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Optimization of Sand Castng Process Parameters for Ferrous Material by Using Design of Experiments

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ABSTRACT : Casting is a age old production technique wherein cavities are formed by a pattern into a porous and refractive material, usually sand, and then liquid metal is poured into the cavity so that it takes up the shape of the cavity, thus forming the required metal product. Various properties of sand such as grain fineness number, green compressive strength, refractive ness, clay content, moisture, mould strength, etc have an appreciable effect over the produced casting [1]. An experimental study was conducted to study the effect of three parameters, namely, moisture content of sand mould, the clay content of sand mixture and grain fineness number of sand on the tensile strength of the casting produced. Experiments were planned using the strategy of design of experiments, level and range of input parameters i.e. moisture, clay content and grain size were selected and then experiments were conducted [8,14]. In each run, the tensile strength of obtained casting was measured using the Universal Testing Machine [12]. Some considerations were put up for the hardness number, visual blow holes, surface finish, pin holes etc. Since we took into account three factors, the use of Taguchi method was made, a total of nine sand mixtures were made for the application of L9 technique [14]. These samples were then put to test for tensile strength and analysis was conducted for the collected data to study the main effects. Optimization was done by Taguchi Technique [2].

I. INTRODUCTION

Sand is defined as granular material that passes through different sizes of strainers or "sieves". According to the classification parameters, material of which 50% or more is coarser than the #200 sieve but which 50% or more is finer than the #40 sieve, is classified as sand. The #200 sieve has openings of 75 microns (0.075 mm) of diameter while the #40 openings are 4.25 millimeters in diameter. If there are large amounts of particles smaller than 75 microns, the material is called clay, or silt. If there are large amounts of particles bigger than 4.25 mm, the material is called gravel [10]. Sand can be classified as: Green sand is composed of a mixture of silica sand, clay 18 to 30% which acts as binder and moisture 6 to 8%. The world green" meant condition of wetness or freshness. Dry sand is basically green sand mould but it also contains 1 to 2% cereal flour and 1 to 2% pitches. Loam sand consists of fine sand plus finely ground refractoriness, clay, graphite and fibrous reinforcements. The clay is up to 50% which provides good binding ability [18]. Facing sand is also called fat sand it makes the face of the mould it is rammed around the pattern to effect the economy. Core sand is the sand used to make the core, it contain high content of silica sand to get high refractoriness. To enhance the properties of sand some additives, binders, clay and moisture are added into it. Additives are sea coal, cereals, saw dust, wood flour, silica flour, fuel oil, iron oxide, dextrin and molasses etc. Binders are inorganic like fire Clay, Kaolinite, Illite, Bentonite etc and organic are cereal binders obtained from wheat and corn, linseed oil, fish oil, soybean oil, mineral oils, pitch and molasses [16]. Sand is widely used as molding material due to its properties like permeability, strength, strength or cohesiveness, refractoriness, flow ability, collapsibility and adhesiveness. The basic testing parameters are Moisture content, Permeability, Green compression strength, Compactability, Wet tensile strength, Mould ability, Friability Loss on ignition, Volatiles content, Grain size & distribution & Dust (dead clay) content. We have selected three parameters Grain Fineness Number of the sand used to prepare the mould, Clay Content present in the sand & Moisture Content of green sand used. The objective of the paper is to investigate the value of grain fineness number of sand, moisture & content clay of the sand at which it gives the highest value of tensile strength for Grey Cast Iron (FG 200) [9].

II. EXPERIMENTATION

We prepared a cuboids pattern of wood of 153 × 40 × 20 mm dimensions, and taper was given to the sides, altering the upper length from 153 mm to 156 mm. To obtain sand of different GFN, a sieve was used to separate course sand from fine. The two obtained samples were mixed in different proportions to get course, medium and fine sand. We mixed different amounts of Bentonite in different samples of sand separated by their GFN. Clay added (Bentonite in the form of calcium) by weight in the mould weighing 6 kg of DRY sand 400 gm- 6.6 % 450 gm- 7.5 % 500 gm- 8.3 % Moisture was added by weight in the mould weighing 6kg of DRY sand 200 ml of Water = 3.2 % 225 ml of Water = 3.7 % 250 ml of Water = 4.1 % [2].

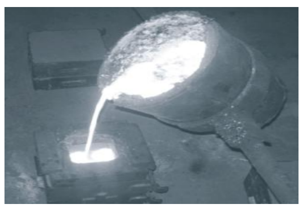
A. Prepration of Mould Cavity and Casting

We placed the pattern on the plane surface, with the taper pointing upwards, covered it with a cope and filled it with sand. Appropriate amount of ramming was done to provide the mould with strength but not so high as to hinder with the permeability of sand. Invert the cope, place the drag above it and adjust the position of sprue pins for the riser and follower [11]. Apply parting powder before filling it with sand and ram it. Separate back the cope and drag and remove the pattern. Cut in the gates before reinverting the drag over the cope.

Molten metal (FG200) is carried in a ladle from the furnace to some type of poring basin. The main purpose of pouring basin is to establish a proper flow system as rapidly as possible [2].

Mould Cavity

Pouring of Metal



Mould after Pouring

Produced Casting

B. Design of Experiment

This experiment was made use Taguchi method (by using MINITAB 15) in order to address the issues and questions being studied. The standard Taguchi -based experimental design used in this study was an L9 (33) orthogonal array [8]. This basic design uses up to three control factors, each with three levels .A total of nine runs must be carried out, using the combination of levels for each control factor (Moisture, Clay, GFN). The control factors and noise factors are independent variables, and the response factor is the dependent variable. The control factors are the basic, controlled parameters used in casting process [14, 15].

Run	*Moisture*	*Clay*	*G.F.N.*
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Orthogonal Array Design of L9(3*3)

C. Observations and Calculations

GFN Calculation

GFN Sand Sample 1

Sieve number	*Retained sample (gm) Fi*	*Retained % Pi*	*Weightage Factor Wi*	*WiPi*	*GFN*
6	0	0	3	0	
12	0	0	5	0	
20	0	0	10	0	
30	0	0	20	0	
40	0.5	1	30	30	
50	6	12	40	480	$\frac{6520}{100} = 65$
70	26	52	50	2600	
100	7.5	15	70	1050	
140	7	14	100	1400	
200	2	4	140	560	
270	1	2	200	400	
Pan	0	0	300	0	
	T = 50	T = 100		T = 6520	

GFN Sand Sample 2

Sieve number	*Retained sample (gm) Fi*	*Retained % Pi*	*Weightage Factor Wi*	*WiPi*	*GFN*
6	0	0	3	0	
12	0	0	5	0	
20	0	0	10	0	
30	0	0	20	0	
40	0.5	1	30	30	
50	6	12	40	480	$\frac{7400}{100} = 74$
70	18	36	50	1800	
100	13	26	70	1820	
140	7.5	15	100	1500	
200	3.0	6	140	870	
270	1.5	3	200	600	
Pan	0.5	1	300	300	
	T = 49	T = 98		T = 7400	

GFN Sand Sample 3

Sieve number	*Retained sample (gm) Fi*	*Retained % Pi*	*Weightage Factor Wi*	*WiPi*	*GFN*
6	0	0	3	0	
12	0	0	5	0	
20	0	0	10	0	
30	1	2	20	40	
40	0.5	1	30	30	
50	7	14	40	560	$\frac{8010}{100} = 80$
70	15	30	50	1500	
100	12.5	30	70	1750	
140	8	16	100	1600	
200	3.5	7	140	980	
270	2.5	5	200	1000	
Pan	1	2	300	600	
	T = 50	T = 100		T = 8010	

Moisture added by weight in the mould weighing 6 kg of dry sand

Moisture added by weight

S. No.	*Weight of Water (gm)*	*% (w.r.t.Sand)*
1.	200	3.2
2.	225	3.7
3.	250	4.1

Clay (bentonite) added in the mould weighing 6 kg of dry sand

Clay (Bentonite) added in the form of calcium

S. No.	*Weight of Bentonite (gm)*	*% (w.r.t.Sand)*
1.	400	6.6
2.	450	7.5
3.	500	8.3

III. RESULTS

Tensile strength

Experiment	*Tensile Strength (MPa) N/mm^2 1st Trial*	*Tensile Strength (MPa) N/mm^2 2nd Trial*
1.	190	188
2.	187	194
3.	196	196
4.	188	192
5.	200	194
6.	202	195
7.	194	190
8.	189	186
9.	192	201

Effect of Moisture, Clay & GFN on the Tensile Strength

Moulds with varying Moisture (3.2, 3.7, 4.1%), Clay content (6.6, 7.5, 8.3%) and Grain Fineness Numbers (65, 74, 80) were prepared [18, 19]. Then Grey Cast Iron FG 200 with Carbon 3.27% and Silicon 2.30% poured into the molds, which got melted in the Electric Induction Furnace .Nine trials were conducted, two runs in each trial. Casted specimens were then machined on turning centre. Then the specimens were tested on Ultimate Tensile Tester (UTM). The Means and S/N rations were got by using the Mini Tab 15 software.

S/N ratio = Amount of Energy for intended Function / Amount of energy wasted

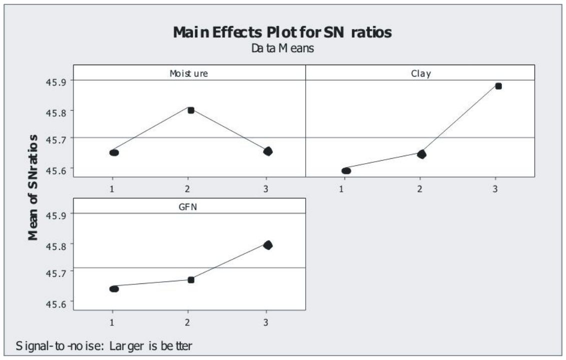
Signal/Noise Ratio

Moisture	*Clay*	*GFN*	*Tensile*	*Tensile*	*S/N*	*Mean*
3.2	6.6	65	190	188	45.52887	189.0
3.2	7.5	74	187	194	45.5935	190.5
3.2	8.3	80	196	196	45.84512	196.0
3.7	6.6	74	188	192	45.57363	190.0
3.7	7.5	80	200	194	45.8863	197.0
3.7	8.3	65	202	195	45.95116	198.5
4.1	6.6	80	194	190	45.66461	192.0
4.1	7.5	65	189	186	45.45919	187.5
4.1	8.3	74	192	201	45.86042	196.5

Signal to Noise Ratio. Larger is better, is the criteria chosen for Signal to Noise ratio [15]. Because in case of Grey Cast Iron casting, as the material is brittle, Ultimate Tensile Strength is the criteria to check the life. So higher the value of Tensile Strength more would be the life. By taking the S/N ratio means for various levels, the values are shown in above said table. For example the value shown against level 1 of moisture is the mean of S/N values corresponding to level one *i.e.* 3.2%. From the table the rank 1st is Clay, rank 2nd is GFN and rank 3rd is Moisture. This certifies that Clay is the prominent factor between the others, considered for the experiments. The Main effects Plot for S/N ratios depicts that the value is maximum when the Moisture is at 2nd levels, Clay at 3rd level and GFN at 3rd levels [10, 11].

Response for S/N Ratios

Level	*Moisture*	*Clay*	*GFN*
1.	45.66	45.59	45.65
2.	45.80	45.65	45.68
3.	45.66	45.89	45.80
Delta	0.15	0.30	0.15
Rank	3	1	2

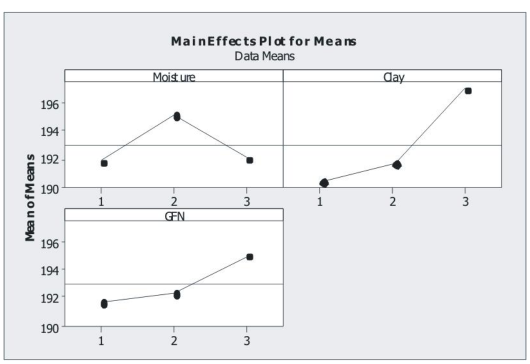


A. Results for Means

By taking the mean of mean values for various levels, the values are shown above. For example the value shown against level 1 of Moisture is the mean of Mean values corresponding to level 1st *i.e.* 3.2% in all the three trials. From the table of means the rank 1st is Clay, rank 2nd is GFN and rank 3rd is Moisture. This certifies that Clay is the prominent factor between the others, considered for the experiments. The Main effects Plot for Means depicts that the value is maximum when the Moisture is at 2nd levels, Clay at 3rd level and GFN at 3rd levels [14, 15].

Response for Means

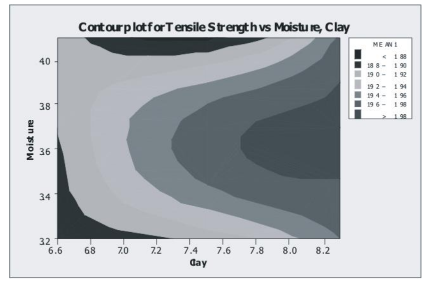
Level	*Moisture*	*Clay*	*GFN*
1	191.8	190.3	191.7
2	195.2	191.7	192.3
3	192.0	197.0	195.0
Delta	3.3	6.7	3.3
Rank	3	1	2



B. Contour Plot for Tensile Strength vs. Moisture, Clay

Contour plots of Tensile Strength vs. Moisture, Clay depicts the Tensile Strength is maximum or more than 198 N/mm^2 is, when the clay content is between 7.8% to 8.3 % (app.) and Moisture is between 3.5 to 3.9 % (app.). The value of Tensile strength is medium (192-194) N/mm^2 is when clay content is between 6.8% to 7.0 % (app.) and Moisture is between 3.2 to 4.1 % (app.). The value of Tensile strength is minimum from the experiments conducted less than 188 N/mm^2 when clay content is between 6.6% to 7.0% (app.) and Moisture is between 3.2 to 3.6 % (app.) or 4.0 to 4.1%. It is clear that, the Tensile strength is maximum, when Clay increases from 7.8% to 8.3 % (app.), the more Bentonite and Moisture is be between increases from 3.5 to 3.9 % (app.) [9].

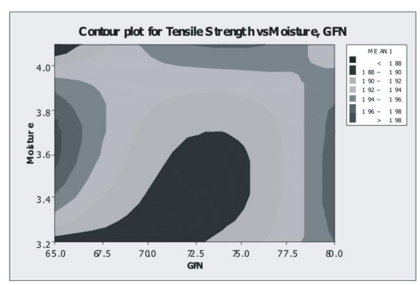
Contour Plot TS vs. Moisture, Clay



C. Contour Plot for Tensile Strength vs. Moisture, GFN

Contour plots of Tensile Strength vs. Moisture, GFN depicts the Tensile Strength is maximum or more than 198 N/mm^2 is, when the GFN content is between 65 to 66 (app.) or 79 to 80 (app.) and Moisture is between 3.6 to 3.7% (app.) or 3.2 to 3.8% (app). The value of Tensile strength is medium (192-194) N/mm^2 is when GFN is between 67.5-77.5 (app.) and Moisture is between 3.3 to 4.1 % (app.) The value of Tensile strength is minimum from the experiments conducted less than 188 N/mm^2 is when GFN content is between 65 to 73 (app.) and Moisture is between 3.2 to 3.6% (app.) or more than 4.1%. So it is clear that, the Tensile Strength is maximum, when GFN is increases from 65 to 66 or 78 to 80, *i.e.* Coarse or fine, and Moisture increases from 3.2 to 3.8% [7, 9].

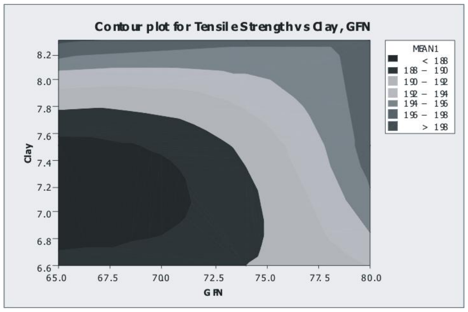
Contour Plot TS vs. Moisture, GFN



D. Contour Plot of Tensile Strength vs. Vlay, GFN

Contour plots of Tensile Strength vs. Clay, GFN depicts the Tensile Strength is maximum or more than 198 N/mm^2 is, when the clay content is between 7.2% to 8.3% (app.) and GFN is between 65 to 80 (app.). The value of Tensile strength is medium (192-194) N/mm^2 is when clay content is between 6.6% to 8.0% (app.) and GFN is between 65 to 80 (app.). The value of Tensile strength is minimum from the experiments conducted, less than 188 N/mm^2 is when clay content is between 6.7% to 7.5% (app.) and GFN is between 65 to 71 (app). So it is clear that, the Tensile Strength is maximum at the GFN value of sand goes from coarse to fine, and the Clay, *i.e.* Bentonite percentage increases from 7.3% onwards [7, 9].

Contour Plot for TS vs. Clay, GFN



IV. CONCLUSION

To study the influence of process parameters like Moisture, Clay content and Grain Fineness Number on FG 200 Grey Cast Iron castings Tensile Strength, Taguchi was implemented which is part of Design of Experiments (DOE). This is a numerically study that identifies the variables in a process or product that are critical parameters or cause significant variation in the process, other parts of DOE are Classical and Shainin. Other Statical Tool is Statical Process Control (SPC) with TQM tool [6, 8, 15].

The Tensile strength was significantly influenced by Clay with means being 190.3, 191.7 and 197.0 respectively for 6.6%, 7.5% and 8.3% respectively. However the Tensile Strength was not significantly influenced by Moisture and Grain Fineness Number. Main Effects Plot for Means depicts that the value is maximum when the Moisture is at 2nd levels, Clay at 3rd level and GFN at 3rd levels. Delta shows the range between chosen levels of a factor, and a factor with maximum value of delta is said to be prominent influencing factor, influencing the Tensile Strength of castings [14].

The S/N ratios response table depicts the means for various values at the defined level for the said factor. Delta depicts the range from the three levels. The factor with the maximum value of delta is said to be prominent factor, influencing the Tensile strength. So the most prominent factor is Clay with 3rd level and the value is 8.3%, the second most prominent factor is GFN at the 3rd level with value 80 and the last factor is Moisture is at 2nd level with value 3.7% [15].

Selected Control parameters Values

Factors	*Moisture*	*Clay*	*GFN*
S/N Ratio	45.80	45.89	45.80
Level	2	3	3
Value	3.7	8.3	80

The effect of Moisture, Clay on the Tensile Strength as depicted in the contour plot that Tensile Strength is maximum, when the clay content is between 7.8% to 8.3% (app.) and Moisture is between 3.5 to 3.9% (app.). The recommended percentage is 6.5% to 9.0% for clay, higher percentage imparts strength to the moulding sand so that after ramming the mould does not lose its shape. However the higher percentage, decreases the permeability of the mould . Moisture recommended percentage is 3.4% to 4.0%. The moisture helps the clay to acquire its bonding action. If the water is in excess, strength is reduced and the mould gets weakened [17, 18].

The effect of Moisture, GFN on the Tensile Strength as depicted in the contour plot that Tensile strength is maximum, when the GFN content is between 65 to 66 (app.) or 79 to 80 (app.) and Moisture is between 3.6 to 3.7% (app.) or 3.2 to 3.8% (app). The GFN recommended is 70 to 80. However more coarse sand enhances the permeability but reduces strength, as the fine sand improves the strength but reduces the permeability. Moisture should be appropriate to maintain the strength [11].

The effect of Clay, GFN on the Tensile Strength as shown in contour plots that Tensile Strength is maximum or more than 198 N/mm^2 is, when the clay content is between 7.2% to 8.3% (app.) and GFN is between 65 to 80 (app.). The strength increases as the sand grains goes coarse to fine, at the maximum value of clay considered for these experiments. Clay which is responsible for bonding sand grain together. However higher percentage reduces the permeability [17, 18].

V. CONFIRMATION RUN

While the relative values for each of these parameters were consistent with the literature review, one can see in S/N control parameters table that the combination of selected control parameters values was not actually carried out in the experiment. Since the Taguchi method selects only a small number of combinations of control variables (rather than all combinations as per the DOE method) [14], this situation was expected. Due to this situation, a conformation was necessary in order to validate the results. The objective of the conformation run was to determine that the selected values would produce better Tensile Strength than those produced in the first part of the experiment. To create this comparison, the researchers compared the Tensile strength mean of products produced using the selected control parameters values to the Tensile Strength mean of products produced in the first described earlier was turned using the set up described earlier. The response variable used in the conformation run was the mean TS, in N/mm^2.

The values below indicate the results of the conformation run, including the mean TS of each specimen [1]. This comparison confirms that the selected control parameter values using the Taguchi parameter design process produced the highest Tensile Strength for the control parameter values in this experiment.

Result of the Conformation Run

Sample#	*Tensile strength* (*N/mm²*)
1.	198
2.	200
3.	196
4.	197

VI. DISCUSSION

In this study ,the analysis of confirmation experiments has shown that Taguchi parameters design can successfully verify the optimum process parameters, clay is 8.3% (3rd level), GFN is 80 (3rd level), and Moisture is 3.7% (2nd level). The material used for these experiments is Grey Cast Iron (FG200). In order to set the process parameters 4 confirmation runs were conducted [15]. Therefore, the optimum Tensile Strength was verified in green sand casting parameters. Taguchi parameter design can provide a systematic procedure that can effectively and efficiently identify the optimum Tensile Strength in the process control of individual casting processes is also allows industry to reduce process or product variability and minimize product defects by using a relatively small number of experimental runs and costs to achieve superior quality products [14]. This project not only demonstrates how to use Taguchi parameter design for optimizing casting performance with minimum cost and time to industrial readers but also shows the Industrial Technology educator a project exercise in any Taguchi-related curricula. Further study could consider more factors in the project to see how the factors would affect Tensile Strength. Also, further study could consider the outcomes of Taguchi parameter design when it is implemented as a part of the management decision making processes. The Clay content has found to be the most significant effect to produce higher value of Tensile Strength (N/mm^2). From the analysis of result in castings using conceptual S/N ratio approach, the following can be concluded from the present study:

- Taguchi is robust design method is suitable to analyze the casting problem.
- Conceptual S/N ratio draws the final result.
- In the Green sand casting process, use of clay 8.3%, GFN 80 and Moisture 3.7% are recommended to obtain better Tensile Strength for the specific test range [1].
- Generally, the use of higher clay content, higher GFN and medium Moisture content leads to better Tensile Strength.

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