 0.045 | -0.084 | 0.771 | 0.918 | 0.472 | 0.720 | 4 |
| 0.678 | 0.943 | 0.785 | 0.299 | 0.344 | 0.124 | 0.256 | 15 |
| 0.000 | 0.054 | -0.083 | 0.714 | 0.901 | 0.469 | 0.695 | 7 |
| 0.860 | 0.923 | 0.686 | 0.259 | 0.349 | 0.135 | 0.248 | 17 |
| -0.140 | 0.576 | 0.000 | 1.000 | 0.462 | 0.371 | 0.611 | 9 |

From GREY Relational analysis result on Table 4.9, it shows as simulation conducted at trial model number seven selected as optimum process parameter of simulation result. However, in order to now the optimum parameter combination we are going to Minitab software. In order to assess the influence of factors on the response, the mean and the Signal-to-noise ratio for each control factor are calculated. The decisive factor - ‘smaller is

better' used for choosing the S/N ratio. The response table for means and S/N ratio is given at Tables 4.10 and 4.11.

Table 4.10:- Response table for S/N ratios of rejection rate for casting defects at various levels of input parameters.

“Smaller is better”

| S/N ratio of rejection rate for casting defects | | | | |
|--|---------------------------------|--------------------------|----------------------------|------------------|
| Level | Mold initial temperature | Designed Scenario | Pouring temperature | Flow rate |
| 1 | 7.097 | 6.289 | 6.557 | 9.860 |
| 2 | 6.430 | 6.153 | 6.578 | 6.388 |
| 3 | | 7.848 | 7.156 | 4.042 |
| Delta | 0.666 | 1.695 | 0.599 | 5.818 |
| Rank | 3 | 2 | 4 | 1 |

Table4.11:- Response table for means of rejection rate for casting defects at various levels of input parameters

| Mean of rejection rate for casting defects | | | | |
|---|---------------------------------|--------------------------|----------------------------|------------------|
| Level | Mold initial temperature | Designed Scenario | Pouring temperature | Flow rate |
| 1 | 0.4886 | 0.5443 | 0.5228 | 0.3487 |
| 2 | 0.5361 | 0.5350 | 0.5122 | 0.5252 |
| 3 | | 0.4577 | 0.5020 | 0.6632 |
| Delta | 0.0476 | 0.0867 | 0.0208 | 0.3145 |
| Rank | 3 | 2 | 4 | 1 |

The figures 4.22(A) and 4.22(B) represents the main effect plots for means and S/N ratio of casting defects, respectively. From this tables and figures, it can concluded as the flow rate of molten metal and designed scenario has the most influential factor respectively for changing the percentage of casting defects and pouring temperature has less effect.

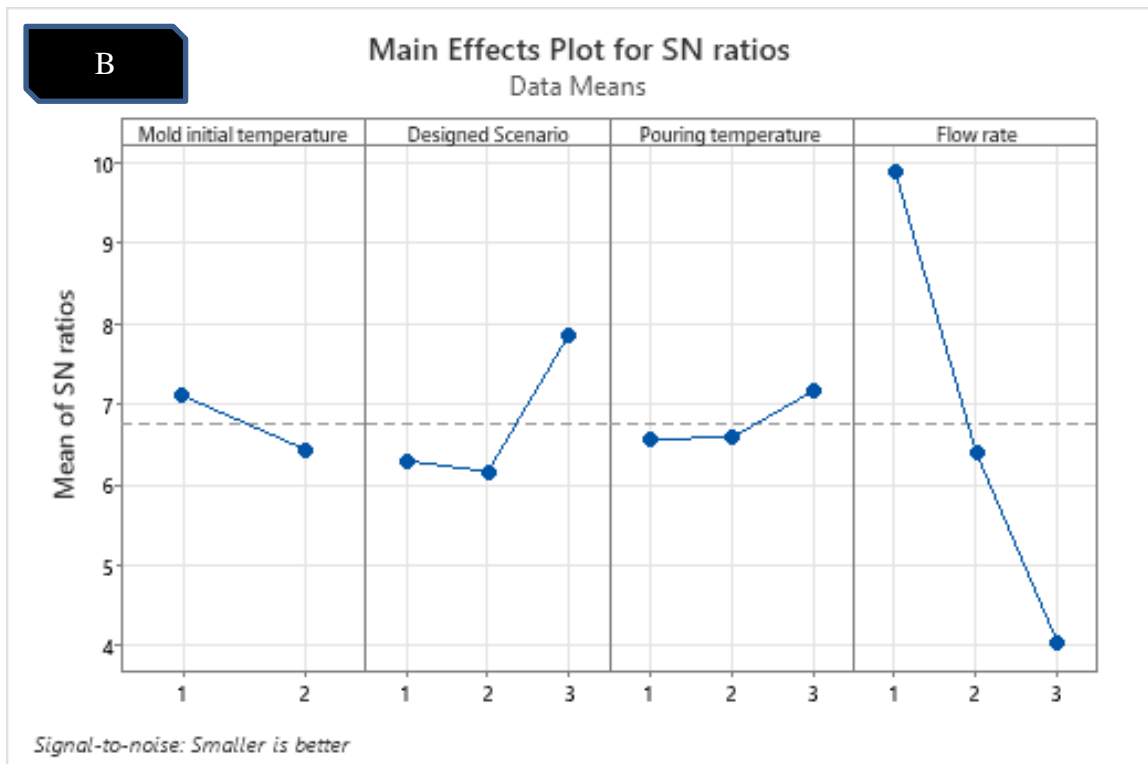
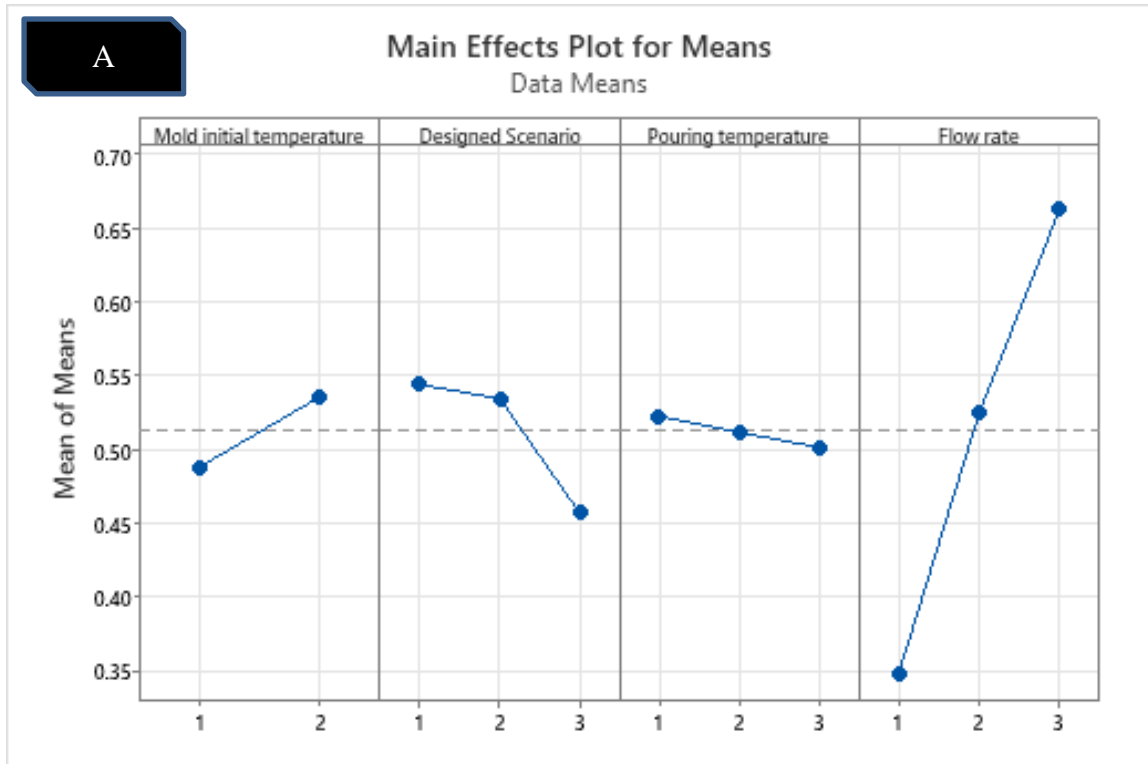


Figure 4.22:- : Main effect plots for (A) mean values and (B) S/N ratios of rejection rate due to casting defects

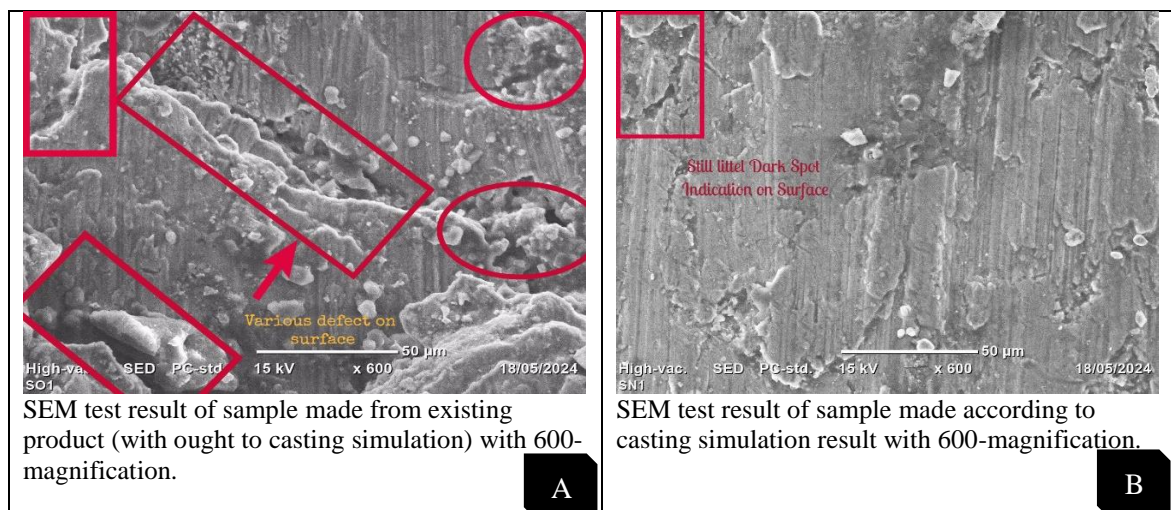
4.3 Experimental result

Scanning electron microscopy (SEM) makes use of signals produced from the interaction between an electron beam and a sample surface. The signal is collected from the interaction volume of the electron beam in the sample. For a given sample, the voltage used to accelerate the electrons determines the interaction volume. When operating at a low voltage (< 5kV), the interaction volume decreases and shrinks towards the outer surface. This means the collection of signals is only from the outer surface layers. Therefore, the images obtained have more detailed information of the surface morphology and chemistry of this outer layer.

During Experimental test six different sample has visited under SEM (Scanning Electron Microscope) that uses a focused beam of **electrons** to scan the sample surface.

4.3.1 SEM image of specimens taken nearest to surface of product

During this specimen, preparation the specimen directly taken from nearest to the surface of the product fabricated. Surface taken specimen was far from the middle section of products. Two sample with a name of SO1 (Sample taken from existing old product with ought casting simulation software) and sample SN1 (Sample taken from product casted according to casting simulation result) tested under scanning electron microscope with 600 and 1500 magnification and their result are presented at Figure 4.23.



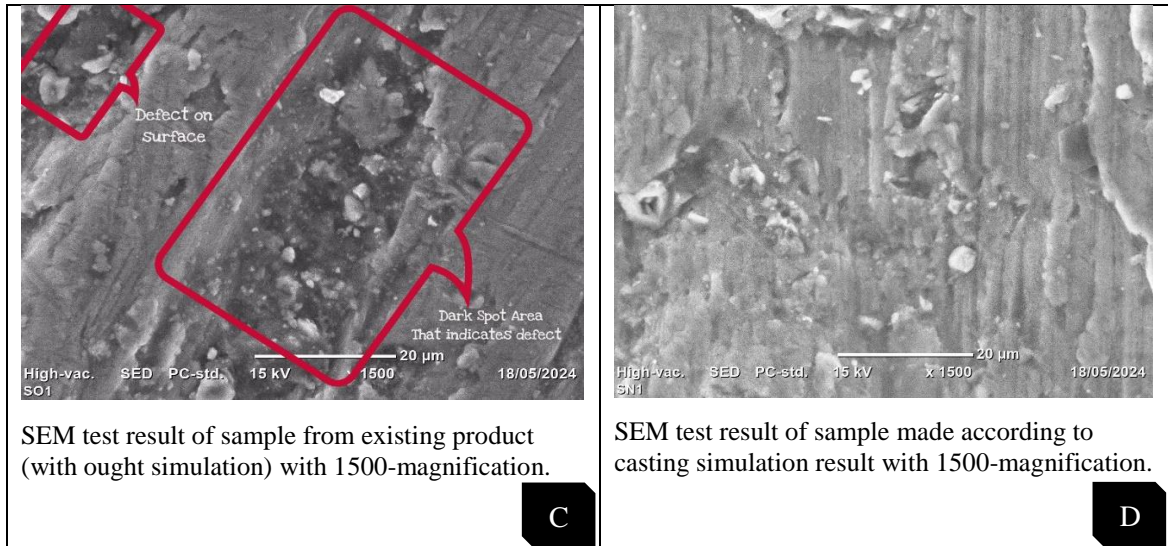


Figure 4.23:- SEM image of specimen

As indicated on result of Figure 4.23 during both 600 and 1500magnification there is a high result of dark spot and oxide particle observed. So the result of dark spot on SEM always indicate as there was a defect on surface and little distance from surface of specimen. From result again it shows as all specimen which fabricated according to PROCAST simulation result are observed as brighter spot which means those specimen was heavier and reflect more electron on back

4.3.2 SEM result of sample taken from middle section of product.

During this specimen, preparation the sample directly taken from middle section of the product fabricated. Two sample with a name of MO1 (Sample taken from existing old product with ought casting simulation software) and sample MN1 (Sample taken from product casted according to casting simulation result) tested under scanning electron microscope with 600 and 1500 magnification and their result are presented on Figure 4.24.

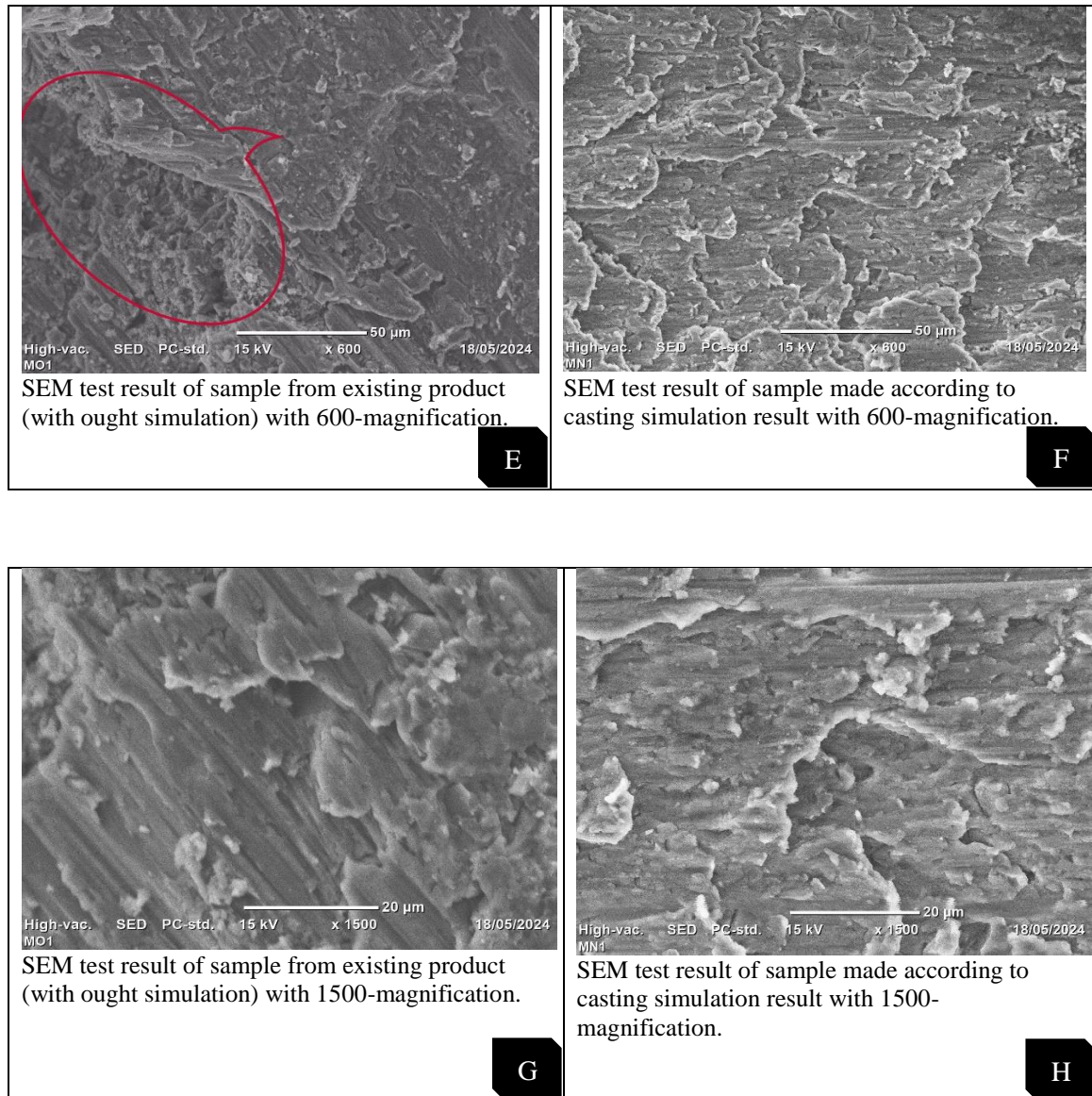


Figure 4.24:- Microstructure examination result of middle specimen

Again also after sample examination within secondary electron detector the result presented on Figure 4.24. The secondary electron detector are emitted from the sample by inelastic scattering. The number of secondary electrons detected represents the signal intensity and is combined with the position of the beam to produce gray-scale images showing the sample's topography, as seen in Figure 4.24. Elements that are heavier and reflect more electrons will appear brighter in the image so back-scattered electrons can show best contrasts in molecular structure and composition. However, the identity of each different elements cannot be determined with SEM alone, an EDS and TEM attachment would have to be used to quantify the relative abundance of different elements.

Chapter Five

5 Conclusion and recommendation

5.1 Conclusion

Nowadays casting is very versatile process used for number of engineering applications in today's world. However, in Ethiopia most of casting foundries run away through trial and error, which takes more resource and unnecessary time. In this study, defects minimization of casting processes studied in order to minimize the rejection level, maximize productivity, quality and targeted to take the level of casting industries one-step forward. Because simulation based trials, do not involve wastage of material, energy and labor, by using casting simulation method it is possible to minimize the percentage of rejection of casting due to defects.

This study was targeted on three scenario, scenario number one was currently existed model and scenario number two and three were newly proposed models. Casting through simulation was conducted according to Taguchi L-18 orthogonal array. Depending on simulation result, the best run with optimum process parameter was selected through grey analysis and experimental cast conducted on selected model inside foundry. After all the conclusion of this work is as follows.

- ✚ From Taguchi's method and gray relational analysis the optimum process parameters, was found as 'A2B3C2D3', (which is mold initial temperature was 25 °C, gating system scenario three, pouring temperature at 2nd phase with 670 °C and the third flow rate was 2Kg/s.
- ✚ Only variation of process parameter (mold initial temperature, pouring temperature and flow rate) changes maximum range of shrinkage porosity at the node level minimized from 77.05 percent to 71.5percent. So process parameter variation with ought modeling a new gating system minimizes only 5.55 percent of shrinkage porosity at node level ad also minimize 3.5% volume of shrinkage porosity.
- ✚ The total point on which hotspot defect visited minimized from more than 35 expanded point at currently existing model to limited span distance of only 14 points on selected trial model.

- ✚ From different recorded defect shrinkage, porosity and hotspot defect were the most significant defects, which were highly observed on the middle section (at distance 29mm from the surface of only thicker section) of the product.
- ✚ From simulation, run result conducted according to Taguchi L-18 orthogonal array 100 percent of void defect elimination achieved.
- ✚ Finally, from the simulation result maximum total defect on ISO surface of product minimized from 55.62cm to 26.58cm, which means 52.22percent total defect minimization achieved on selected trial mode.
- ✚ From SEM result is possible to conclude as those specimen fabricated according to simulation result was heavier and reflect more electrons, because they was appear brighter in the image. Back-scattered electrons can show contrasts in chemical composition.
- ✚ An SEM image produced from the intensity of back-scattered electrons and the beam position can show the distribution of different elements in the sample. Specimen that are heavier and reflect more electrons was appeared as brighter in the image so back-scattered electrons can show contrasts in molecular and chemical composition. However, each defect identifying for different specimen cannot be determined with SEM alone, an EDS and TEM attachment would have to be used to quantify the relative abundance of different elements.

5.2 Recommendation

- ❑ Because of better defect minimization observed for selected product, developing a model according to scenario three was mostly recommendable to come up with better quality and minimum defect product for case company.
- ❑ It is more and more time, quality and resource effective to work with simulation casting rather than conducting Taguchi Method Experimental casting in order to identify optimum process parameter.
- ❑ Most of our country's casting foundries have not implement this type of defect identification software and trained labor. Therefore, if they have the determination to create a better professional in this regard it will move the country's casting foundry one-step further.
- ❑ For future, it needs to conduct a more simulation analysis for other product that are mostly critical to increase the quality and efficiency of products at case company.

5.3 Future work areas

Next time it is required to conduct various researchs on this sector with different casting material on different product. Many products are available which needs to fabricate from different material for different purpose, therefore, it is better to modernize different foundries including the case studies foundries through:-

- ✚ Practice a trend of using casting software to identify different defect and minimize at minor range at foundry level before conducting experimental.
- ✚ Further investigation and research on **many critical parts or product**, which need to be casted with a better quality and limited defect level needed.
- ✚ At present both simulation and experimental analysis done through using currently existing mold, sand, and pattern at case study organization and achieved with better defect minimization. However, there is still the possibility of gaining better results than this research by changing above listed materials depending on the result of best PROCAST Simulation software.
- ✚ This research conducted on product made up of Aluminum A356, but it needs to conduct another research with different material and products.

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Appendix A

Figure A1:- Drawing of Selected Model (Scenario Number Three, Trial number seven).

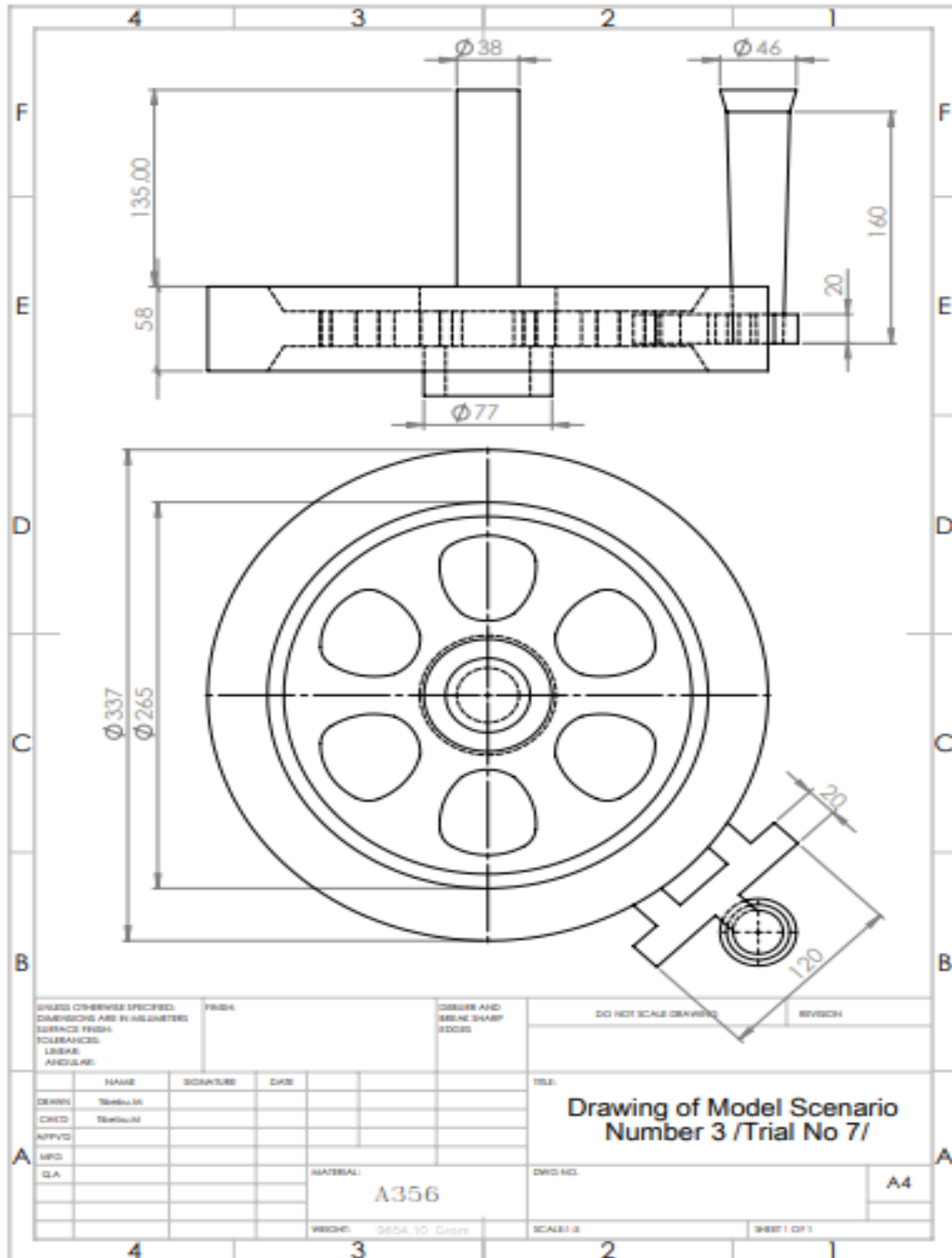


Figure A2:- Visual mesh for two new volume created of selected model (Scenario number three, Trial model number seven)

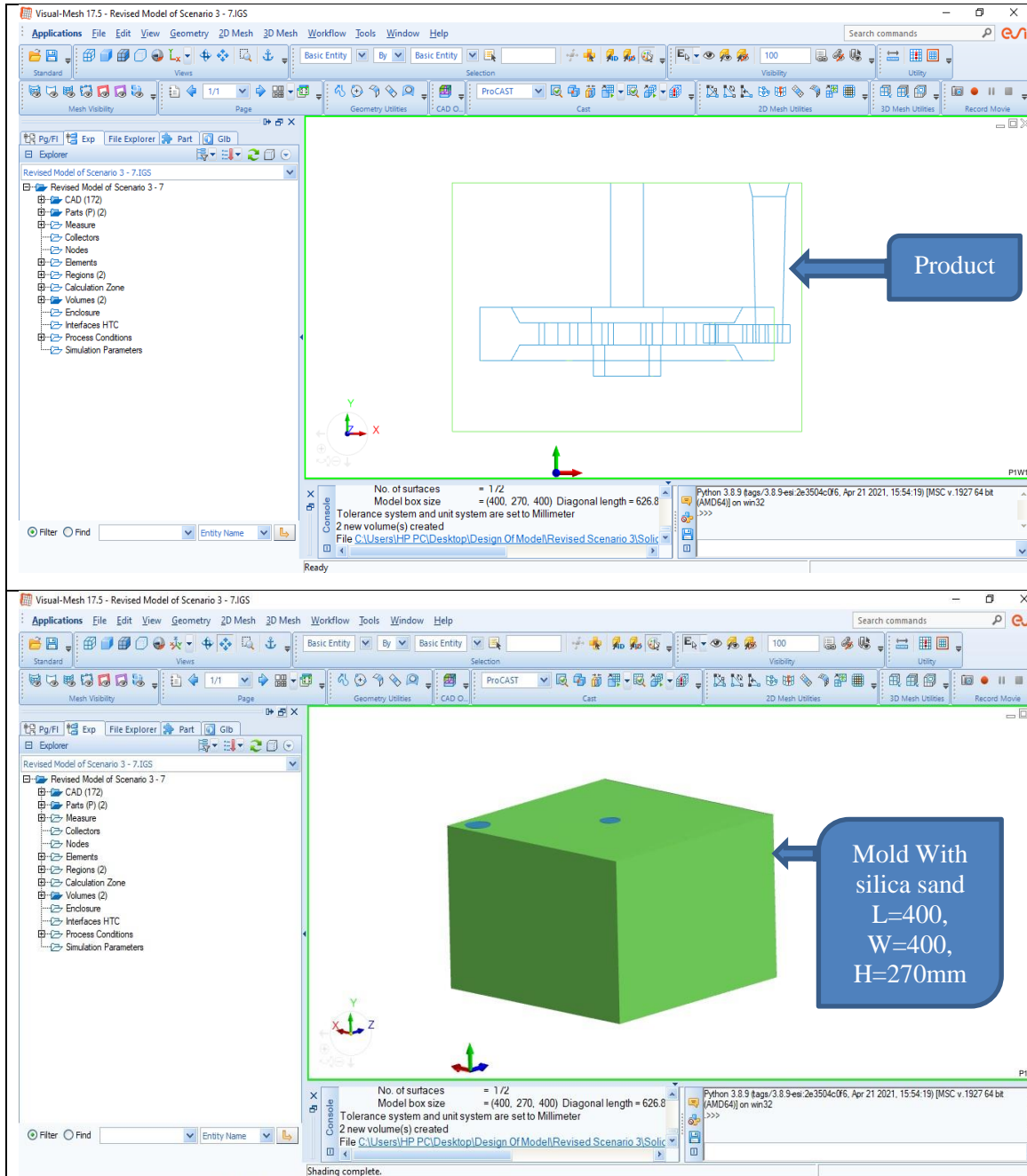


Figure A3:- Automatic detecting of overlapping surface between two volumes of selected model (Scenario number three, Trial model number seven)

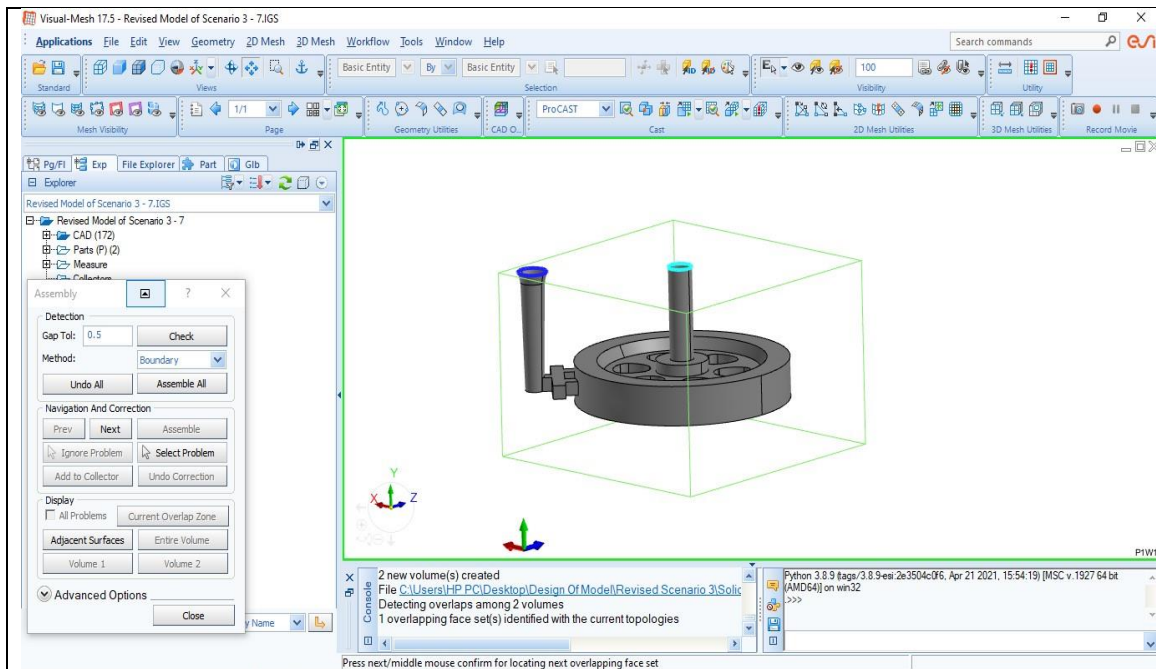


Figure A4:- determining global mesh element size and mesh type of selected model (Scenario number three, Trial model number seven).

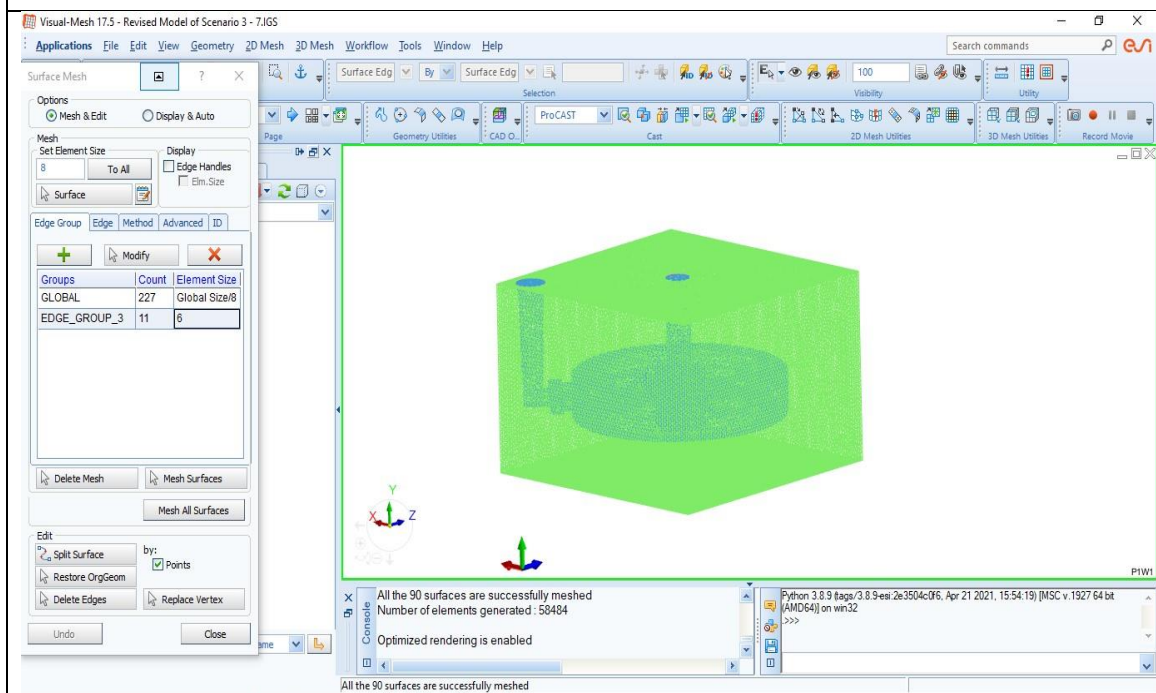


Figure A5:- Determining mesh element size of edge and mesh type of selected model (Scenario number three, Trial model number seven).

✚ Six mesh size and Trio types of mesh defined.

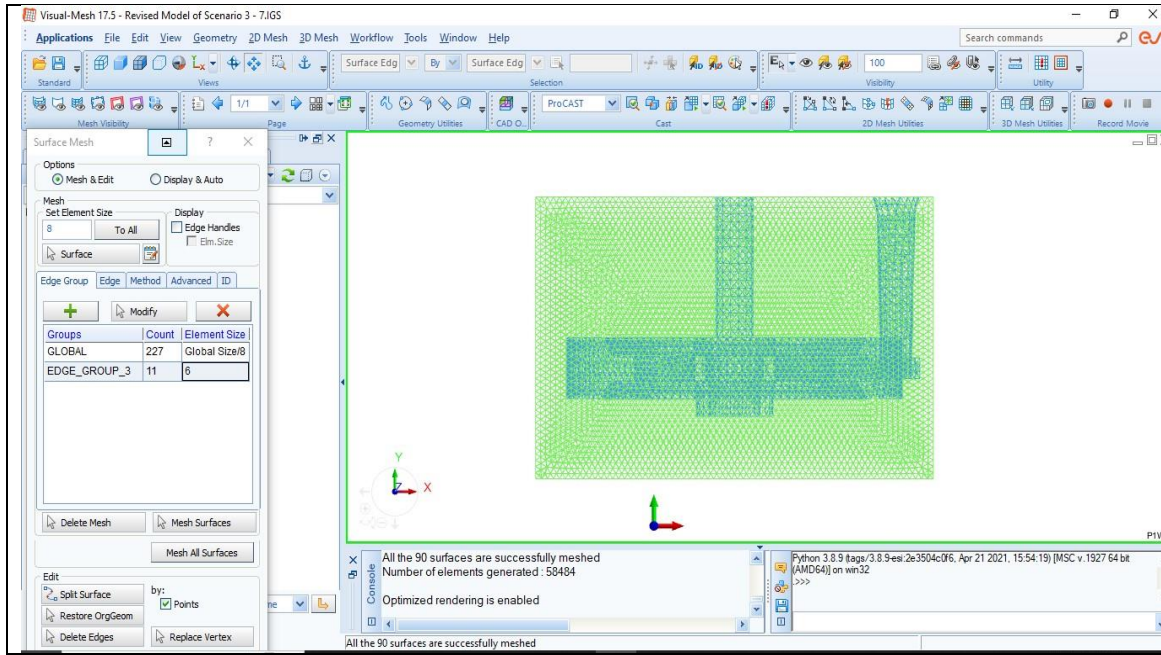


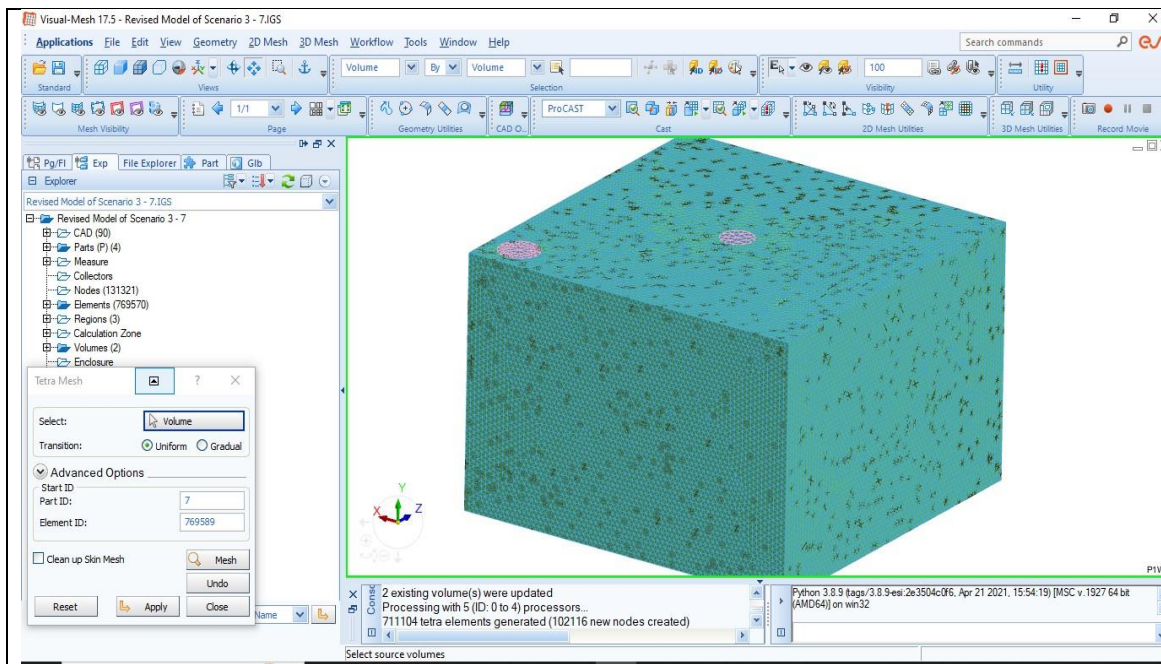


Figure A6:- Volume mesh for selected model (Scenario number three, Trial model number seven).

-  Totally 711,104 number of tetra element generated.
-  In addition, 102,116 number of new node created.



Appendix B

Figure B1:- Defining of job (Gravity Sand Casting) for selected model (Scenario number three, Trial model number seven).

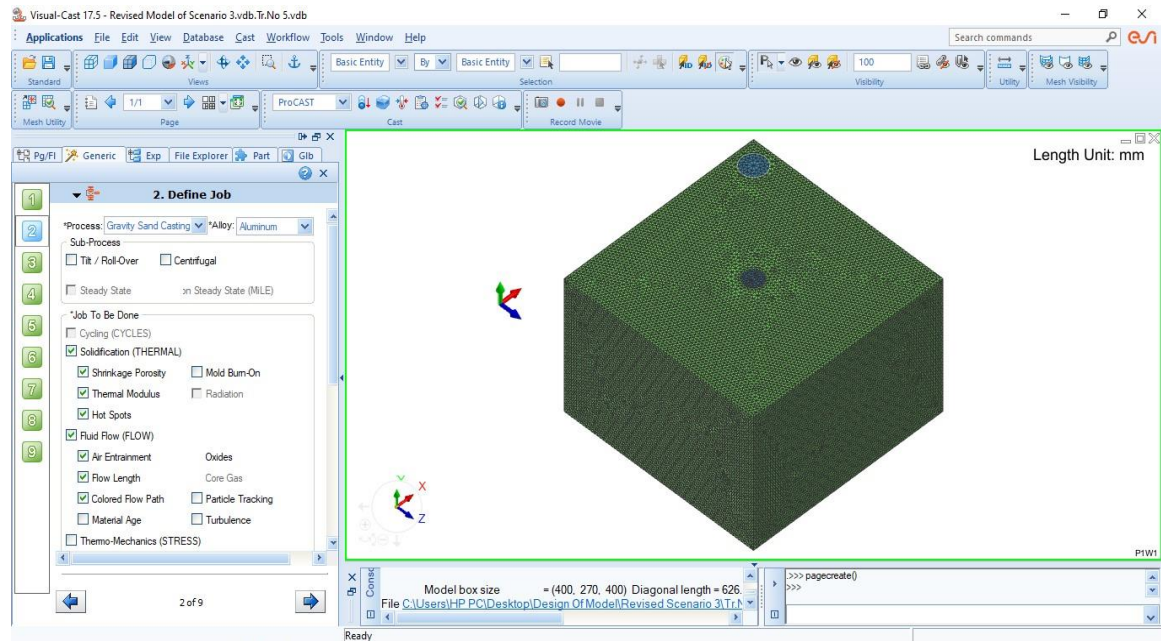


Figure B2:- Defining of gravity for selected model (Scenario number three, Trial model number seven).

 -Y Direction selected for a gravity direction.

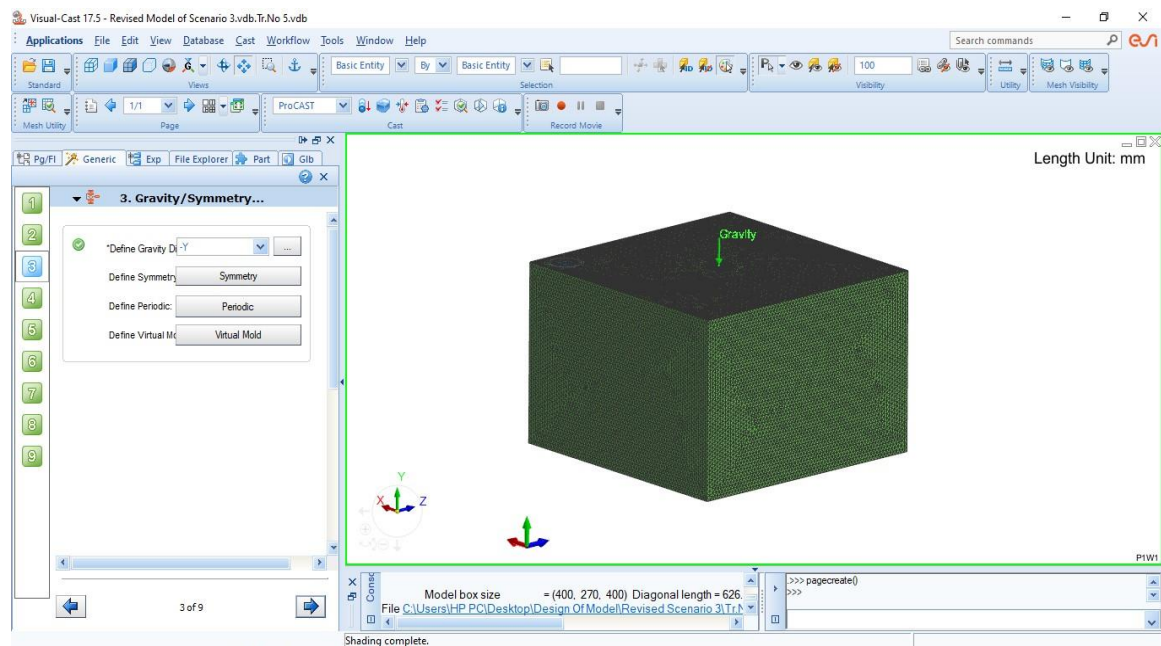


Figure B3:- Volume manager for selected model (Scenario number three, Trial model number seven).

✚ Silica sand mold (400x400x270) with 20 °C initial temperature.

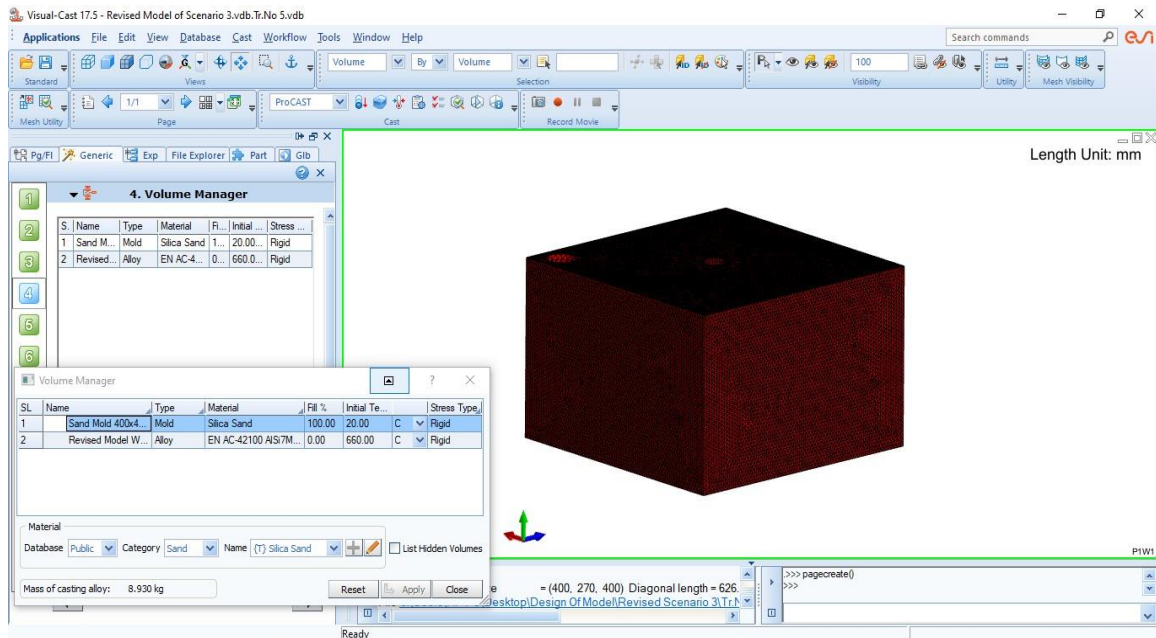


Figure B4:- Volume manager for selected model (Scenario number three, Trial model number seven).

✚ Pulley product alloy from A356 (EN AC-42100 AlSi7Mg0.3)

✚ Mass of casting alloy= 8.930Kg.

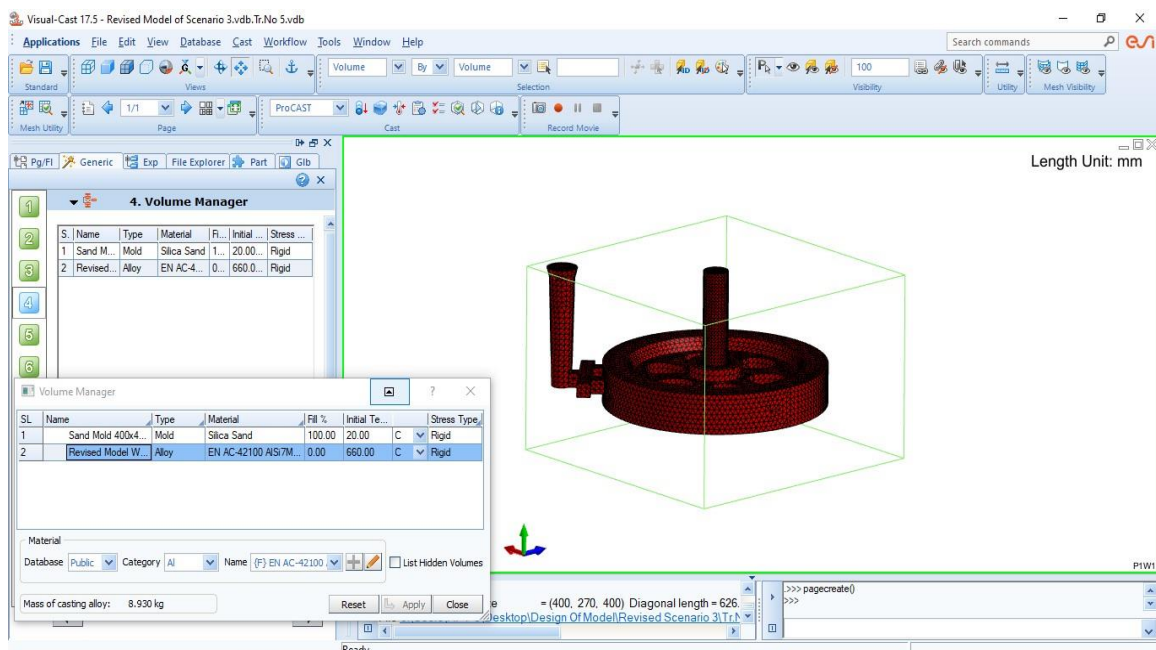


Figure B5:- Interface HTC manager for selected model (Scenario number three, Trial model number seven).

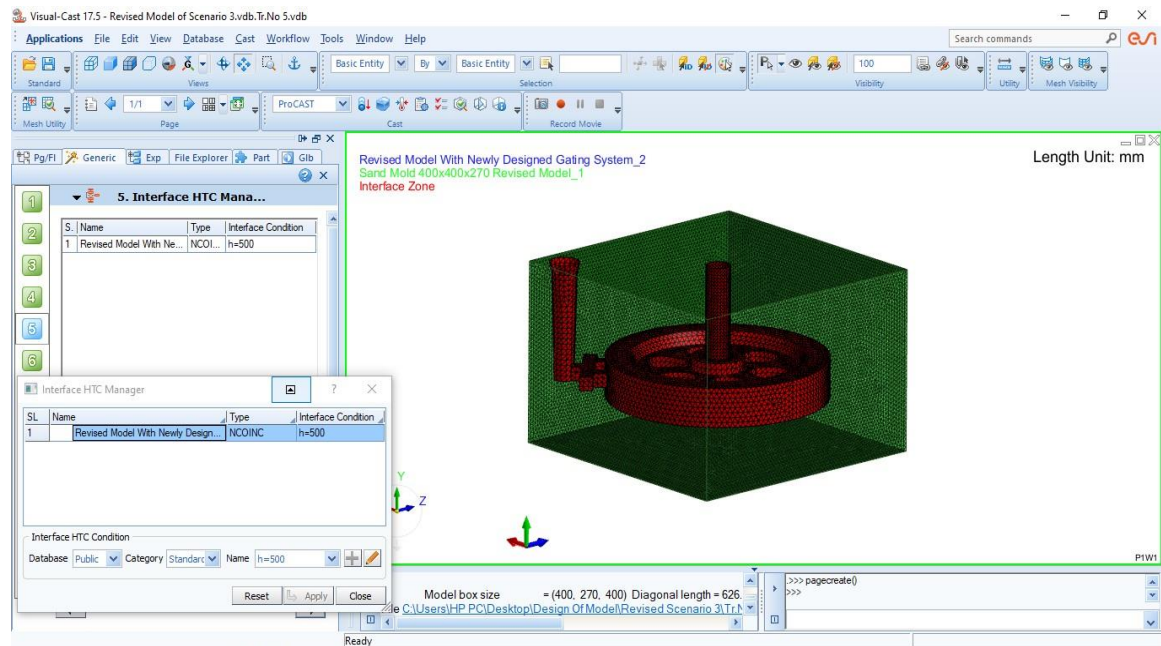



Figure B6:- Process condition for selected model (Scenario number three, Trial model number seven).

 Air cooling type boundary condition applied.

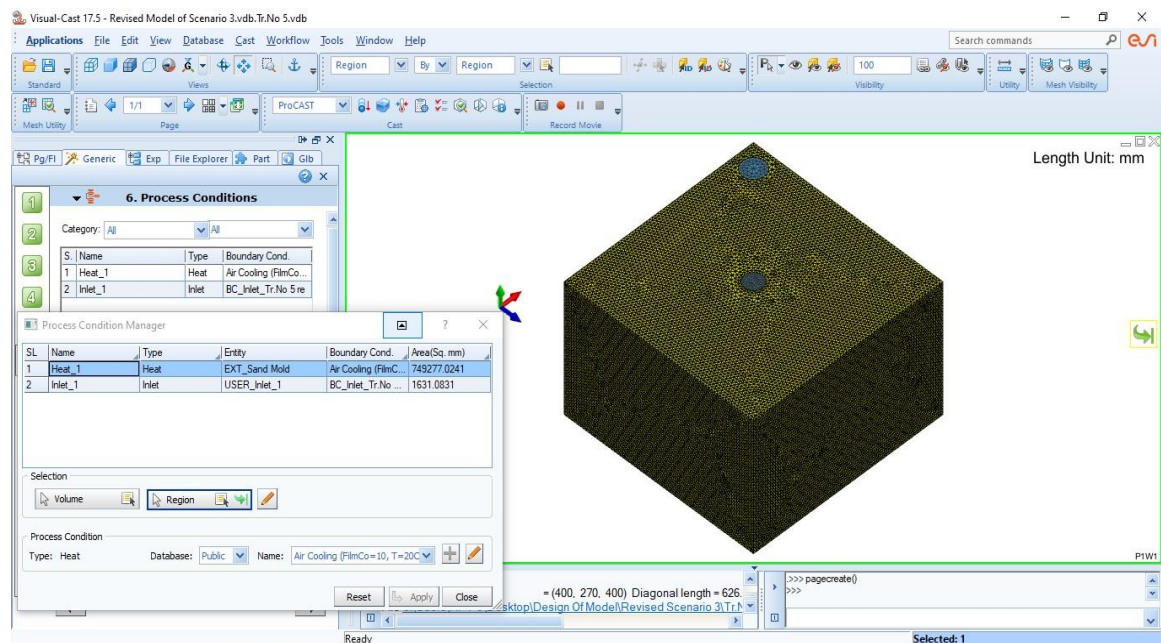



Figure B7:- Inlet process condition for selected model (Scenario number three, Trial model number seven).

 Selected inlet region of sprue cap.

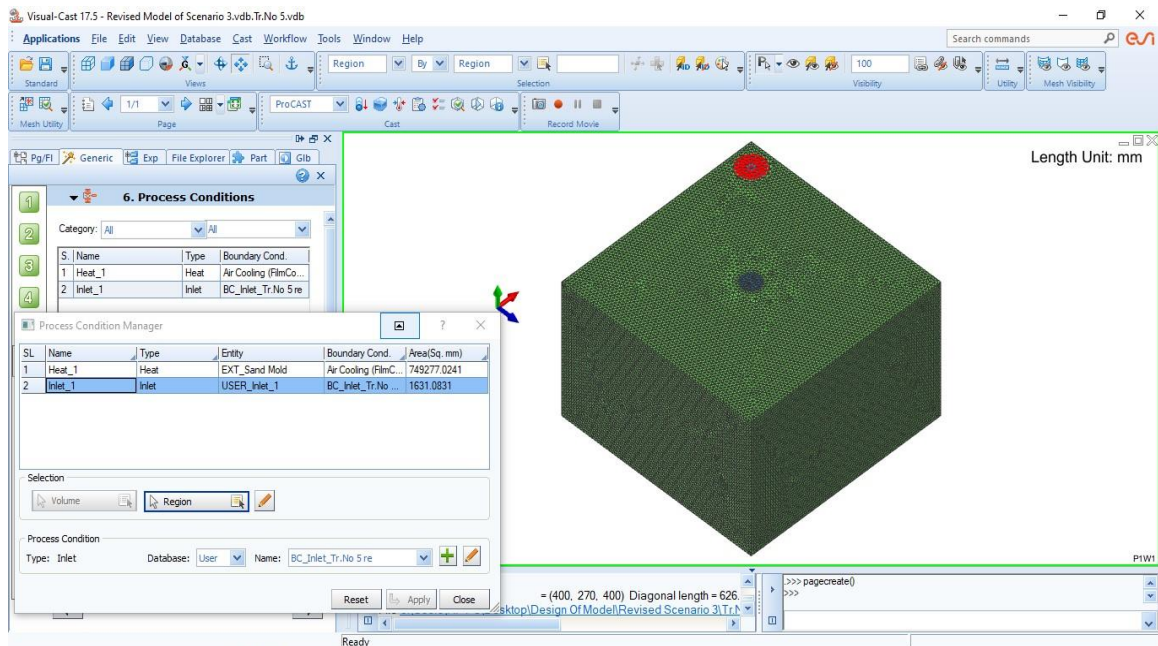
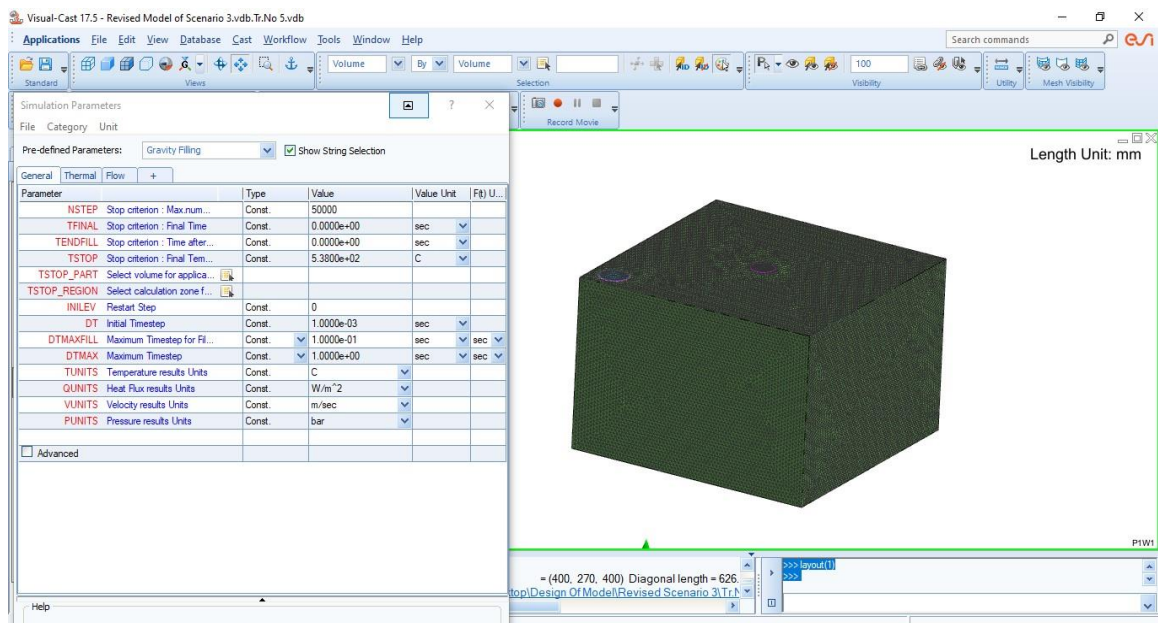


Figure B8:- Pre defined simulation parameter for selected model (Scenario number three, Trial model number seven).



Appendix C

Figure C1:- Shrinkage porosity result comparison.

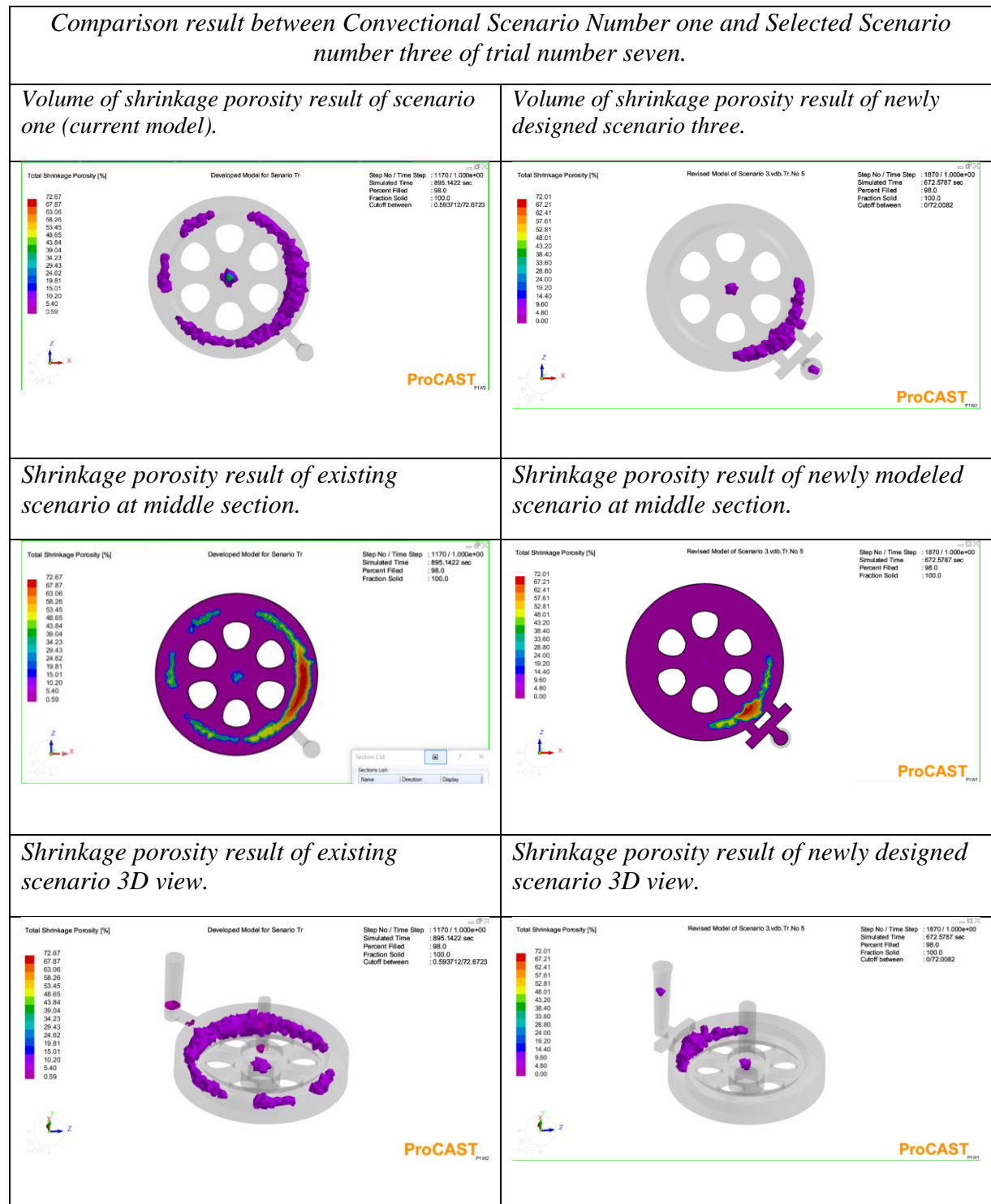


Figure C2:- Hotspot result comparison

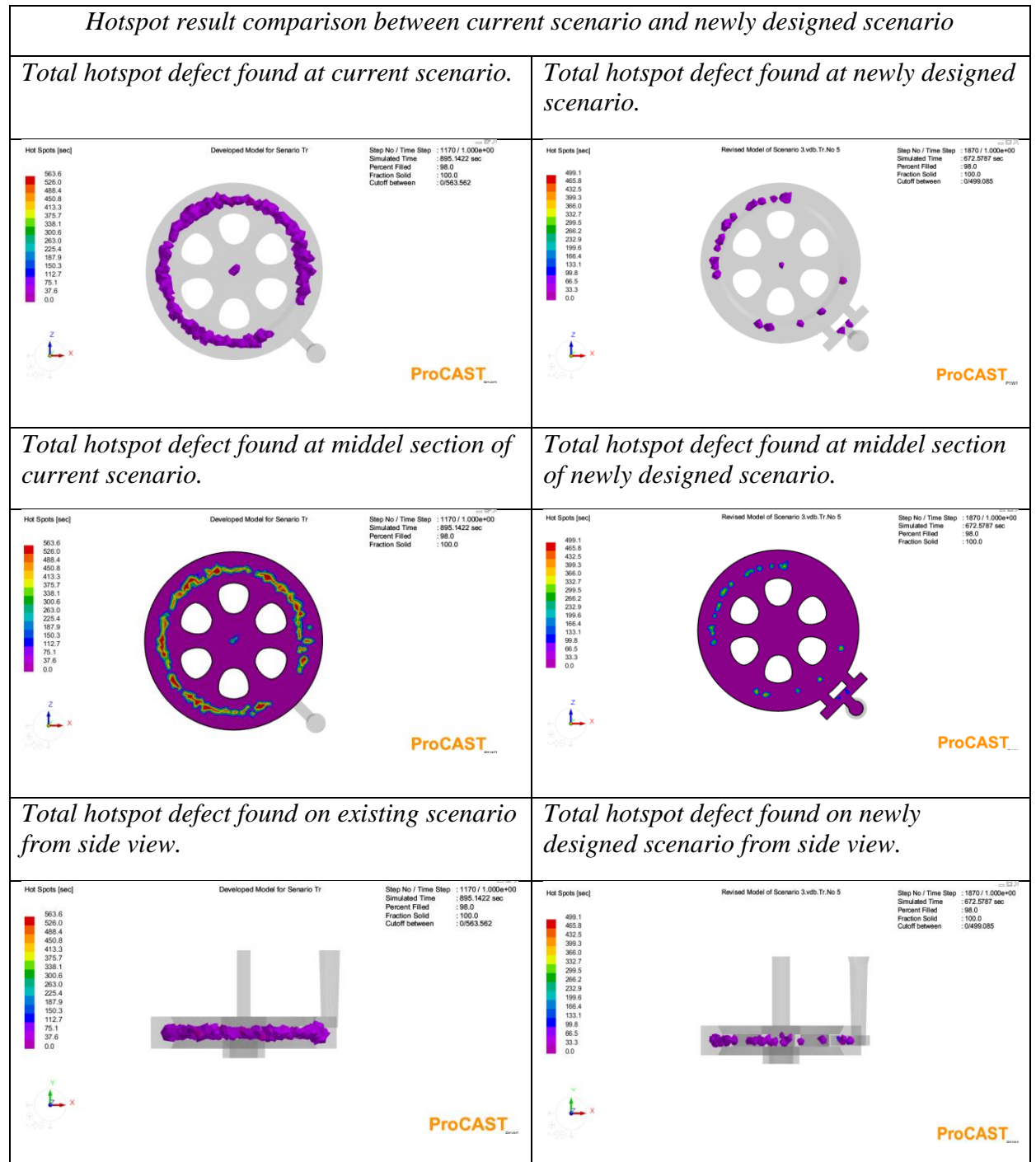


Figure C3:- Defect distance result on ISO surface.

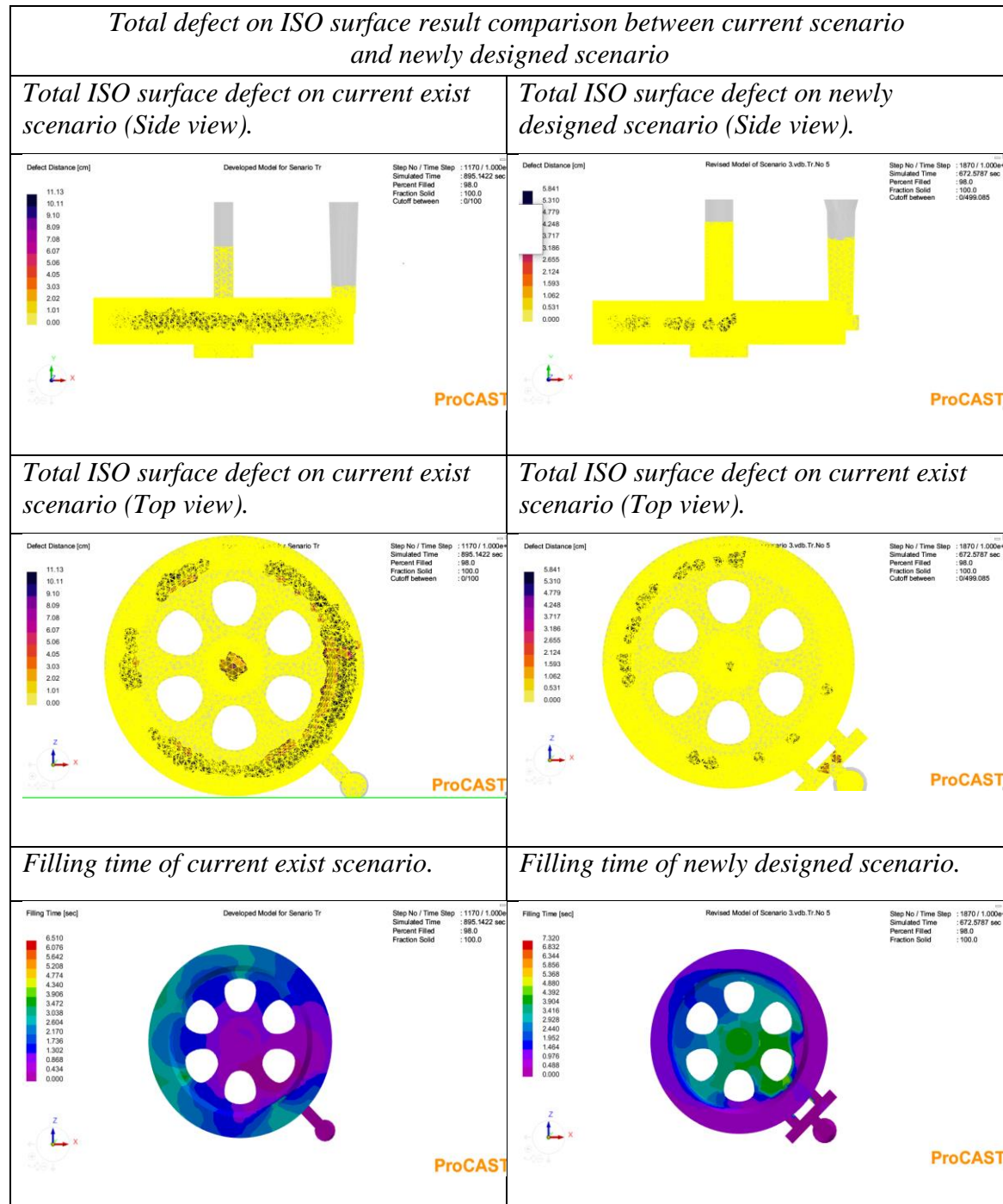


Figure C4:- Temperature Vs Time graph result of selected scenario at each node.

