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Effect of Input Parameters on The Mechanical Properties of Green Sand Mould

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Abstract

Among all the methods of metal forming, green sand moulding is the most commonly used method due to its low cost and high speed of work. Main constituents of green sand mould are sand, water, coal dust and binder. Mechanical properties like permeability, green compressive strength, mould hardness, compactibility and moisture content of green sand directly affects the quality of castings produced. This research is done to investigate the effect of input parameters (bentonite, garcolap powder, water) on the mechanical properties of green sand mould. Three levels of each input parameter were considered, and the experiments were designed using design expert software version-13. The regression analysis was performed on the experimental results using Minitab software version-21 to evaluate the effect of bentonite, garcolap powder and water on mechanical properties of green sand mould. Twenty experiments were designed by the software. Values of mechanical properties of green sand like compactibility, permeability, mould hardness, green compressive strength and moisture content were measured by performing experiments on specimen prepared from green sand in accordance with the IS: 1918-1966. Measured values were compared with the standard for validation. Results of this research clearly indicate that bentonite is the only input parameter which has the highest effect on mechanical properties of green sand mould.

Keywords: Bentonite, Green Sand Moulding, Compactibility, Permeability, Mould hardness, Green compressive strength, Moisture content

1. Introduction

Casting, also known as metal forming, is the most popular manufacturing process to give desired shape to various metals [1]. Types of casting processes are sand casting, centrifugal casting, shell casting, investment casting, die casting etc. More than 80% of casting products are made using green sand moulding process. The reason behind this is its main constituent silica sand which is available in large quantities and at low cost [2, 3, 5, 6, 19]. Silica sand has characteristics like permeability, resistance to high temperatures, collapsibility, refractoriness, mouldability etc. which makes it best suited for green sand-casting process [4, 7]. Basic steps for sand casting are sand mix (green sand) preparation, core and pattern making, mould preparation, melting, pouring of molten metal, cooling and solidification, mould removal, finished casting, cleaning and inspection shown in figure-1.1 [8, 11, 15, 19].

Main constituents of the green sand are silica sand (80-90%), water, binder (bentonite 10-20%) and coal dust (2-10%). To prepare expandable moulds different types of sands available are zircon, olivine, chromite, quartz etc. [9, 12, 13]. Quarts is the most popular sand among all because of its plethora in nature. At the temperatures ranging from 560 to 580 °C quartz sand increase in volume which is its major drawback [5, 19]. Additionally, a variety of organic compounds like formaldehyde, phenol and furfuryl alcohol are used to bound the core sands. Mostly binders are thermally degrading at high temperatures ranging from 750 to

1000°C [10, 14, 16, 18]. To prepare green sand various binders available are bentonite, montmorillonite, kaolinite, polygorskite, hydromica, vermiculite, allophane and halloysite [12, 16, 17].

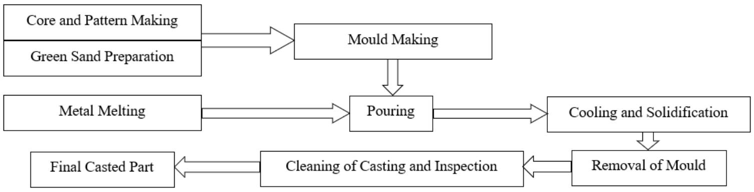

Fig. 1. Casting Process Steps

1.1. Bentonite

A binder must have characteristics like easy collapsibility during shrinkage of metal, high strength, can be easily handled and do not distort core while baking takes place [8, 11, 18]. Bentonites are clayey rocks that originated as a result of bentonitization process of a volcanic glass occurring in the pyroclastic rocks such as tuffs and tuffites. It consists of montmorillonite accompanied by other clayey minerals [3, 7]. Bentonite is available in large quantities throughout the world. It is a natural clay with a soft and fine texture. When mixed with water it swells, forms a paste, and obeys Pozzolanic properties. It is a perfect inorganic binder with greater swelling capacity, rebounding ability, resistance to the temperature of molten metal, large number of organic additives, multiple use, low cost etc. [5, 6, 9, 13].

Above characteristics of bentonite make it the most suitable binder for green sand moulding. Therefore, more than 70% of iron castings are manufactured using green sands having bentonite as a binder [16, 17, 18]. It is rich in clay minerals having high amount of montmorillonite accompanied by calcium or sodium with low amount of kaolinite, sulphides, feldspar, quartz, illite carbonates, sulphates, and organic matter [3, 15]. It belongs to the group of minerals known as alumino-silicates [2, 7, 12, 16].

There are two types of bentonites available named as sodium bentonite and calcium bentonite. Calcium bentonite possesses properties like less sensitive to moisture, greater potential for absorption of water and better resistance to high temperatures which makes it most preferable as a binder [20]. Comparison of properties of both types of bentonites are shown in Table-1.1.

Table 1.
Comparison of properties of calcium and sodium bentonite [20]

Properties	Sodium (Na) Bentonite	Calcium (Ca) Bentonite
Swelling	Higher	Lower
Plasticity	Lower	Higher
Rigidity of Absorbed Water Layer	Lower (First three molecular layer)	Higher (First four molecular layer)
Liquid Limit	Higher	Lower
Green Strength	Slightly Lower	Higher
Dry Strength	Higher	Lower
Hot Strength	Very High	Lower

2. Experiment Design

To design the experiments three levels of input parameters were set as bentonite 8, 10 and 12 gm, garcolap powder 1, 2 and 3 gm and water 8, 10 and 12 ml from the experience of the supervisor from the industry. Other two parameters reclaimed sand 200 gm and mixing time 5 minutes were kept constant. For DOE design expert software version-13 was used. Then Minitab software version-21 has been utilized for regression analysis of the results to identify the influence of input parameters on mechanical properties of green sand mould. Designed experiments are tabulated in the Table 2.

Table 2.
Experiments Designed by Design Expert Software

Exp. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Bentonite (gm)	10	12	8	6.6	10	10	10	8	10	10	13.4	8	8	12	10	10	12	10	12	10
Garcolap Powder (gm)	0.3	3	3	2	2	2	2	1	2	2	2	1	3	1	3.7	2	1	2	3	2
Water (ml)	10	12	8	10	10	10	13.4	8	10	10	10	12	12	12	10	6.6	8	10	8	10

3. Test Material and Method

To perform the tests mentioned in Table 2 green sand was prepared by mixing reclaimed sand (figure 2), bentonite (figure 3), garcolap powder (figure 4) and water for 5 minutes mixing time. WD-XRF analysis has been carried out to determine the chemical composition of the bentonite used for experimentation. Resulted composition is shown in Table 3. All the testing materials were prepared, and tests were performed on calibrated equipment in accordance with the IS:1918-1966. Detailed methodology for experiments performed is described below

Fig. 2. Reclaimed Sand

Fig. 3. Bentonite

Fig. 4. Garcolap Powder

Table 3.
Chemical Composition of Bentonite by WD-XRF Analysis

Test Parameter	SiO_2	Fe_2O_3	Na_2O	MgO	Al_2O_3	K_2O	CaO	TiO_2	P_2O_5	SO_3	MnO
Concentration (%)	51.714	16.48	8.265	3.638	15.047	0.114	2.15	1.176	0.584	0.705	0.127

3.1. Test Specimen Preparation

For testing purpose standard cylindrical specimen (figure 5) prepared by taking green sand of 150gm specific weight as per IS 1918-1966. The dimensions of test specimen are 50.8 $\pm$ 0.03 mm height and 50.8 mm diameter (or of 50 $\pm$ 0.3 mm height and 50 mm diameter). Place the weighted quantity of green sand in the specimen container carefully. After levelling the sand in the container, gently lower the ramming head into the specimen container, until it is supported by the sand. Slowly raise the rammer weight by hand or by cam to the full height of the specimen and let it fall. Repeat twice, making a total of 3 rams to get the standard test specimen [21].

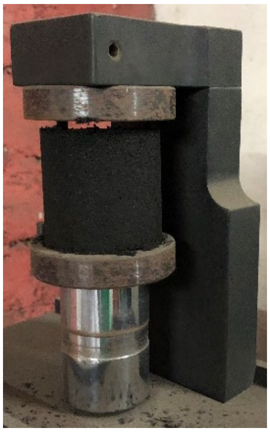

Fig. 5. Testing Specimen

3.2. Compactibility Test Procedure

Prepare the testing specimen as described above in the section 3.1 and measure the distance between top edge of the specimen container and top surface of prepared specimen using testing scale (figure 6) before removing the specimen from the container [21]. This distance measured by the scale indicates the compactibility.

Fig. 6. Testing Scale

3.3. Permeability Test Procedure

Permeability tester from Versatile Equipment PVT LTD (figure 7) is used to check permeability. Put the prepared test specimen in the tester. Set the tester on O-P. Wait until water level is steady and take the reading. Compare the reading with the given table on the tester and check the permeability.

3.4. Mould Hardness Test Procedure

Prepare cylindrical test specimen as described earlier. Use mould hardness tester while test specimen is in the specimen container (figure 8) to take the reading.

3.5. GCS Test Procedure

To determine green compressive strength of the green sand test specimen is placed in Universal Strength machine manufactured by Kelsons Testing Equipment (figure 9). Mount the test specimen on the machine table and start the machine. Machine will apply gradual load on to the specimen until specimen breaks. When specimen breaks reading will be displayed on the screen which is the required GCS.

3.6. Moisture Content Test Procedure

Take 7 gm green sand and put it in the upper cap of moisture tester. Put 1 gm calcium carbide (CaC2) in the green sand. Properly mix them for 1.5 minutes [21]. Close the machine and you can see reading on the display of moisture teller (figure-1.10). Consider that reading as percentage moisture.

Fig. 7. Permeability Tester

Fig. 8. Mould Hardness Tester

Fig. 9. Universal Strength Machine

Fig. 10. Moisture Teller

Table 4.
Result of Experiments Performed

Exp. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Compactibility (%)	47	54	42	40	47	48	45	46	47	47	55	44	43	52	48	49	53	47	54	47
Permeability (unitless)	100	84	123	130	100	102	97	119	99	100	88	121	115	89	94	105	87	100	85	100
Mould Hardness (No.)	77	89	67	59	72	72	79	69	72	72	90	64	65	87	85	76	89	72	86	72
GCS (kg/cm2)	950	1025	780	750	925	924	980	810	923	925	1150	790	835	1070	1040	895	1095	927	1065	924
Moisture (%)	4.2	5.4	3.1	3.3	4.5	4.5	5	3.5	4.5	4.5	5.2	3.7	4	5.3	4.9	3.8	4.5	4.5	4.9	4.5

4. Result Analysis and Discussion

Table 4 shows the results obtained from the tests. For the multiple regression analysis target values set for response parameters (from the standard range) are compactibility 48%, permeability 115, mould hardness 78, GCS 1150kg/cm2 and moisture 5%. Results of multiple regression analysis performed using Minitab software version-21 is shown in the figures below. In these results X1 state values for bentonite, X2 for garcolap powder and X3 for water.

Figure 11 shows that among bentonite, garcolap powder and water; water is marked with gray background means that it has not any significant effect on compactibility of the green sand. Diagnostic report for compactibility figure 12 shows that there is not any strong curvature, clusters, or any large residues. Points also fall randomly on both the sides of zero. Which means that there is no problem with the regression model. Final model equation from model building report for compactibility (figure 13) is compactibility = 35.1 + 1.304X1 – 5.02X2 + 0.5X1 * X2. This report also depicts that bentonite contributes the most (approximately 90%) in the response changes of compactibility while role of garcolap powder is around 3%. Figure 14 shows the optimal solution is X1=9.98003 and X2=3.7 to get compactibility value as 48%. Alternate solutions are also given in the same figure. And there are 95% chances of getting the values of compactibility in the range between 44.472% to 51.528%

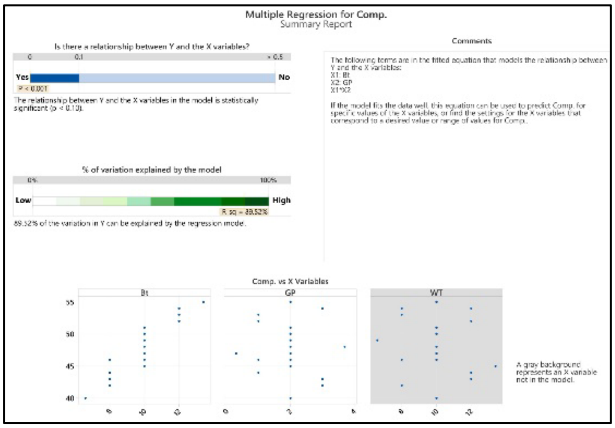

Fig. 11. Summary Report for Compactibility

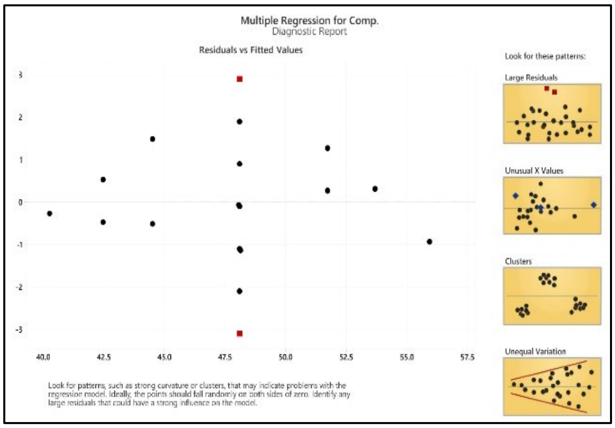

Fig. 12. Diagnostic Report for Compactibility

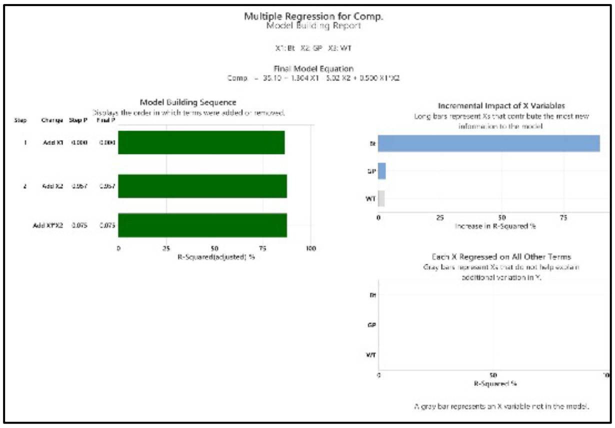

Fig. 13. Model Building Report for Compactibility

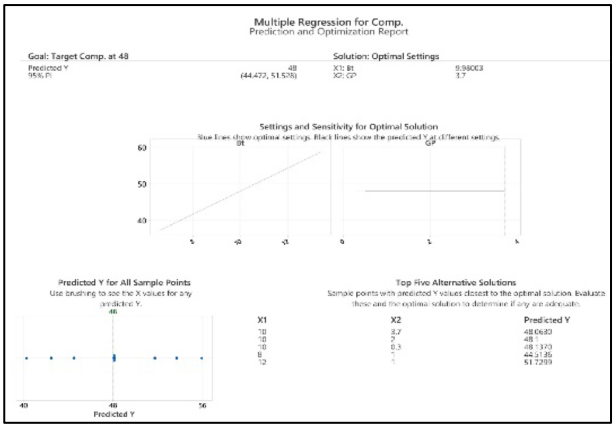

Fig.14. Prediction and Optimization Report for Compactibility

Summary report (Figure 15) shows that garcolap powder and water has not any significant effect on permeability of the green sand as they are marked with gray colour. Figure 16 shows diagnostic report for permeability which says that there is not any strong curvature, clusters, or large residues. Randomly fallen points meant that there is no problem with the regression model. As shown in figure 17 final model equation for permeability is permeability = 245.7 – 21.66X1 + 0.712X1^2. According to this report bentonite is the most (approximately 95%) responsible parameter for changes in permeability. Prediction and optimization report (figure 18) depicts the optimal solution is X1=8.30036 to get permeability value as 115. It also gives alternate solutions. In 95% cases the values of permeability will fall in the range between 104.03 to 125.97.

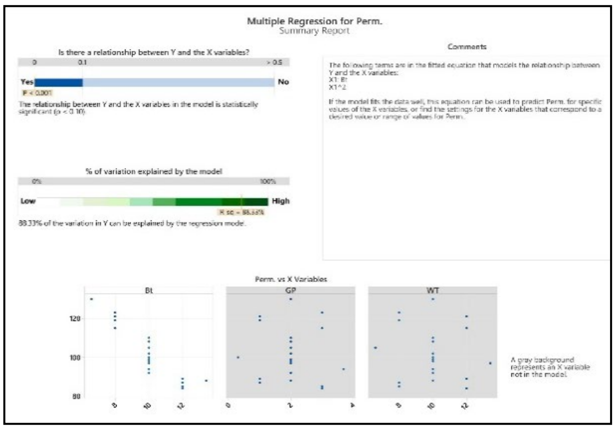

Fig. 15. Summary Report for Permeability

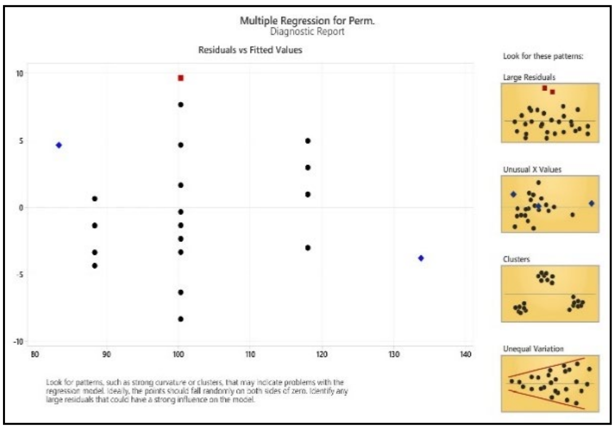

Fig. 16. Diagnostic Report for Permeability

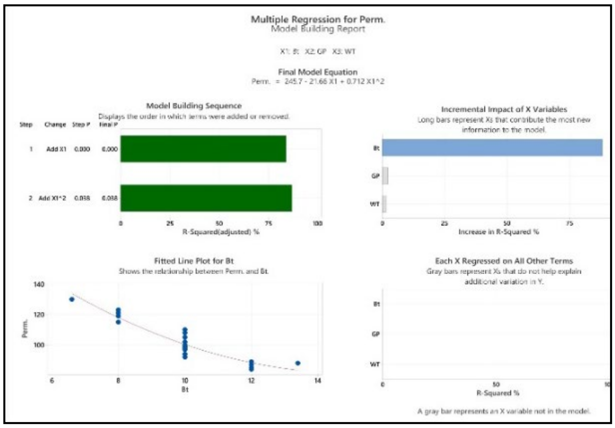

Fig. 17. Model Building Report for Permeability

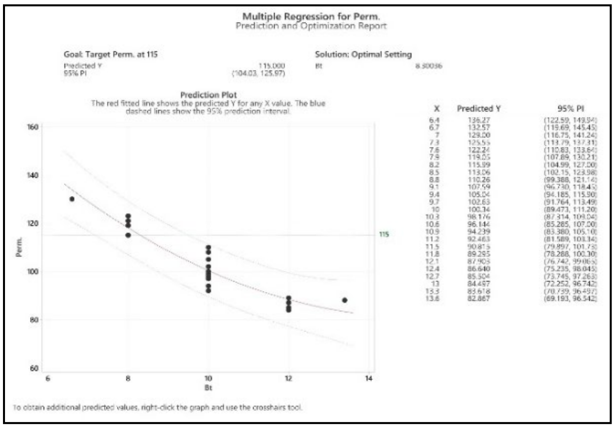

Fig. 18. Prediction and Optimization Report for Permeability

In summary report shown in figure 19 water is marked with gray background which depicts that it has not any significant effect on mould hardness of the moulding sand. Diagnostic report from figure 20 reflects that because there is not any strong curvature, clusters, or large residues and even points are randomly fallen; there is no problem with the regression model. From figure 21 final model equation for mould hardness is mould hardness = 30.92 + 5.033X1 – 6.87X2 + 1.928X2^2. Model building report also depicts that bentonite is the most influencing parameter approximately 95% for mould hardness changes while contribution of GP is nearly 4%. As per prediction and optimization report (figure 22) to get targeted mould hardness 78 optimal solution is X1=9.16066 and X2=3.7. More alternate solutions are also mentioned in the same report. There are 95% chances to get the values of mould hardness in the range of 69.016 to 86.984.

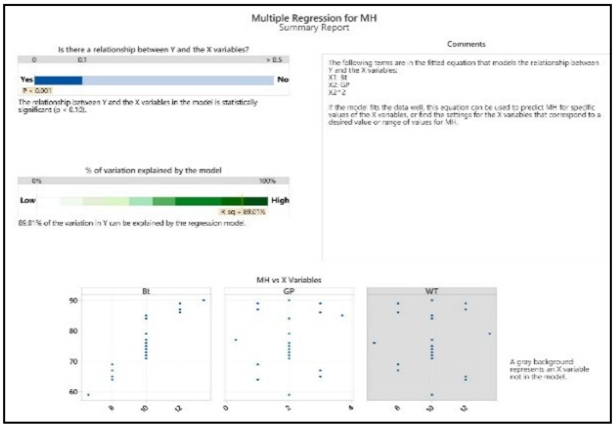

Fig. 19. Summary Report for Mould Hardness

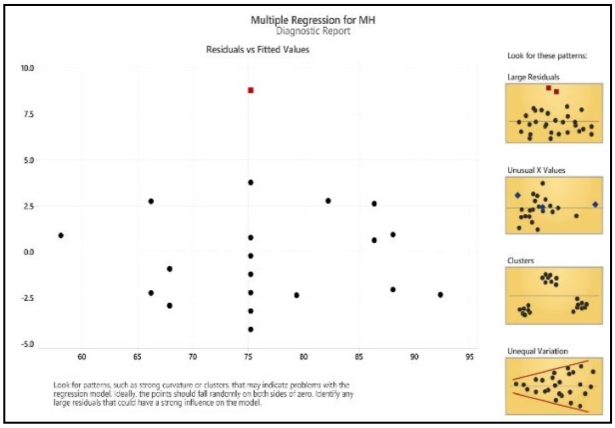

Fig. 20. Diagnostic Report for Mould Hardness

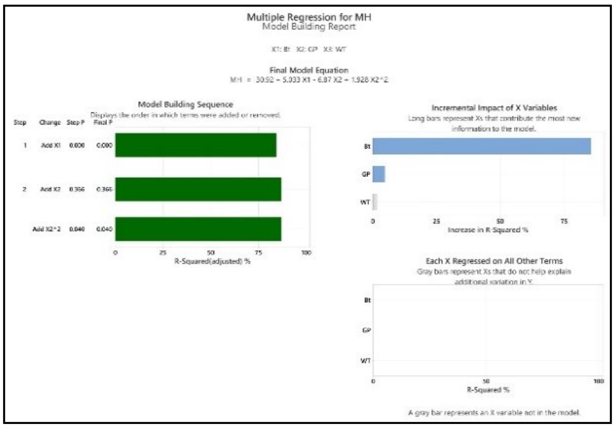

Fig. 21. Model Building Report for Mould Hardness

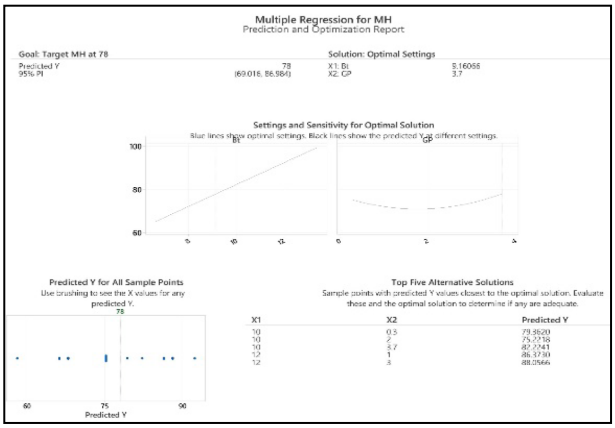

Fig. 22. Prediction and Optimization Report for Mould Hardness

As per summary report (figure 23) garcolap powder and water are marked with gray colour which means that they have not any significant effect on GCS of the green sand. There is not any strong curvature, clusters, or large residues in the diagnostic report (figure 24). Points are also fallen randomly on both the sides of zero. Therefore, there is no problem in the regression model. As mentioned in the figure 25 final model equation for GCS is GCS = 321.9 + 62.41X1. It also reflects that bentonite is approximately 95% responsible for GCS variations of green sand mould. Figure 26 shows prediction and optimization report which says that to get GCS value as 1150 kg/cm2 optimal solution is X1=13.2687. Alternate solutions are also available. The range for GCS is 1046.8 kg/cm2 to 1253.2 kg/cm2 in the 95% cases.

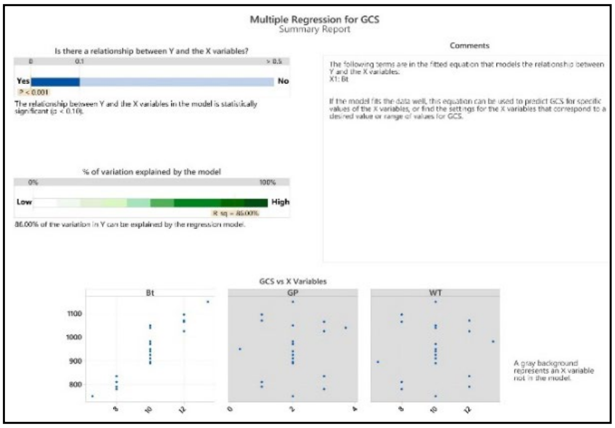

Fig. 23. Summary Report for GCS

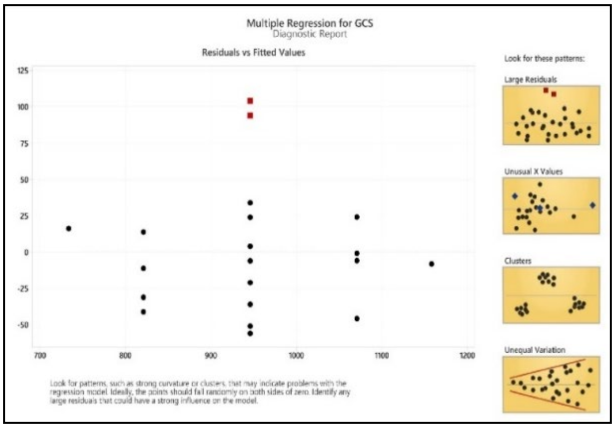

Fig. 24. Diagnostic Report for GCS

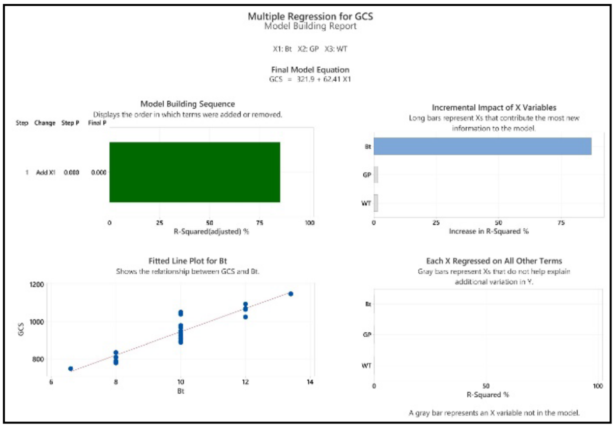

Fig. 25. Model Building Report for GCS

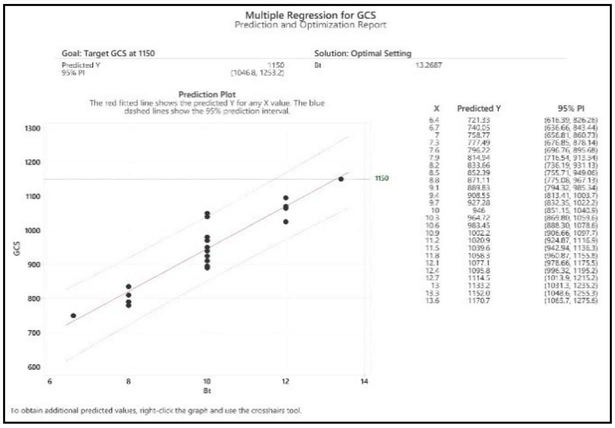

Fig. 26. Prediction and Optimization Report for GCS

Figure 27 shows the summary report which says that garcolap powder (as marked with gray background) has not any significant effect on moisture of the green moulding sand. Absence of any strong curvature, clusters, or large residues in the diagnostic report (figure 28) reflects that there is no problem in the regression model. Points are also fallen randomly on both the sides of zero. Final model equation for moisture is moisture = -0.498 + 0.3276X1 + 0.1611X3 (figure 29). Model building report also depicts that bentonite is approximately 85% responsible for moisture changes while water is approximately 15% responsible. As per prediction and optimization report (Figure 30) to get moisture value as 5% optimal solution is X1=10.19 and X3=13.4. Various alternate solutions are also available. In the 95% cases the range for moisture is 4.3276% to 5.6424%.

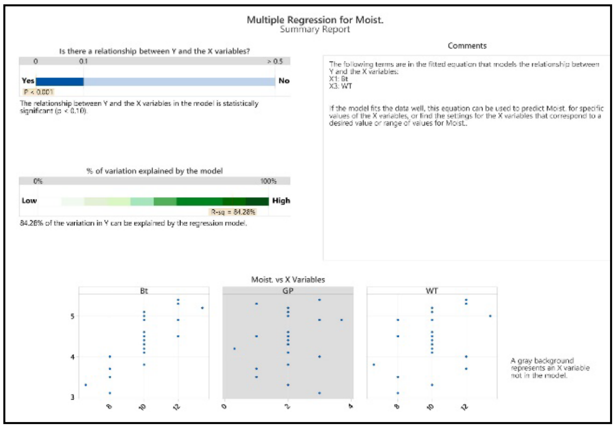

Fig. 27. Summary Report for Moisture

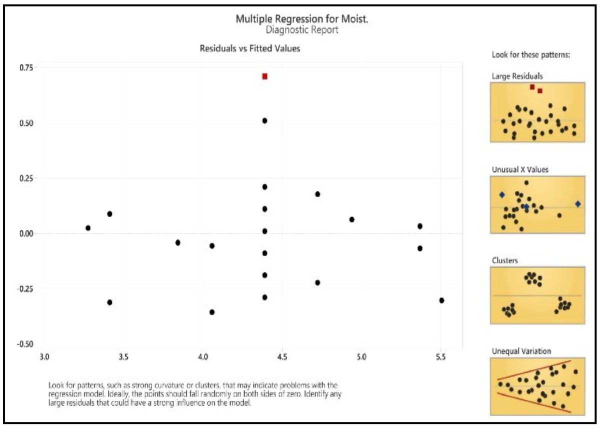

Fig. 28. Diagnostic Report for Moisture

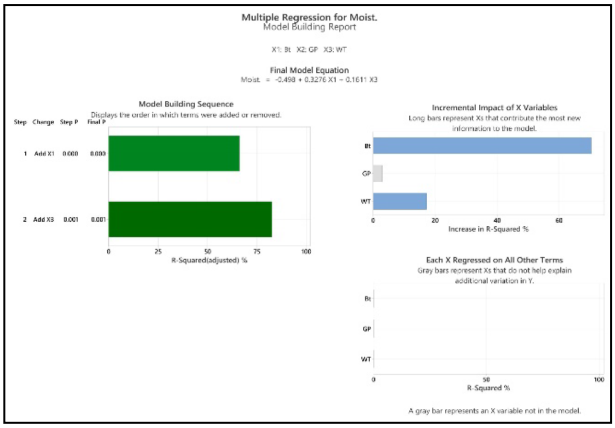

Fig. 29. Model Building Report for Moisture

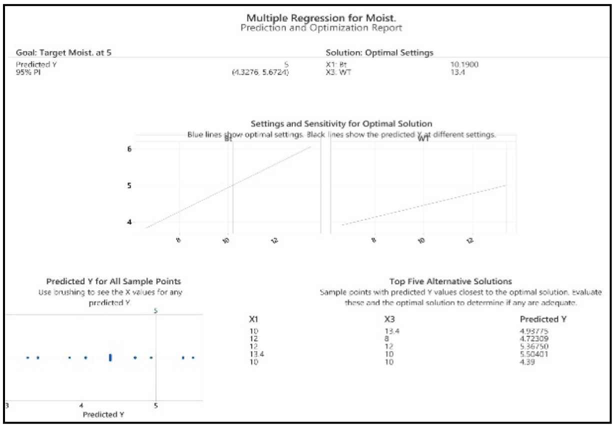

Fig. 30. Prediction and Optimization Report for Moisture

5. Conclusion

- WD-XRF analysis is effective to know the chemical composition of bentonite.
- Experiments designed using design expert software are quite effective to get the data for regression analysis in Minitab software to investigate the effects of input parameters on mechanical properties of green sand mould.
- Results of regression analysis depict that water has no significant effect on compactibility, permeability, MH, and GCS. It is only approximately 15% responsible for moisture changes in green sand mould.
- Regression analysis also says that garcolap powder has no significant effect on permeability, moisture, and GCS. It has approximately a 3% effect on compactibility changes and approximately a 4% effect on MH changes.
- In addition, regression analysis reflects that bentonite is the only input parameter who has influence on all mechanical properties of green sand mould.
- Model building reports of compactibility, permeability, mould hardness, green compressive strength and moisture content clearly show that bentonite possesses the most percentage (approximately 85% to 95%) of influence on mechanical properties of green sand mould.
- Therefore, quality and quantity of bentonite is a very important aspect to be taken into consideration for the preparation of green sand.
- Further research can be carried out to investigate the effect of bentonite on green sand mould.
- Model equations generated by Minitab software can be used to predict the values of response parameters which can be validated by actual experiments.

Acknowledgement

All the experimental work and tests have been carried out at "Fine Cast India Private Limited", Anand, Gujarat. Currently the industry is using bentonite clay binders' system. To determine the chemical composition of bentonite WD-XRF analysis done at Sophisticated Instrumentation Centre for Applied Research and Testing (SICART), Anand facility.

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