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RESEARCH ARTICLE OPEN ACCESS

Experimental Investigations of the Impact of Mould Holding Time and Mould Filling Sequence on Casting Defects in Green Sand Moulded Cast Iron Casting

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ABSTRACT:
This study investigates the importance of mould holding time on the resulting casting for green sand mould and cast iron casting. The study was conducted on four significant properties of green sand mould: moisture content (%), green compressive strength (g/cm^2), mould hardness, and mould permeability. It also includes the mould filling sequence's impact on mould parameters and casting output. The terms defined as FIFF (First In First Fill) and LIFF (Last In First Fill) for mould formation and filling sequence, and then analysis of various mould parameters as mentioned above is done—data collected through the available data history and actual readings through the mobile app. The variation in individual parameters with mould number in a particular sample batch and holding time is studied and interpreted. The study highlights the importance of having time in casting health for manual foundry and the way to minimise the defects in casting by managing holding time for a particular batch. Future research could enable manual foundries to predict the casting defect by analysing the casting holding time and other parameters.

Key words: Mould Holding Time, Moisture Content, Green Compressive Strength, Casting Defects, Filling Sequence.

I. I.INTROUCTION

Green sand moulding is one of the oldest practices in sand casting. In casting, a mould requires specific properties for defect-free casting. For a long time, research has been conducted regarding the study of mould properties, with or without time consideration. In the era of automation, most foundries have adopted robotics, but many foundries still use the traditional method. In the conventional method, mould making, metal pouring, and casted part removal processes are manual. Hence, there is a greater possibility of defective casting. To minimise defects, mould preparation, final pouring and solidification should be carefully observed and analysed. There are various methods to analyse the presence of casting defects. As mould properties are dynamic and depend upon n parameters, many permutations and combinations exist. If we study the casting procedure for the same product, maybe each time we get a new combination of values of properties. Hence, it isn't easy to standardise the casting procedure without initial considerations. Initial considerations were made based on theory, literature review and the design of the experiment method. The primary focus of the study is defect occurrence due to poor mould health. The mould health is decided in two ways: by varying the initial composition of the mould, and the second is by keeping the same initial composition but varying the holding time of the mould. The second approach is used as the basis of analysis. The experiments were carried out in a manual foundry in the Kolhapur area. The scope of study is limited to:

1. The standard mould design and uniform mould composition for mould batches.
2. Optimisation of mould properties, i.e. considering properties mentioned below as variables and another constant.
(i) Moisture content.
(ii) Green Sand Strength
(iii) Mould Hardness
(iv) Mould Permeability
3. The standard mould handling and casting procedure is followed.
4. Manual Foundry
5. Cast Iron casting with Green sand mould.
6. Standard moulding time for each mould.

7. Standard composition of pouring material.
8. Standard pouring temperature and velocity.

II. LITERATURE REVIEW:

As the foundry industry is a region of unending possibilities, through controlled experiments and consistent trials, researchers investigated how mould parameters impact the casting quality and how the mould-related timings play a crucial role in mould health, i.e. the ability of the mould to produce healthy and defect-free casting.

Alisir and Cevik,2020[1] showed the Effect of different sand and binder properties on the nature of casted components. Also, the Impact of changing the composition of sand and binder on heat dissipation through the mould, i.e., the mould's conductivity and strength.

The study conducted by Dabade and Bhedasgaonkar [2] highlighted the Analysis of casting defects using design of experiments-Taguchi Method, specifically used for defects occurring due to green sand mould for turbocharger pipe and for parameters: moisture content, mould hardness, green compressive strength and mould permeability.

Another study by Kishore and Kumar[3] investigated the Effect of mould permeability on casted components—the relationship between moisture content and permeability, and the combined effect of these two on the element. The primary causes of blow holes are reduced permeability and higher moisture content.

The study of the significant defects in sand casting, their causes, remedies, and explanation of the research gap that occurred due to uncertainty and lack of standardisation in the casting industry was studied and validated by Getaneh and Bezabh[4].

Landage M. G studied the Overall Casting Procedure Sequence and detailed information regarding Casting Defects.[5].

Ghubade and Kumar's[6] study discusses uncontrollable mould factors that decide casting quality and defects due to manual foundry culture.

Pandit and Deshpande [7] analysed the Investigation of Process variables in casting and the role of mould parameters in determining casting quality.

Nandgopal and Sivakumar [8] published a detailed study regarding the impact of Green Compressive Strength and Mould Hardness on Casting under Experimental investigation on the influence of mould wall thickness and hardness on green sand mould permeability.

The casting defects in cast iron due to mould sand mixture, mould design, geometry and casting alloy being poured were studied and analysed by Sertucha and Lacaze [9].

III. RESEARCH GAP:

The foundry industry is a space where one can find unlimited combinations of parameters, and due to standardisation difficulties and experimental limitations, there is always a broad scope for research and development in the casting industry. Most of the time, during the design of experimentation, there is always a thin line of limitation that bounds the research compass. The output of the literature survey is that in the foundry, the mould parameters play roles as vital as molten metal or material parameters. The mould properties stated are considered steady with respect to time. Hence, the significance of the time factor is not in the scope of the study according to the overall literature review. The time factor can be a bottleneck point in the rejection problem in many casting industries from both the mould and molten material points of view. Over time, the variation in mould properties gives hidden causes of rejection and inefficient production. Hence, deep digging into this research point will provide fruitful outcomes to eliminate some unavoidable issues in casting some context. Thus, the points of view considered for defect prediction will enhance and deliver results with more accuracy and fewer production losses.

IV. PROBLEM IDENTIFICATION:

After a literature survey and analysis of findings and research gaps, the detailed problem statement chosen for the study was to understand the impact of the time spent between mold formation and actual metal pouring on the mold health (whether mold can produce defective or healthy casting) by considering characteristic properties of mold sand mixture and molding time and holding time to predict the defect possibility and to reduce the casting rejectionsfor green sand moulded cast iron castings.

V. CASTING PROCESS:

A flow of the typical foundry process is shown in Table 1.

Table No. 1: Typical foundry procedure

1. Pattern Making	Create a model of the object.
2. Mould Making	Make a cavity to hold the molten metal.
3. Core Making	Prepare cores for hollow sections.
4. Mould Assembly	Assemble the mould and gating.
5. Melting	Melt metal in a furnace.
6. Pouring	Pour molten metal into the mould.
7. Cooling	Let the metal solidify.
8. Mould Removal	Break or remove the mould.
9. Cleaning	Clean and finish the casting

Metal Casting is one of he foundation processes in mechanical engineering. In mechanical engineering.

a. Pattern Making: A pattern replicates the object that needs to be cast. It's slightly larger than the final product to account for metal shrinkage as it cools. The pattern can be made from wood, plastic, or metal materials.

b. Mould Making: The pattern is used to create a mould cavity**.** The mould can be made from sand, metal, or ceramic. For example, sand is packed around the pattern in sand casting to form the mould. There are usually two parts of a mould:

- Cope (top half)
- Drag **(**bottom half)

c. Core Making (if needed): Cores are made separately and inserted into the mould if the final object needs hollow sections (like pipes or holes). These are usually made from sand and removed after casting.

d. Mould Assembly: Once the mould and core are ready, they are assembled. This includes:

- Placing the core (if any)
- Creating the gating system (channels for molten metal to flow)
- Venting to allow gases to escape

e. Melting the Metal: The chosen metal (e.g., aluminium, steel, bronze) is melted in a **furnace until** it reaches the desired temperature and becomes a liquid.

f. Pouring: The gating system carefully pours the molten metal into the mould. It flows into the cavity and fills the shape of the desired object.

g. Cooling & Solidification: The metal can cool and solidify after pouring. The time this takes depends on the size and material of the casting.

h. Mould Removal: Once solidified, the mould is broken open or removed to reveal the casting. In sand casting, the sand is broken away and reused for future moulds.

i. Cleaning: The casting is cleaned to remove any remaining mould material or excess metal from the gating system. This may involve grinding, sandblasting, or chemical cleaning.

VI. PARAMETERS SELECTION:

Several parameters of the mould show an effect on the output casting. Here, the following parameters are in the scope of the study, and the remaining will be considered under the limit and constant with time.

1. Moisture Content (%)
2. Green Compressive Strength (g/cm^2)
3. Mould Hardness (no.)
4. Permeability (no.)

The moisture content is the main property that causes an impact on the other mentioned parameters, such as:

1. Moisture content increases, mould hardness rises to a specific limit, and hardness decreases if the moisture content becomes excessive.
2. Permeability decreases with moisture content. Hence, high moisture, low permeability.
3. Green compressive strength shows a relationship similar to hardness. Initially increases, but then decreases.

- **Process Parameters Considered -**

1. **Moisture Content** - Moisture content refers to the percentage of water in the green sand mixture. It is a crucial factor that affects the mould's plasticity and strength. Water activates the clay binder in the sand, helping the particles stick together. It also allows the sand to mould intricate shapes and hold form during handling.
2. **Green Compressive Strength- This** is the amount of pressure the green sand can withstand before failing or breaking, while it is still moist. Adequate compressive strength ensures that the mould maintains its shape during the handling and pouring

of molten metal. It also prevents deformation under pressure.

3. **Mould Hardness: Mould hardness indicates the resistance of the mould** surface to deformation or damage when pressed. It measures how firm or compacted the mould surface is. Proper hardness helps the mould resist erosion from the flowing metal and contributes to achieving accurate dimensions and a smoother casting surface.
4. **Permeability: Permeability measures how easily gases and steam can pass through the green sand mould**. It's essential for the safe escape of gases during casting. Molten metal generates gas as it enters the mould cavity. Good permeability allows these gases to escape, avoiding defects and ensuring a smoother surface finish.

Table 2 shows typical ranges for process parameters.

Table No.2: Typical ranges for the parameters

Sr no	Parameter	Defects	Safe Range
1.	Moisture Content	Mould cracking or breaking Poor compaction Erosion defects, blowholes, and gas porosity Rough surface finish Dimensional inaccuracy	2.8-4.5(%)
2.	Green Compressive Strength	Mould collapse during pouring Deformation, misruns, or incomplete castings	1500-1800 (g/cm^2)
3.	Mold Hardness	Surface erosion, Metal penetration Poor dimensional accuracy	80-100
4.	Permeability	Blowholes Gas porosity Pinholes due to trapped gases	100-160

Casting defects: Due to an imbalance in the mentioned characteristics, the casting may show the following defects and a lowered production rate. The above parameters should stay in a predefined safe range to avoid this.

VII. TIME IN CASTING PROCESS:

In the sand casting process, time is a critical factor that directly impacts the final casting's strength, accuracy, and overall quality. At each mould preparation and application stage, one must consider the time to ensure a successful casting. Also, the time plays a vital role in both critical constituents of casting, i.e. mould and pouring material (Usually metal). Here, the scope of research is focused only on the mould. Hence, the categories of time defined related to mould are only considered.

In the casting process, controlling time-related factors is crucial to achieving high-quality results. Two key time elements involved are moulding time and holding time of the mould**.** Both play a significant role in ensuring that the mould functions correctly and that the final cast product meets design and structural requirements.

1. Moulding Time: Moulding time is required to prepare, shape, and set the mould before pouring molten metal into it. This includes filling the moulding box with sand or other materials, ramming it around the pattern, and allowing it to harden to form a steady mould cavity.

Importance of Moulding Time:

1. Ensures that the mould develops adequate strength.

2. Prevents mould collapse or distortion during metal pouring.

3. Helps achieve accurate dimensions and fine surface finish on the casting. Impact:

For example, one mould requires 30 seconds for moulding, and then, for a batch of 30 moulds, 900 seconds, i.e., 15 minutes, are needed. When the last mould formed, the age of the first mould was 14 minutes and 30 seconds!

2. Holding Time: Holding time refers to the period after the molten metal is poured into the mould, when the mould is left undisturbed to allow the metal to cool and solidify completely.

Importance:

- Ensures complete and uniform solidification of the molten metal.
- Prevents defects such as cracks, warping, and internal stresses.
- Maintains the desired shape and mechanical properties of the casting.

Impact:

For example, after the formation of a batch of 30 moulds, the pouring starts after 15 minutes of the formation of the last mould. Hence, the first mould holding time will be 29 minutes and 30 seconds. One mould takes 20 seconds. For filling. Then, here the mould sequence taken for pouring plays a vital role. We can correlate it with the FIFO-LIFO concept used in inventory management. FIFO (First In First Out) can be written as FIFF (First In First Fill), and LIFO (Last In Last Out) can be written as LIFF (Last In First Fill).

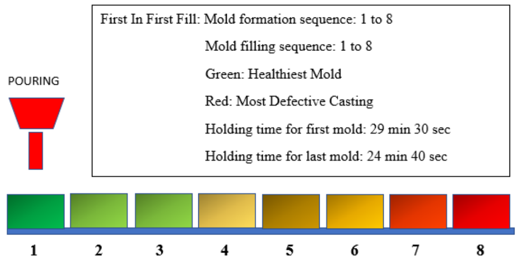

Fig. No. 1 FIFF Method of filling sequence

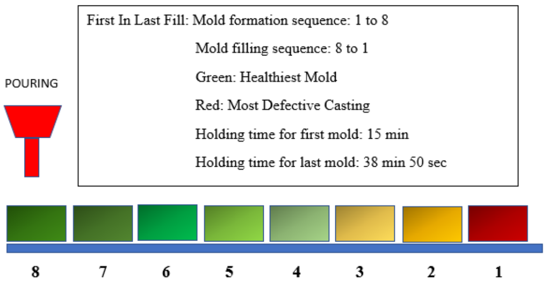

Fig. No. 2FILF Method of filling sequence

III. SAMPLE DATA:

The data is analysed, and the mould health index is defined using the available data analysis. The variations in mould parameters and degradation for mould properties due to moulding time, holding time (both FIFF and FILF):

- Moulding Time: 3 or 5 sec
- Holding time: 10 min (initial for all batches)
- Pouring Time: 10 sec

FIFF Method:

Holding Time for Individual Mould:
Actual Holding Time: (For Mould 1)
Addition of moulding time of remaining moulds(From 2 to 30)+ Initial Holding Time

Actual Holding Time: (For Mould 2)
Addition of moulding time of remaining moulds (From 2 to 30)+ Initial Holding Time Pouring Time of First Mould

FILF Method:

Holding Time for Individual Mould:
Actual Holding Time: (For Mould15)
=Initial Holding Time

Defect Images:

Actual Holding Time: (For Mould 7)

Addition of moulding time of mould15+, Initial Holding Time, Pouring Time of 15th Mould.

The following photographs show defects observed.

Fig. 3. Blowholes

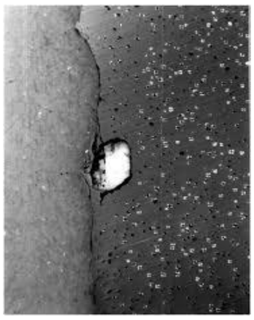

Fig. 4. Erosion

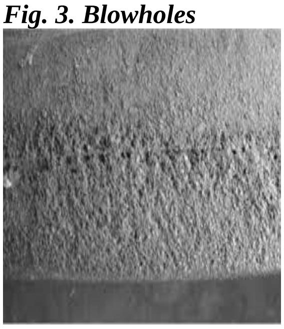

Fig. 5. Pinholes

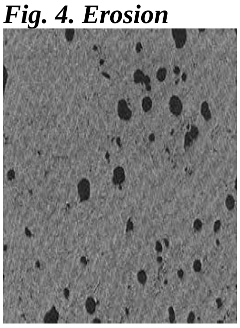

Fig. 6. Gas porosity

IX. OBSERVATIONS:

The observed results from sample data are given in Table 3 as follows:

Table No.3 Observations for the FIFF sequencing method

Mould No.	Moulding Time (Sec)	Holding Time (Sec)	Moisture Content (%)	Green Compressive Strength (g/cm^2)	Mold Hardness	Permeability	Defect Presence
Initial	-	-	3.3	1589	91	125	-
1	3	662	3.0	1500	93	130	No
2	5	667	3.0	1498	93	132	No
3	5	672	3.0	1497	93	134	No
4	5	677	2.9	1497	93	134	No
5	3	684	2.9	1493	94	135	No
6	5	689	2.9	1490	94	138	Yes
7	3	696	2.9	1487	94	138	Yes
8	5	701	2.8	1484	94	139	Yes
9	5	706	2.8	1478	94	142	Yes
10	5	711	2.8	1468	95	145	Yes
11	5	716	2.7	1464	95	145	Yes
12	5	721	2.7	1455	96	145	Yes
13	3	728	2.6	1430	96	148	Yes
14	3	735	2.6	1408	97	150	Yes

15	5	740	2.6	1395	97	153	Yes

Table No.4 Observations for the FILF sequencing method

Mould No.	**Moulding Time (Sec)**	**Holding Time (Sec)**	**Moisture Content (%)**	**Green Compressive Strength (g/cm^2)**	**Mold Hardness**	**Permeability**	**Defect Presence**
Initial	-	-	3.3	1589	98	155	Yes
1	3	800	2.5	1448	97	152	Yes
2	5	787	2.6	1456	97	148	Yes
3	5	772	2.7	1460	96	144	Yes
4	5	757	2.7	1469	95	140	Yes
5	3	742	2.8	1480	94	138	Yes
6	5	729	2.9	1485	94	135	No
7	3	714	2.9	1490	94	135	No
8	5	701	3.0	1496	94	133	No
9	5	686	3.0	1500	94	132	No
10	5	671	3.0	1509	93	132	No
11	5	656	3.1	1510	93	130	No
12	5	641	3.1	1515	92	130	No
13	3	628	3.1	1520	92	129	No
14	3	615	3.2	1526	92	129	No
15	5	600	3.2	1530	92	128	No

Table No. 5: Sample data observations

Sample	**FIFF**	**FILF**
Batch Mould Count	15	15
Molding Sequence	1-15	1-15
Pouring Sequence	1-15	15-1
Defect Present	10	6
Healthy Casting	5	9

Note: ***Initial Holding Time:*** *Time between the Last moulding and the First Pouring. During this period, ladle filling, mould parameters testing, and metal melting occur.*
Actual holding time: *The actual holding time of each mould is the period between moulding and pouring the same mould.*

X.INTERPRETATION:

For FIFF and FILF Sequence, Mould no vs Individual Parameter graph plotted and analysed as follows:

For First In First Fill:

- **Moisture Content:**

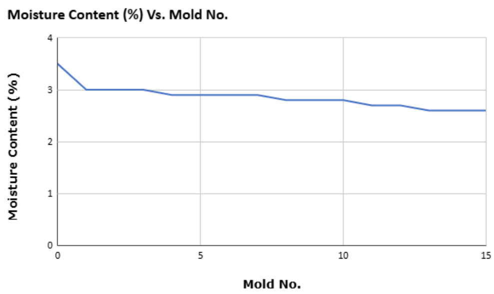

Fig7. Moisture content vs Mould No. (FIFF)

For FIFF, as mould filling ranged from 1 to 15, at initial holding of 10 minutes, a significant decrease in moisture content was observed due to filling of the first moulded mould, and an average reduction in moisture content of each mould was observed. Hence, Defects like blow holes are observed in the resulting casting.

- **Green Compressive Strength:**

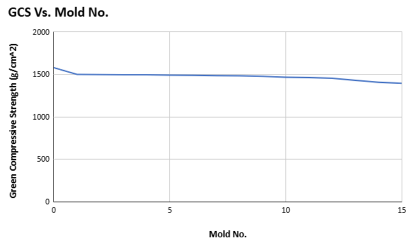

Fig 8. Green Compressive Strength vs Mould No. (FIFF)

For FIFF, as mould filling ranged from 1 to 15, at initial holding of 10 minutes, a significant decrease in Green Compressive Strength and due to filling of the first moulded mould, an average reduction in green compressive strength of each mould, hence Defects like erosion and blowholes are observed in the resulting casting.

- **Mould Hardness:**

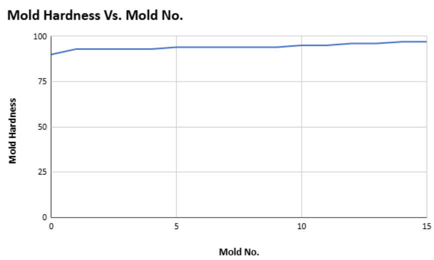

Fig 9. Mold Hardness vs Mold No. (FIFF)

For FIFF, as mould filling ranged from 1 to 15, at initial holding of 10 minutes, a significant increase in Mould Hardness was observed, due to filling of the first moulded mould, and an average rise in mould hardness of each mould. Hence, Defects like erosion, pinholes, and penetration were observed in the casting.

Permeability:

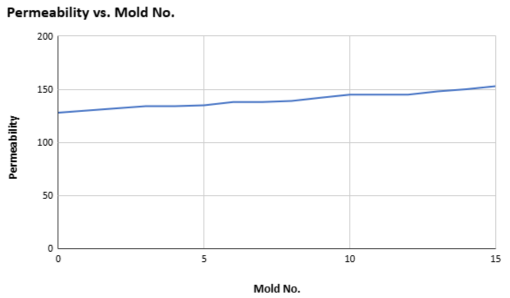

Fig 10. Permeability vs Mould No. (FIFF)

For FIFF, as mould filling ranged from 1 to 15, at initial holding of 10 minutes, a significant increase in Mould Permeability and due to filling of the first moulded mould, average increase in mould permeability of each mould, hence Defects like erosion and gas porosity are observed in the resulting casting.

For First In Last Fill:

- **Moisture Content:**

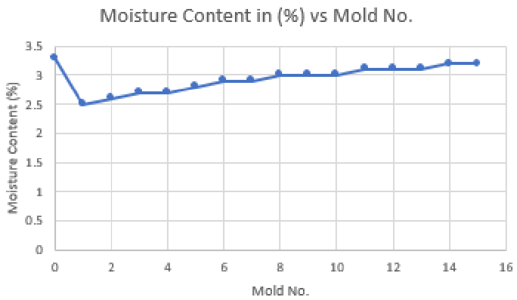

Fig 11. Moisture content vs Mould No. (FIlF)

For FILF, as mould filled from 15 to 1, though at initial holding of 10 minutes, the moisture content reduces significantly, the last moulded mould was first filled, hence not much loss in 15,14,13, etc., no moulds, therefore guarantee of defectless casting. Here, a gradual decrement in moisture content from 15 to 1 no. Mold seen. Despite this, rapid decrement for the first few moulds due to more holding time, hence the chances of defects like blowholes.

- **Green Compressive Strength:**

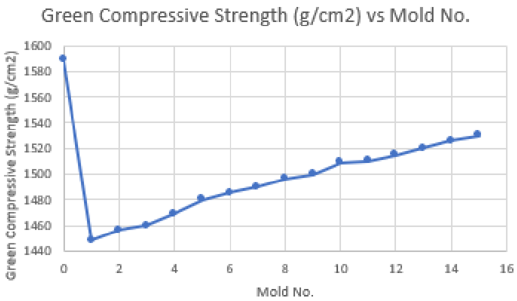

Fig 12. Green Compressive Strength vs Mould No. (FILF)

For FILF, as mould filled from 15 to 1, though at initial holding of 10 minutes, green compressive strength reduces significantly, the last moulded mould was first filled, hence not much loss in 15,14,13, etc., no moulds, therefore guarantee of defectless casting. Here, a gradual decrement in green compressive strength from 15 to 1 no. Mold seen. Despite this, there is a rapid decrement for the first few moulds due to more holding time, hence the chances of defects like erosion.

- **Mould Hardness:**

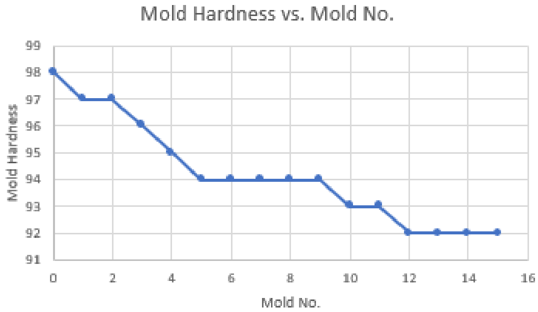

Fig. 13 Mold Hardness vs Mold No. (FILF)

For FILF, as mould filled from 15 to 1, though at initial holding of 10 minutes, the moisture content increases significantly, the last moulded mould was first filled, hence not much gain in 15,14,13, etc., no moulds, therefore guarantee of defectless casting. Here, a gradual increment in mould hardness from 15 to 1. Mold seen. Despite this, there is a rapid increment for the first few moulds due to more holding time, hence the chances of defects like blowholes.

- **Permeability:**

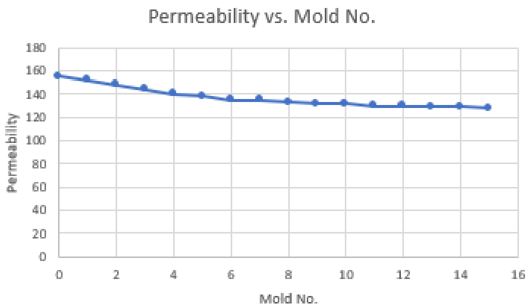

Fig 14. Permeability vs Mould No. (FILF)

For FILF, as mould filled from 15 to 1, though at initial holding of 10 minutes, the moisture content increases significantly, the last moulded mould was first filled, hence not much gain in 15,14,13, etc., no moulds, therefore guarantee of defectless casting. Here, a gradual increment in mould hardness from 15 to 1. Mold seen. Despite this, rapid increments for the first few moulds are due to more holding time, hence the chances of defects like pinholes and gas porosity.

XI. DISCUSSION:

From the graphs, it can be suitably interpreted and understood that the holding time and filling sequence are essential in casting properties. The sequencing patterns discussed, i.e. FIFF (First In First Fill) and FILF (First In Last Fill), were chosen for experimentation. For the FIFF approach, the mould is already aged as the first moulded mould is selected from the first fill. The waiting period for each mould is approximately equal. Hence, the average value distribution for each parameter, but the values do not lie within the desired limit. Therefore, there is a higher chance of defects. In the FILF approach, the mould parameters are conserved as the last moulded fresh mould taken for the first fill. Hence, there is a higher chance of healthy castings. Here, a gradual change in mould parameters is seen, causing the first-formed mould to wait longer than the last-formed mould. Hence, the first-formed moulds have a higher chance of defective casting. The moisture content (%) and green compressive strength decrease, and mould hardness and permeability increase with increasing initial holding time, the same for all moulds. The actual holding time depends on the initial and individual holding times. Hence, the filling sequence creates a significant impact on the quality of casting.

XII. CONCLUSION:

The investigation conducted for the impact of holding time and filling sequence highlights the importance of holding time and filling sequence for defect-free, healthy casting and minimising the reduction in rejection. According to observations and analysis, the First In First Fill (FIFF) method gives more rejections than First In Last Fill (FILF). Hence, in the FIFF method, though all moulds provide the same age, more ageing occurs, hence more chances of defects. In the LIFO method, the last few moulds may show defects, but the first few show a healthy nature and defect-free casting. The FILF method is suitable for achieving effective production and a lower rejection rate. From the perspective of time, moulding time is primarily standard, as is casting, but the reduction in initial holding time can help reduce defects. If the initial holding time is standard or one cannot reduce it, then adjust the mould parameters accordingly so that after the initial holding time, at the time of pouring, the mould parameter value of the individual mould will remain within limits. Hence, there is a lower chance of defects.

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