Product Design & development of High-Pressure moulding machine and analysis of various mould properties

M Lavakumar and Arokya Agustin S
Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur, Chennai, Tamilnadu, India
Email: lavakumar_m17@srmuniv.edu.in

Abstract. Although there are many advanced technologies for metal casting, green sand casting is one of the most commonly used casting processes today due to its low cost of raw materials, and ability to produce a variety of castings both in size and composition, and the ability to recycle the moulding sand. The green sand-casting process is one of the most versatile processes in manufacturing because it is used for most metals and alloys even with high melting temperatures such as iron, copper, and nickel. Understanding the conventional and modern green sand moulding method can help redesign for manufacturability and utilize processes for modernization of foundry; that meet specific requirements. The flexibility of moulding is demonstrated by the number of moulding processes currently available. This wide range of choices offers design engineers and component users’ enormous flexibility in their metal forming needs. Each process offers distinct advantages and benefits when matched with the proper product application. This project is to design a high-pressure moulding machine and study, compare mould properties achieved by different moulding methods, that help improve product quality.

1. Introduction
Sand casting is one of the primary casting processes which uses sand as the moulding material. As much as 60% of the metal castings are produced using the sand-casting process. Sand as a moulding material is cheap and can be reusable. Green sand is one of the common sands used in sand casting process. Green sand is a mixture of a variety of materials such as silica sand, coal dust, bentonite & water. As the name suggest the sand is green in nature i.e., wet till the metal is poured in the moulds[1].The mould sand has certain characteristics namely Refractoriness, Chemical inertness, Permeability, Cohesiveness bond etc., These characteristics help in achieving good mould quality. Some of the important sand properties that are tested in foundries are Compactibility, Permeability, Hardness, Green Compressive strength. Compactibility test is carried out to know how the sand will compact during moulding and thus determine the quantity of sand required per mould. The result is the distance from the top of the tube to the surface of the sand after ramming which is interpreted in percentage compactibility [1].

Permeability test is conducted to see how the gases can escape the mould cavity through the sand. The permeability number has no units. The grain size, shape, type of bonding material, moisture content of the sand and compactibility of the sand play an important role in achieving a good permeability number. Both B and C scale hardness testers are available, but the C scale hardness is more accurate at higher hardness values. A good hardness means that the mould will have better finish and dimensional accuracy, however, if the hardness is more, it will lead to mould cracking [2]. For the mould to stay well packed green compressive strength is a critical parameter. If the green strength is
low, the mould could break too early and if the green strength is too high it will become difficult to remove the sand during knockout [3]. There are many ways to make a sand mould namely Hand moulding; Mechanized sand moulding; High pressure sand moulding [4]. Hiren Khalasi [1] did a study using design of experiment-based approach which is adopted to obtain an optimal setting of moisture content, grain particle size and temperature of pouring metal related parameters of green sand casting. Mahesh [2] did a study to find optimum level of hardness in sand casting process, experimental results show that, vent hole diameter plays a crucial role in hardness of sand-casting process and the optimum level is recommended for further research. Guharaja [3] did a study of various significant process parameters of green sand-casting processes and the effect of selected process parameters and its levels on the casting defects and the subsequent optimal settings of the parameters have been accomplished using Taguchi’s parameter design approach. Raghwendra Banchhor [4] did a studied about the various green sand moulding processes currently available in industries and has briefed their advantages over other processes. CharnnarongSaikaew [5] did a study to find the optimal amount of recycled sand and new bentonite and water for reducing iron casting waste using the following analysis techniques. The results show what is the optimal amount in % of recycled mould sand and bentonite and water to produce good quality sand moulds. This paper work is for studying various mould properties to determine the optimal sand squeezing force and designing a moulding machine to achieve good mould quality for small scale foundries.

2. Materials
For this experiment purpose the sand parameters are kept constant for all the specimens to be used. The composition of the Green sand is as follows: Return sand – 300 kg; New sand – 50kg; Bentonite – 3kg; Coal dust – 2kg; Water addition – 8.2 liter [5]. All the ingredients are mixed well in a sand mixture, and this will produce green sand with ~3.5% moisture content. The machine design is for box size 520mm x 520mm. As per industrial standard machines already available in the market, Jolt squeeze machine has pneumatic cylinder of size 400 mm dia.

Total load applied = area x pneumatic pressure (in kg/cm²)
Load= 40*40*(3.142/4) * 6.5 = 8171.42 kg ; Area of box = 52*52 = 2704 cm²;
Load/cm² of sand = 8171.42/2704 = 3.02kg/cm²
So, a load of 3 kg/cm² is being applied on sand, when sand is rammed using industrial standard machines available in the market. The experiments are conducted at 2, 3, 4, 5, 6, 7, 8, 9, 10 kg/cm² of loads to analyses how each property behave. Now it is important to understand how to apply the above said force to obtain a standard specimen prepared using a 100mm long, 50mm dia tube. The specimen diameter is 50mm. Hence, it is required to convert the load accordingly as; Specimen cross sectional area = \( \frac{a \times a \times \pi}{4} \times 5 \times 5 \times \frac{3.142}{4} = 19.6 \text{ cm}^2 \). To check properties achieved through jolt squeeze moulding machine(3kg/cm²), the weight that needs to be applied to prepare the specimen is Load = area*load/cm² = 19.6*3 = 58.8kg ~ 60 kg. The Specimens are prepared using sand rammer, the sand is filled in the tube of size 50mm dia and 100 mm long. The ramming mass will be used as per below table and rammed 3 times.

| Force (kg,cm²) | Equivalent ramming weights (in kgs) |
|---------------|-----------------------------------|
| Hand moulding (2kg/cm²) | 40 |
| Jolt squeeze (3kg/cm²) | 60 |
| 4 kg/cm² | 80 |
| 5 kg/cm² | 100 |
| 6 kg/cm² | 120 |
| 7 kg/cm² | 140 |
| 8 kg/cm² | 160 |
| 9 kg/cm² | 180 |
| 10 kg/cm² | 200 |
3. Experiment
For the experimental study of compactibility 10 specimens are prepared for each load. Thus 100 specimens are prepared for each test. Compactibility is the percentage decrease of sand when a standard load is applied on it. The specimen is prepared using sand rammer with 100mm long, 50mm dia tube. From this experimental analysis, it can be seen that there is not much change in the compactibility above 6 kg/cm² load.

Table 2. Analysis of compactibility.

| Load       | 2 kg/cm² | 3 kg/cm² | 4 kg/cm² | 5 kg/cm² | 6 kg/cm² | 7 kg/cm² | 8 kg/cm² | 9 kg/cm² | 10 kg/cm² |
|------------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|
| Samples    |          |          |          |          |          |          |          |          |           |
| 33%        | 35%      | 36%      | 37%      | 40%      | 41%      | 41%      | 41%      | 42%      | 42%       |
| 33%        | 35%      | 36%      | 37%      | 40%      | 41%      | 41%      | 42%      | 42%      | 42%       |
| 32%        | 35%      | 36%      | 37%      | 40%      | 41%      | 41%      | 42%      | 42%      | 42%       |
| 33%        | 34%      | 35%      | 38%      | 40%      | 41%      | 41%      | 41%      | 42%      | 42%       |
| 33%        | 35%      | 35%      | 38%      | 41%      | 41%      | 41%      | 41%      | 41%      | 42%       |
| 33%        | 34%      | 36%      | 37%      | 40%      | 41%      | 41%      | 41%      | 42%      | 42%       |
| 32%        | 35%      | 36%      | 38%      | 40%      | 41%      | 41%      | 41%      | 41%      | 41%       |
| 33%        | 34%      | 35%      | 37%      | 40%      | 41%      | 41%      | 41%      | 41%      | 42%       |
| 33%        | 35%      | 35%      | 38%      | 40%      | 41%      | 41%      | 41%      | 41%      | 42%       |

For the experimental study of hardness, specimens obtained from compactibility test are used. The hardness is measured by using the hardness tester, it shows the output in number from 0 to 100. The hardness scale is as shown below. From this experimental analysis, it can be seen that there is not a huge change in the hardness number above 6 kg/cm² load.
Figure 2. Mould hardness scale.

Table 3. Analysis of mould hardness.

| Load  | 2 kg/cm² | 3 kg/cm² | 4 kg/cm² | 5 kg/cm² | 6 kg/cm² | 7 kg/cm² | 8 kg/cm² | 9 kg/cm² | 10 kg/cm² |
|-------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Samples |          |          |          |          |          |          |          |          |          |
|        | 73       | 82       | 85       | 88       | 92       | 93       | 94       | 95       | 95       |
|        | 72       | 83       | 85       | 88       | 94       | 93       | 94       | 95       | 95       |
|        | 73       | 82       | 86       | 89       | 93       | 93       | 94       | 94       | 95       |
|        | 72       | 84       | 83       | 88       | 92       | 93       | 95       | 94       | 94       |
|        | 73       | 81       | 83       | 88       | 93       | 94       | 94       | 94       | 95       |
|        | 74       | 84       | 82       | 89       | 93       | 93       | 94       | 94       | 94       |
|        | 73       | 83       | 86       | 88       | 93       | 94       | 93       | 94       | 95       |
|        | 73       | 83       | 85       | 87       | 92       | 93       | 95       | 94       | 95       |
|        | 72       | 84       | 85       | 88       | 93       | 94       | 95       | 95       | 95       |
|        | 73       | 84       | 85       | 87       | 92       | 94       | 95       | 95       | 94       |

Fresh Specimens are prepared for permeability experiment purpose as the previous specimens would be damaged after the hardness test. The quantity of air that will pass through a standard specimen of sand at a particular pressure is called the permeability of sand. Permeability can be calculated as below

\[ PN = \frac{(V*H)}{P*A*T} \]

Where;
- \( V \) = volume of air in ml passing through the specimen
- \( H \) = Height of the specimen in cm
- \( A \) = Cross sectional area of specimen in cm²
- \( P \) = Pressure of air in cm of water
- \( T \) = Time in minutes

It can be observed from the table that permeability number is decreasing as the load increases, the optimal permeability number can be at 6 kg/cm²; as there is an option to provide vents for the gases to escape the mould cavity [3]. Green strength test is conducted to see how much stress a sand sample can withstand before it cracks internally or externally. The sand specimen is taken out of the specimen tube and is immediately put on the strength testing machine and the force required to cause the compression failure is determined. The green strength of sand is generally in the range of 0.03 to 0.16 MPa. Since the optimal test results were achieved at 6 kg/cm² for all the other properties, the optimal point as 6 kg/cm² for Green compressive strength can be chosen.
Table 4. Analysis of permeability.

| Load  | 2 kg/cm² | 3 kg/cm² | 4 kg/cm² | 5 kg/cm² | 6 kg/cm² | 7 kg/cm² | 8 kg/cm² | 9 kg/cm² | 10 kg/cm² |
|-------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|
| Samples |
| 273   | 243      | 219      | 202      | 185      | 180      | 178      | 178      | 175      |
| 273   | 243      | 219      | 201      | 183      | 180      | 178      | 176      | 175      |
| 278   | 243      | 219      | 200      | 183      | 182      | 177      | 177      | 174      |
| 279   | 241      | 221      | 200      | 183      | 181      | 178      | 176      | 175      |
| 273   | 243      | 219      | 201      | 185      | 181      | 177      | 177      | 175      |
| 275   | 245      | 225      | 200      | 184      | 181      | 180      | 177      | 175      |
| 272   | 249      | 219      | 202      | 185      | 182      | 177      | 178      | 175      |
| 278   | 243      | 219      | 203      | 183      | 181      | 178      | 177      | 174      |
| 273   | 251      | 225      | 200      | 185      | 180      | 179      | 178      | 175      |

Table 5. Analysis of green compressive strength.

| Load  | 2 kg/cm² | 3 kg/cm² | 4 kg/cm² | 5 kg/cm² | 6 kg/cm² | 7 kg/cm² | 8 kg/cm² | 9 kg/cm² | 10 kg/cm² |
|-------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|
| Samples |
| 780   | 930      | 1000     | 1200     | 1400     | 1410     | 1420     | 1430     | 1450     |
| 770   | 940      | 1050     | 1260     | 1470     | 1450     | 1470     | 1420     | 1450     |
| 760   | 910      | 990      | 1188     | 1386     | 1400     | 1420     | 1450     | 1450     |
| 780   | 930      | 1010     | 1212     | 1414     | 1400     | 1420     | 1430     | 1440     |
| 780   | 930      | 1030     | 1236     | 1442     | 1430     | 1430     | 1440     | 1430     |
| 760   | 940      | 1000     | 1200     | 1400     | 1420     | 1430     | 1420     | 1440     |
| 770   | 930      | 990      | 1188     | 1386     | 1410     | 1440     | 1420     | 1440     |
| 780   | 940      | 1000     | 1200     | 1400     | 1420     | 1430     | 1430     | 1440     |
| 750   | 920      | 1000     | 1200     | 1400     | 1410     | 1430     | 1440     | 1450     |
| 770   | 940      | 1020     | 1224     | 1428     | 1420     | 1400     | 1450     | 1430     |

Figure 3. Analysis of compactibility.

Figure 4. Analysis of mould hardness.
From this experimental analysis, it can be observed that as the force applied on the sand during compression increased, there is a direct impact on the mould properties and in a positive way. From all the experimental data collected, it can be observed that 6 kg/cm² of load applied on each square cm of mould can produce a better and good quality mould, and thus eliminate the defects occurring. Based on the above analysis, load applied per cm² at 6 kg/cm² is optimal point. Now it is required to calculate the cylinder diameter required to obtain these 6 kg/cm² loads on sand per cm².

Let cylinder dia be “a”

\[
\text{Load} = a^2 \times (3.142/4) \times 6.5
\]

Area of box = 52*52 = 2704 cm²

\[
\text{Load/cm² of sand} = 6\text{kg/cm²} = (a^2 \times 0.785 \times 6.5)/2704;
\]

\[
a^2 = (6 \times 2704)/ 5.105 = 16224/5.105 = 3179.61
\]

\[
a = 56.38\text{cm}
\]

It can be noted that cylinder diameter is more than the box size 52cm. So cylinder of dia 56cm cannot be used. Hence the pressure needs to be increased to reduce the cylinder diameter. Since air pressure cannot be raised beyond a point, it is better to use hydraulic cylinder, which can be operated at higher pressures. So, it can be concluded that hydraulic system be used for moulding purpose to achieve better mould quality. Now to calculate the hydraulic cylinder diameter required to achieve 6 kg/cm², let the operating pressure be 50 bar.

Let cylinder dia be “a”

\[
\text{Load} = a^2 \times (3.142/4) \times 50
\]

Area of box = 52*52 = 2704 cm²

\[
\text{Load/cm² of sand} = 6\text{kg/cm²} = ((a^2 \times 0.785 \times 50)/2704)
\]

\[
a^2 = (6 \times 2704)/(39.25) = 413.35
\]

\[
a = 20.33\text{cm}
\]

The min diameter of the squeeze cylinder is 20 cm & operating at 50 bar pressure.

4. Manufacturing

List of operations in this moulding machine design are Top box pin lift; Top box removal; New top box placed on the pin lift & pin lift back to home position; Sand filling in top box; Bottom Mould box Squeeze and back to home position; Trolley Movement to position 2; Top Mould box squeeze and back to home position; Bottom box pin lift; Bottom box removal; New Bottom box placed on the pin lift & pin lift back to home position; Sand fill in Bottom box; Trolley movement to position 1.
Figure 7. Cycle time design.

The high-pressure moulding machine was installed at a facility in “Sigma Engineering and castings”

Figure 8. Final moulding machine design.

Figure 9. PLC controlled High Pressure moulding machine.
5. Result and discussion
Below is the image of the mould produced using the designed high-pressure moulding machine. The mould hardness test was conducted on 5 random mould produced using the designed high-pressure moulding machine (mould hardness is the only test that could be easily conducted on the big sized mould, other tests can only be done on specimens of small size).

![Mould produced in the designed machine.](image)

**Figure 10. Mould produced in the designed machine.**

| Mould No | Mould hardness Number (BHN) |
|----------|----------------------------|
| 1        | 92                         |
| 2        | 90                         |
| 3        | 91                         |
| 4        | 93                         |
| 5        | 91                         |

**Table 6. Mould hardness for final moulds produced in machine.**

6. Conclusion
It can be seen that the desired mould hardness is achieved using the moulding machine designed as per the specification achieved from experimental analysis done in section 3 of this paper. Thus, it can be concluded that mould quality can be improved by using high pressure moulding systems and the machine designed and manufactured as mentioned in this paper has given a mould output which has better mould hardness.

7. References
[1] Hiren Khalasi 2016 Optimisation of Process Parameters of Green Sand Casting in Small Scale Foundry, *International Journal for Research in Applied Science & Engineering Technology*. 4, 719-727
[2] G. Mahesh 2017 Experimental Investigation and Optimisation of Hardness in Sand Casting Process by Using the Design of Experiments Approach, *Applied Mathematics & Information Sciences*. 11, 931-938
[3] S. Guharaja 2006 Optimization of green sand-casting process parameters by using Taguchi’s method, *The International Journal of Advanced Manufacturing Technology*. 30, 1040-1048
[4] Raghvendra Banchhor 2014 Critical Assessment of Green Sand Moulding Processes, *International Journal of Recent Development in Engineering and Technology*. 2, 90-98
[5] CharnnarongSaikaew 2012 Optimization of molding sand composition for quality improvement of iron castings, *Applied Clay Science*. 67-68, 26-31