International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Influence of Sprue Design and Riser Configuration on Cast Iron Casting Output Parameters

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A B S T R A C T

Casting is a fundamental manufacturing process in which molten metal is poured into a mold to form a solid object with a desired shape. This method is widely used across industries such as automotive, aerospace, and construction for producing intricate parts with high dimensional accuracy. It offers economic benefits by simplifying the production of complex components and reducing assembly costs. This study explores the optimization of riser design in cast iron casting, focusing on the influence of sprue shape, riser presence, and bottom base well on the casting process and its resulting output parameters. The experimental setup examines various configurations, including cylindrical and square sprue shapes, with and without risers, and the addition of a bottom base well. Output parameters such as mold erosion, filling time, solidification temperature, solidification time, shrinkage, and porosity were analyzed.

The findings indicate that incorporating a riser, especially with a bottom base well, significantly reduces shrinkage and porosity, improving the overall quality of cast iron components. Furthermore, variations in sprue shape and the bottom base well configuration lead to distinct differences in filling dynamics and solidification characteristics, providing valuable insights for optimizing riser design. These results contribute to enhancing casting efficiency, reducing defects, and improving the final product quality.

Keywords: Casting, Casting Defects, InspireCast.

1. INTRODUCTION

Casting is a manufacturing process in which a liquid metal is poured into a mold that contains a hollow cavity of the desired shape, and then allowed to solidify. Once the material solidifies, it is removed from the mold, resulting in a part known as a casting. This process is widely used for creating complex shapes that would be difficult or expensive to produce by other methods. This is one of the oldest and widely used methods of the manufacturing process used to make many types of equipment, tools, materials that would be rather difficult or expensive to make using any other method. In the historic era, many of the weapons and defence equipment were made using the casting process. And, India is termed as the first civilization to use this process for the bulk production of coins. Major Parts like a bed of the Lathe machine, milling machine bed & IC engine equipment are made by using this method.

A large number of metal components in designs used every day are made by casting. The reasons for this include:

(a) Casting can produce very complex geometry parts with internal cavities and hollow sections.

(b) It can be used to make small (few hundred grams) to very large size parts (thousands of kilograms)

(c) It is economical, with very little wastage: the extra metal in each casting is re-melted and re-used

(d) Cast metal is isotropic – it has the same physical/mechanical properties along any direction.

1.1: Basic terminologies of casting process

- Flask: A metal or wood frame in which mold is formed.
- Cope: The upper half of the flask is called cope.
- Drag: The lower half of the flask is called drag.
- Core: Core is used to create an internal hollow cavity in the final product.

- Vents: These are the places created in the mold to carry off-gases produced when the molten metal comes in contact with the sand.
- Mold cavity: This is the hollow space in the mold where the metal part is formed.
- Riser: It is the reservoir of molten metal that supplies additional metal in case of any reduction.
- Runner: It is the passage from where the molten metal can be regulated before reaching the mold cavity.
- Pouring Cup: It is the cup or basin from where molten metal is poured in the metal.
- Pattern: It is the duplicate of the shape needed to form.
- Sprue: It is the cavity through which molten metal flows downward.
- Parting Line: This is the line that separates the cope and

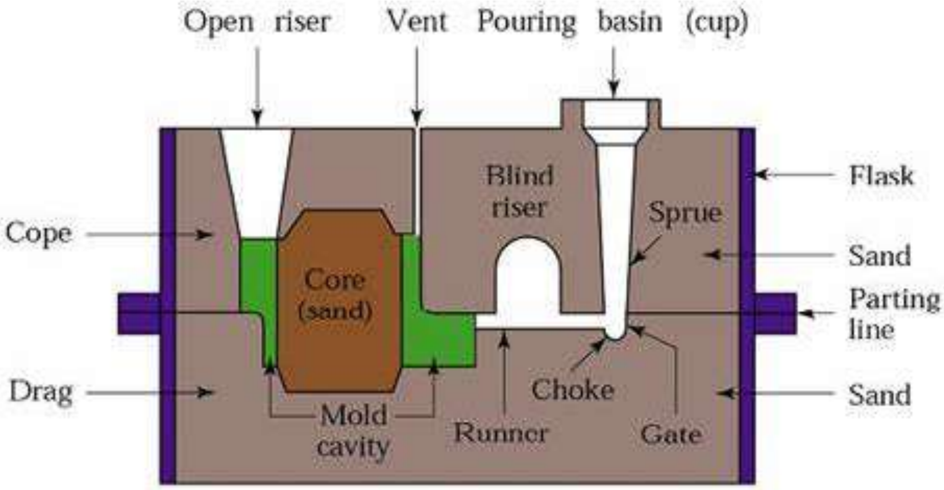


Figure 1.1: Basic Casting process

2. LITERATURE REVIEW

[1]. Md Moinuddin Shuvoa and Guha Manogharan (2021), have done the project entitled "Novel riser designs via 3D sand printing to improve casting performance". In this research, two novel riser designs, ellipsoid and spherical risers, along with traditional cylindrical risers are investigated to understand their effects on the solidification time and entrained air volume fraction in Aluminum alloy (A319) castings. Computational simulations are presented to understand the viability of complex riser shapes by comparing critical parameters such as fluid temperature during filling, solidification, and cooling. In addition, solid fraction (SF) and entrained air volume fraction are also studied during filling and solidification. The results for spherical riser performance showed a 7% increase in feeding time during solidification along with a 47.27% reduction in entrained air volume fraction. The ellipsoid riser studied in this research also showed identical solidification time at half the volume of the conventional cylindrical riser. This indicated a 26.5% increase in casting yield. These riser designs will not only facilitate the design optimization of the casting but also improve the casting performance (feeding, solidification) for difficult to cast materials and geometries.

[2]. Uday A. Dabade and Rahul C. Bhedasgaonkar (2013), have done the project entitled "Casting Defect Analysis using Design of Experiments (DoE) and Computer Aided Casting Simulation Technique", In first part of this paper Taguchi based L18 orthogonal array was used for the experimental purpose and analysis was carried out using Minitab software for 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 is performed using casting simulation technique by introduction of a new gating system designed, solid model developed for four cavities mould. Number of iterations using casting simulation software was performed for mould filling and solidification analysis to reduce the level and intensities of shrinkage porosities in cast component. With new gating and feeding system design reduction in shrinkage porosity (about 15%) and improvement in yield (about 5%) is observed.

[3]. Rudianto Raharjo et.al. (2021), have done the project entitled "Multilevel Pulley Analysis of Sand-Casting Process Results for Metal Casting Simulation Using Altair Inspire Cast", The purpose of this research is to compare the results of actual casting with simulation, to find out what defects are found in actual castings and simulation results. The research shows similarities in the defects produced between castings resulting from the manufacturing process and simulation results such as porosity, shrinkage, and mold erosion. However, castings also have other defects, namely gas defects, shifts, misruns, slanted cores, swells, sand inclusions, and fin defects. Defect equations for multilevel pulleys are obtained with the simulations' results, namely porosity, mold erosion, gas defects, and shrinkage.

[4]. Irawan Malik , Almadora Anwar Sani , and Ali Medi (2019), have done the project entitled "Study on using Casting Simulation Software for Design and Analysis of Riser Shapes in a Solidifying Casting Component", This study, highlighting is given on using casting simulation software which helps foundry industries to design and analysis the size and shape of the riser. Intended for simulation simplification in this study, grain size of mold green sand, casting material quality, casting process parameters are deliberated identical for all design schemes. Only the shape and dimensional variances of sprue/risers are taken into considerations for defects analysis. It is found that defects such as micro and shrinkage porosities, and improper solidification, are directly related to gating and risers system. Casting simulation software is used for mold filling and solidification analysis and it is observed that the proposed gating and risers system design will improve casting results with small defects. From this study, the conclusion can be stated that taper sprue design, also acts as a riser, with an additional four small risers that will produce a small fraction of porosity inside of the casting part. Validation of simulation, in the future, will be proved through experimental trials in the foundry shop.

[5]. Yinfang Jiang et.al. (2011), have done the project entitled "Analysis and Optimization on the Gating System of Aluminum Alloy Piston in Casting", Shrinkage porosity defects occurring in ring groove underside the pin hole of aluminum piston are strongly influenced by the time-varying temperature profiles inside the solidifying casting. By adopting the finite element analysis software PROCAST and combining with production practice, the gating system which has open-cycle ring feeding channel in the bottom of the piston was compared with conventional techniques; the influence of opening angle of ring feeding channel and different process parameters on shrinkage distribution was researched. The results show the gating system with open-cycle ring feeding channel can satisfy progressive solidification and effectively eliminate the shrinkage in ring groove underside piston pin hole, and can greatly reduce the riser size and improve casting yield; the opening angle influences shrinkage distribution and can be adjusted to achieve effective feeding; shrinkage size is influenced by pouring temperature and casting speed which have less effect on shrinkage distribution. The system of ring feeding channel is adopted, the opening angle and process parameters are adjusted, all which can effectively eliminate shrinkage in the bottom of the piston, improve casting yield and process.

3. EXPERIMENTAL DESIGN AND SETUP

The influence of process factors for gravity casting, such as Shape of the sprue, availability of riser, bottom storage, was examined in this research to identify the output parameters such as filling temperature (K), Velocity Max(mm/ms), Mold Erosion (mm/ms), Filling time (Sec), Cold shuts Solidification temperature (K), Solidification time (Sec), Pipe-shrink,Porosity, Total shrinkage volume (mm3).

3.1: Selection of process parameters

The input process parameters selected for this process are Shape of the sprue, availability of riser, bottom storage. The experiments are framed in different possibilities; the framed experiments are tabulated below.

Table 3.1: Parameters and their levels

S. No.	Sprue shape	Riser	Bottom Base well
1	Cylindrical	Yes	Yes
2	Square	No	No

3.2: Design of Steering Gear bracket

A Bracket is the backbone of steering system & its main function is to safely carry the steering gearbox load wherever the operation demands. Basically it is static gearbox weight & load due to twisting of steering system. The material selected for this bracket is cast iron.

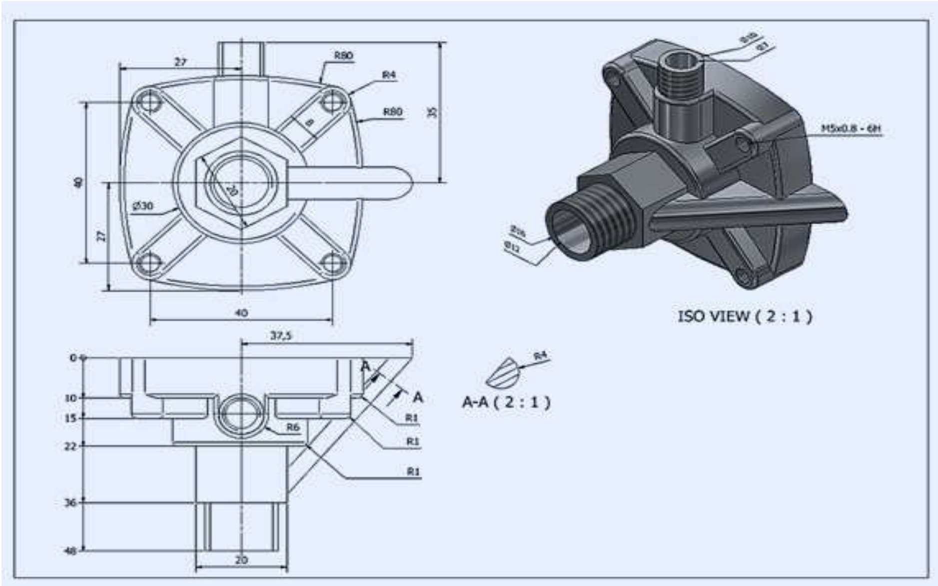
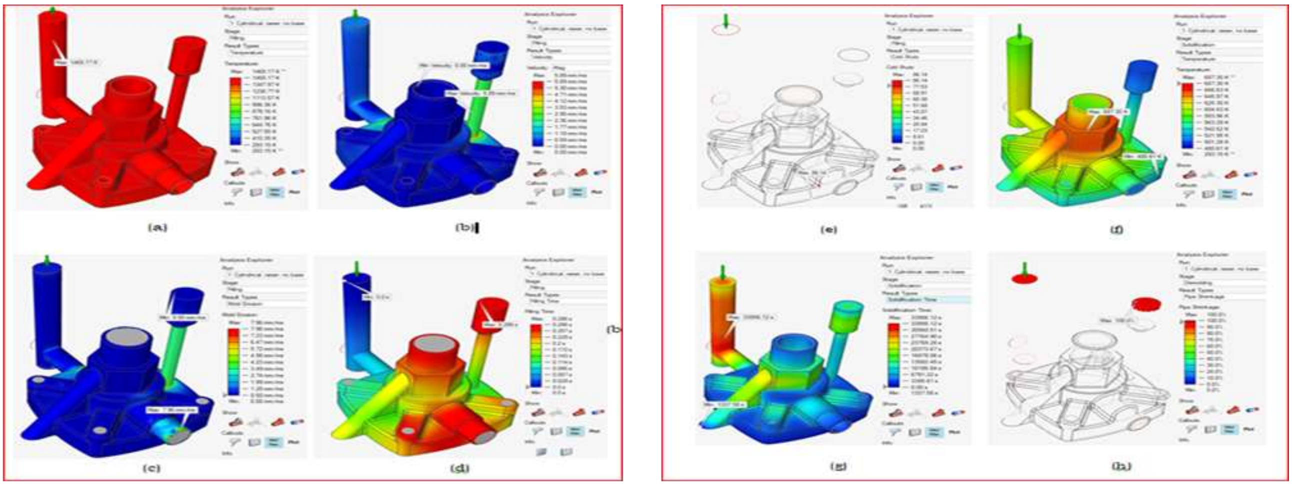
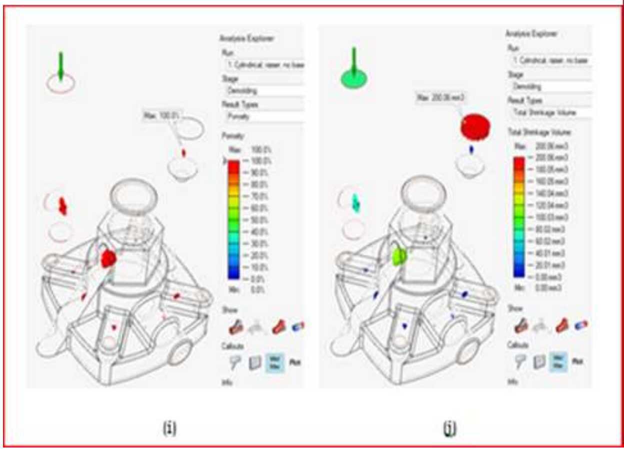


Figure 3.1: Steering Gear bracket

3.3: Condition – 1: Cylindrical Sprue, Riser, No bottom well





Condition 1

S. No.	Parameter	Result
a	Filling temp. (K)	1465.17
b	Velocity Max. (mm/ms)	5.89
c	Mold Erosion (mm/ms)	7.96
d	Filling time (Sec)	0.286
e	Cold shuts	86.14
f	Solidification temperature (K)	687.30
g	Solidification time (Sec)	33956.12
h	Pipe shrink (100%)	@Riser
i	Porosity (100%)	Medium
j	Total shrinkage volume (mm3)	200.06 (riser)

Using the same concept, a total of 8 experiments were conducted. The final results of all 8 experiments are analysed in the next chapter.

4. RESULTS AND DISCUSSIONS

The Steering Gear bracket has been designed using 3D modelling software and casting setup has developed using Altair inspireCast. Material used for this casting is cast iron. Considered some input process parameters which are having significant effect on the result. Parameter-wise analysis is as follows.

4.1: Filling temperature

The filling temperature in casting, also known as the pouring temperature, is the temperature at which molten metal is poured into the mold. It is a critical parameter that directly affects the quality of the final casting.

Table 4.1: Filling temperature in different casting condition

Input Parameters				**Output Parameters**
S. No.	**Sprue shape**	**Riser**	**Bottom Base well**	**Filling temp. (K)**
1	Cylindrical	Yes	No	1465.17
2	Cylindrical	No	No	1465.17
3	Cylindrical	Yes	Yes	1465.21
4	Cylindrical	No	Yes	1465.17
5	Square	Yes	No	1465.17
6	Square	No	No	1465.17
7	Square	Yes	Yes	1465.19
8	Square	No	Yes	1465.18

- The highest filling temperature is achieved in Condition 3 (1465.21 K), which has cylindrical sprue, Riser, Bottom well are the input parameters.
- Adding the bottom base well generally increases the filling temperature slightly. For example, compare condition 3 (1465.21 K) to condition 1 (1465.17 K) and condition 7 (1465.19 K) to condition 5 (1465.17 K).
- The presence of a riser also has a positive impact on filling temperature. In both the cylindrical and square sprue cases, adding a riser (conditions 3 and 7) results in higher filling temperatures than configurations without a riser.
- The cylindrical sprue generally leads to higher filling temperatures compared to the square sprue when both the riser and base well are included.
- The condition 3, achieves the highest filling temperature of 1465.21 K. This suggests that the cylindrical sprue, combined with a riser and base well, optimizes the flow and heat retention during the casting process, leading to better thermal management.

4.2: Velocity

The objective is to determine the best combination of input parameters for achieving the optimal (lowest) velocity, which typically helps in minimizing turbulence and casting defects. Very low velocity may leads to poor filling of cavity.

- Lowest Velocity (5.89 mm/ms in condition 1) can Minimizes turbulence and associated defects (e.g., porosity, cold shuts), but could lead to poor cavity filling, especially in intricate geometries or larger castings.
- Moderate Velocity (5.92 mm/ms to 6.3 mm/ms in conditions 2, 3, 4, 5, 7) provides a balanced mold filling rate that reduces the likelihood of turbulence while ensuring good mold filling, but there is a slight risk of turbulence if the velocity is at the higher end of this range.
- High Velocity (7.26 mm/ms to 7.84 mm/ms in conditions 6 and 8). Fast filling ensures the mold cavity is filled quickly, but increased risk of turbulence, leading to defects like air entrapment, cold shuts, and porosity.

Table 4.2: Velocity in different casting condition

Input Parameters				**Output Parameters**
S. No.	**Sprue shape**	**Riser**	**Bottom Base well**	**Velocity Max. (mm/ms)**
1	Cylindrical	Yes	No	5.89
2	Cylindrical	No	No	6.3

3	Cylindrical	Yes	Yes	5.92
4	Cylindrical	No	Yes	6.23
5	Square	Yes	No	6.22
6	Square	No	No	7.26
7	Square	Yes	Yes	6.19
8	Square	No	Yes	7.84

The best input condition for mold filling velocity is condition 3 (Cylindrical Sprue, Riser, Base Well). It achieves a velocity of 5.92 mm/ms, providing a balance between avoiding turbulence and ensuring proper filling.

4.3: Mold Erosion

Mold erosion in casting refers to the physical wear of the mold surface caused by the abrasive action of the molten metal as it flows into the mold cavity. This erosion can occur during the filling process, where high-velocity metal flow, turbulence, or the impact of molten metal on the mold surface can cause material from the mold to be displaced or removed.

- **High** Mold Erosion is observed **in condition 5 (Square Sprue, Riser, No Base Well):** Mold Erosion is **12.75 mm/ms.** Very high erosion, likely leading to increased mold wear and potential defects in the casting.

Table 4.3: Mold Erosion in different casting condition

Input Parameters				**Output Parameters**
S. No.	**Sprue shape**	**Riser**	**Bottom Base well**	**Mold Erosion (mm/ms)**
1	Cylindrical	Yes	No	7.96
2	Cylindrical	No	No	7.7
3	Cylindrical	Yes	Yes	9.98
4	Cylindrical	No	Yes	5.98
5	Square	Yes	No	12.75
6	Square	No	No	6.23
7	Square	Yes	Yes	7.13
8	Square	No	Yes	5.83

- **Moderate Mold** Erosion **is observed in conditions 1, 2, 3, 7:** Mold Erosion ranges from **7.13 mm/ms to 9.98 mm/ms.** While not as severe as the highest erosion rates, these values are still relatively high and could lead to moderate mold damage over time.
- **Low Mold Erosion is** observed **in conditions 4, 6, 8:** Mold Erosion ranges from **5.83 mm/ms to 6.23 mm/ms.** These experiments show the lowest erosion rates, which would help preserve the mold and reduce the likelihood of casting defects related to erosion.

The best input condition **for Mold Erosion is Condition 8 (Square Sprue, No Riser, Base Well)** shows the lowest mold erosion value at **5.83 mm/ms**, making it the optimal condition for minimizing mold erosion.

4.4: Filling time

Mold filling time in casting refers to the duration required for molten metal to completely fill the mold cavity. It is a critical factor in casting processes, as it influences the quality of the final product, including the occurrence of defects, the solidification process, and the overall efficiency of the casting operation. Shorter filling times are generally desirable as they can lead to more efficient production, but too short a time could potentially lead to incomplete filling or defects. The balance between filling speed and quality needs to be considered.

- **Fastest Mold Filling Time is observed in condition 2 (Cylindrical Sprue, No Riser, No Base Well):** Filling Time = **0.263 sec.** Fastest filling time, which could lead to higher production efficiency. But Potential risk of turbulence or incomplete filling if the filling time is too short.

Table 4.4: Filling time in different casting condition

Input Parameters				**Output Parameters**
S. No.	**Sprue shape**	**Riser**	**Bottom Base well**	**Mold Filling time (Sec)**
1	Cylindrical	Yes	No	0.286
2	Cylindrical	No	No	0.263
3	Cylindrical	Yes	Yes	0.31
4	Cylindrical	No	Yes	0.286
5	Square	Yes	No	0.308
6	Square	No	No	0.285
7	Square	Yes	Yes	0.325
8	Square	No	Yes	0.32

- **Moderate Mold Filling Times is observed in conditions 1, 4, 5, 6:** Filling Times range from **0.285 sec to 0.308 sec.** These times provide a balanced approach, ensuring the mold fills efficiently without overly high speeds that could cause defects. Slightly longer than the fastest time but still within acceptable limits.
- **Slowest Mold Filling** Time **is recorded in condition 7 (Square Sprue, Riser, Base Well):** Filling Time = **0.325 sec.** The longer filling time could help reduce the risk of turbulence, ensuring a smoother flow into the mold. **But** slower filling times could lead to inefficiencies in production.

*The **best input condition*** for minimizing mold filling time is **condition 2 (Cylindrical Sprue, No Riser, and No Base Well)**. This configuration results in the fastest filling time of **0.263 seconds**, which is ideal for achieving efficient production without compromising the quality of the casting.

4.5: Cold shuts

Cold shuts occur when two relatively cold streams of molten metal from different gates meet and do not fuse together properly during the casting process. This problem is visible to the naked eye – giving the appearance of a crack separating the two sections. Cold shuts can either extend through part of the casting or the entire workpiece.

Table 4.5: Cold shuts in different casting condition

Input Parameters				**Output Parameters**
S. No.	**Sprue shape**	**Riser**	**Bottom Base well**	**Cold shuts**
1	Cylindrical	Yes	No	86.14
2	Cylindrical	No	No	84.83
3	Cylindrical	Yes	Yes	90.29
4	Cylindrical	No	Yes	82.39
5	Square	Yes	No	86.51
6	Square	No	No	80.56
7	Square	Yes	Yes	88.94
8	Square	No	Yes	82.31

- For cylindrical sprues, cold shuts range from 82.39 to 90.29 and square sprues, cold shuts range from 80.56 to 88.94. Square sprues generally result in lower cold shuts compared to cylindrical sprues.
- With a riser, cold shuts tend to be higher compared to no riser in both sprue shapes. Riser No tends to result in lower cold shuts.
- Square sprues consistently show lower cold shuts compared to cylindrical sprues. No riser generally leads to fewer cold shuts. Cold shuts are lower when there is no Bottom Base Well.

The best condition for minimizing cold shuts, based on the data, is using a Square Sprue with No Riser and No Bottom Base Well (condition 6). This condition resulted in the lowest cold shuts observed in the data (80.56), indicating it is the optimal setup to minimize defects in this casting process.

4.6: Solidification temperature

The solidification temperature in casting refers to the specific temperature at which a molten metal or alloy begins to solidify as it cools down. This temperature is crucial in casting processes because it affects the quality and properties of the final product.

Table 4.6: Solidification temperature in different casting condition

Input Parameters				**Output Parameters**
S. No.	**Sprue shape**	**Riser**	**Bottom Base well**	**Solidification temperature (K)**
1	Cylindrical	Yes	No	687.3
2	Cylindrical	No	No	689.4
3	Cylindrical	Yes	Yes	695.93
4	Cylindrical	No	Yes	694.62
5	Square	Yes	No	1465.13
6	Square	No	No	700.16
7	Square	Yes	Yes	696.9
8	Square	No	Yes	1319.81

- Cylindrical Sprues result in significantly lower solidification temperatures compared to Square Sprues.
- Cylindrical Sprues generally have lower solidification temperatures when a riser is used and for Square Sprues, solidification temperatures are extremely high with a riser compared to without it.
- Cylindrical Sprues tend to have higher temperatures with a bottom base well. Square Sprues show an extreme increase in temperature with a bottom base well.

The best condition for minimizing the solidification temperature, based on the provided data, is using a Cylindrical Sprue with Riser Yes and Bottom Base Well No (condition 1). This condition results in the lowest solidification temperature of 687.3 K, which is optimal for reducing the temperature during the casting process.

5.10: Total shrinkage volume

Total shrinkage volume in casting refers to the total volume of metal that contracts and potentially creates voids or defects during the cooling and solidification process. It represents the cumulative reduction in volume from the molten state to the solidified state of the casting.

- Cylindrical Sprues tend to have lower total shrinkage volumes compared to Square Sprues. The lowest shrinkage is achieved with a cylindrical sprue, particularly with a riser and a bottom base well.
- Cylindrical Sprues show reduced shrinkage when using a riser. Square Sprues tend to have higher shrinkage with a riser, especially when a bottom base well is used.

Input Parameters				**Output Parameters**
S. No.	**Sprue shape**	**Riser**	**Bottom Base well**	Total shrinkage volume (mm3)
1	Cylindrical	Yes	No	200.06
2	Cylindrical	No	No	246.57
3	Cylindrical	Yes	Yes	199.17
4	Cylindrical	No	Yes	272.89
5	Square	Yes	No	304.45

6	Square	No	No	290.98
7	Square	Yes	Yes	324.46
8	Square	No	Yes	310.99

- **Cylindrical Sprues** generally show lower total shrinkage with a bottom base well. **Square Sprues** show increased shrinkage with a bottom base well.

The best condition for minimizing total shrinkage volume, based on the data, is using a **Cylindrical Sprue** with **Riser** and **Bottom Base Well (condition 3)**. This combination consistently results in the lowest shrinkage volume of 199.17 mm³, which is optimal for reducing shrinkage in the casting process.

5. CONCLUSIONS

After successful completion of the project, the following conclusions are drawn.

- The condition 3, achieves the highest filling temperature of 1465.21 K. This suggests that the cylindrical sprue, combined with a riser and base well, optimizes the flow and heat retention during the casting process, leading to better thermal management.
- The best input condition for mold filling velocity is condition 3 (Cylindrical Sprue, Riser, Base Well). It achieves a velocity of 5.92 mm/ms, providing a balance between avoiding turbulence and ensuring proper filling.
- The best input condition for Mold Erosion is Condition 8 (Square Sprue, No Riser, Base Well) shows the lowest mold erosion value at 5.83 mm/ms, making it the optimal condition for minimizing mold erosion.
- The best input condition for minimizing mold filling time is condition 2 (Cylindrical Sprue, No Riser, and No Base Well). This configuration results in the fastest filling time of 0.263 seconds, which is ideal for achieving efficient production without compromising the quality of the casting.
- The best condition for minimizing cold shuts, based on the data, is using a Square Sprue with No Riser and No Bottom Base Well (condition 6). This condition resulted in the lowest cold shuts observed in the data (80.56), indicating it is the optimal setup to minimize defects in this casting process.
- The best condition for minimizing the solidification temperature, based on the provided data, is using a Cylindrical Sprue with Riser Yes and Bottom Base Well No (condition 1). This condition results in the lowest solidification temperature of 687.3 K, which is optimal for reducing the temperature during the casting process.
- The best condition for minimizing the solidification time, based on the provided data, is using a Square Sprue with Riser Yes and No Bottom Base Well (Condition 5). This condition results in the lowest solidification time of 30647.64 seconds, which is optimal for faster solidification.
- The best condition for minimizing pipe shrinkage, based on the data, is using a Square Sprue with Riser and No Bottom Base Well (condition 5). This setup consistently results in small shrinkage inside, which is ideal for reducing defect locations compared to other conditions.
- The best condition for minimizing porosity, based on the provided data, is using a Square Sprue with Riser and No Bottom Base Well (condition 5). This setup consistently results in very low porosity, making it the optimal condition for achieving high-quality casting with minimal porosity.
- The best condition for minimizing total shrinkage volume, based on the data, is using a Cylindrical Sprue with Riser and Bottom Base Well (condition 3). This combination consistently results in the lowest shrinkage volume of 199.17 mm³, which is optimal for reducing shrinkage in the casting process.
- Overal optimum condition: Option 1: Condition 7 (Square sprue with raiser and bottom base well) seems to be the most balanced in terms of managing porosity, shrinkage location, and overall solidification and filling times. It shows medium porosity and controlled pipe shrinkage with a good distribution of shrinkage at the sprue and riser, ensuring better casting quality. The solidification parameters are also within an acceptable range for good microstructure control.
- Overal optimum condition: Option 2: If minimizing porosity is the highest priority, Condition 8 (Square sprue without raiser and with bottom base well) could also be considered, but the high solidification temperature and internal shrinkage may require further optimization.

Acknowledgement

It is my pleasure to acknowledge, with deep appreciation to all those who have helped and guided me throughout the project work.

I would like to express my sincere gratitude to my Project Guide ***Mr. G. Gopinath,*** Asst.Professor of Department of Mechanical Engineering, JBIET, for his invaluable guidance, constant support, and cooperation throughout the project.

I am also deeply thankful to **Mr. G. Gopinath**, Assistant Professor, and P.G Coordinator, Department of Mechanical Engineering, JBIET, for his timely guidance, technical inputs and suggestions despite of his busy schedule.

My heartfelt thanks to **Dr. Anoop Kumar Shukla**, HOD, Department of Mechanical Engineering, JBIET, for his continued encouragement and technical guidance throughout the course of this project.

I would also like to extend my special thanks to **Dr. P.C. Krishnamachary**, Principal of JBIET, and the Management of JBIET for providing the necessary facilities to carry out this project.

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