A Statistical Approach for Optimizing the Properties of Industrial Waste

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Abstract: Disposal of the waste material is major concern for industries. Red mud is an example of industrial waste having no effective waste recovery. About 1 ton of alumina is produced from 3 tons of bauxite and about 1 ton aluminium is produced from 2 tons of alumina. Depending on the raw material processed, 1-1.5 tons of red mud is generated per ton of alumina produced. The cost of red mud disposal is expensive, accounting for about 2% of the alumina price. Waste foundry sand is another industrial waste produced during No-bake sand system. On an average 1 ton of casting produced by No-bake process generates about 1.5-2 tons of waste foundry sand. In the present work, the waste material of foundry together with red mud is used as an aggregate to develop certain value added product by mechanical and thermal treatments. An attempt has been made in this work to use both these products together with a view to study their characteristics in the as-received conditions followed by experimentation based on the statistical principle governing Taguchi and ANOVA techniques. This work assesses the behavior of a predetermined shaped compact while sintering with optimization of the process parameters. The study revealed that the temperature and time of sintering have a significant effect on the compressive strength, water absorption and apparent porosity .Sintered product has a pH of 8.17 which is very close to the neutral value.

***Index Terms* - Red mud, Foundry waste, Taguchi and ANOVA**

I. INTRODUCTION

Aluminium is a light weight, high strength and recyclable structural metal. The commercially mined aluminium ore is bauxite, as it has the highest content of alumina with minerals like silica, iron oxide, and other impurities in minor or trace amount. The primary aluminium production process consists of three stages starting with mining of bauxite, followed by refining of bauxite to alumina by the Bayer process and finally smelting of alumina to aluminium. In the Bayer process, the insoluble product generated after bauxite digestion with sodium hydroxide at elevated temperature and pressure to produce alumina is known as red mud or bauxite residue. The waste product derives its colour and name from its iron oxide content **[1]**. As the bauxite has been subjected to sodium hydroxide treatment, the red mud is highly alkaline with a pH in the range of 10.5-12.5. Approximately 35-40% of the processed bauxite ore goes into the waste as red mud**.** It is estimated that annually 70 million tons of red mud is produced all over the world, with 0.7 million tons in Greece, 2 million tons in India, 30 million tons in Australia and nearly 30 million tons in China **[2]**.

Red mud is an alkaline waste material of bauxite ore processing for alumina extraction. The Bayer process is commonly used for digestion of bauxite ore in a solution of concentrated NaOH at temperatures between 150−230˚C under pressure **[3].** During the digestion process, aluminum reacts with NaOH to form soluble sodium aluminate leaving red mud slurry. Red mud slurry is highly alkaline having pH > 13, due to presence of NaOH and Na_2CO_3 (1−6%), these are expressed in terms of Na_2O **[4, 5].** The main constituents of red mud are: Fe_2O_3 (30−60%), Al_2O_3 (10−20%), SiO_2 (3−50%), Na_2O (2−10%), CaO (2−8%), TiO_2 (trace−10%) **[6].**The main problems of storing red mud slurry are costly maintenance of large red mud pond areas, risk of caustic for all living organisms, leakage of alkaline compounds into the ground water, overflow of materials and dusting of dry surfaces interfere with nearby rehabilitation on plant life**.** Table 1 provides a list of typical composition of red mud obtained from NALCO, Damanjodi, Odisha, India.

Table 1: Chemical composition of red mud

Composition	Fe_2O_3	Al_2O_3	SiO_2	Na_2O	CaO	TiO_2
Weight %	52.39	16.05	12.38	4	1.8	2.28

1.1 Physical Properties of Red Mud

- Fineness of red mud varies in between 1000-3000 cm^2/gm.

- The specific surface area of red mud is around 10 m^2/g.
- Its pH is varies in between 10.5 to 12.5 hence alkaline in nature.
- Specific gravity of red mud is found to be 2.64 & the specific weight 3.4 g/cc.

Waste foundry sand is another industrial waste collected from Shree Hans Alloys, Dholka, India shown in Table 2 is produced during No-bake sand system. The No-bake sand system is basically an Air-set system which consists of polymeric substances for developing bonding of the sand grains during moulding and core making. These substances are volatile in nature and escape from the moulding sand as a casting is poured. When the formulated sand is used several times in moulding and core making, it not only loses its properties but also degrades itself due to fragmentation. This sand cannot be recycled further and it becomes a waste material. On an average, 1 ton of casting produced by No-bake process can generate about 1.5-2 tons of waste foundry sand. This solid waste material is available in powder form in a foundry unit which practices Air-set system. This powder adds to pollution of air, water and soil. Disposal of this waste material is a cause of concern for foundry industry. In the present work, an attempt has been made to use this waste material of foundry together with another industrial waste such as red mud as an aggregate to develop certain value added product by mechanical and thermal treatments. Initially, the two waste materials red mud and waste foundry sand have been characterized respectively for pH, grain fineness and chemical composition. Experimental work based on the Taguchi approach is carried out with a view to optimizing the parameters.

Table 2: Chemical composition of foundry waste

Composition	Fe_2O_3	Al_2O_3	SiO_2	Na_2O	CaO	TiO_2
Weight %	3.99	17.55	61.46	3.2	1.6	1.5

1.2 Taguchi Method

Taguchi method is a statistical method developed by Taguchi and Konishi. Initially it was developed for improving the quality of goods manufactured (manufacturing process development), later its application was expanded to many other fields in engineering [**7**]. Professional statisticians have acknowledged Taguchi's efforts especially in the development of designs for studying variation. Taguchi suggested a specially designed method called the use of orthogonal array to study the entire parameter space with lesser number of experiments to be conducted. Taguchi thus, recommends the use of the loss function to measure the performance characteristics that are deviating from the desired target value. Taguchi specified three situations:

- Larger the better (for example, agricultural yield).
- Smaller the better (for example, carbon dioxide emissions).
- On-target, minimum-variation (for example, a mating part in an assembly).

II. EXPERIMENTAL WORK

The value of the loss function is further transformed into signal-to-noise (S/N) ratio. Usually, there are three categories of the performance characteristics to analyze the S/N ratio. They are nominal-the-best, larger-the-better, and smaller-the-better.
Signal-to-noise ratio (abbreviated SNR) is a measure used in science and engineering that compares the level of a desired signal to the level of background. It is defined as the ratio of signal power to the noise power often expressed in decibels. A ratio higher than 1:1 (greater than 0 dB) indicates more signal than noise. SNR is as the reciprocal of the coefficient of variation, that is the ratio of mean to standard deviation of a signal or measurement [**8**].

$$SNR = \mu / \sigma \qquad (1)$$

Where μ is the signal mean or expected value and σ is the standard deviation of the noise. Success in achieving the desired results involves a careful selection of process parameters and bifurcating them into control and noise factors. Selection of control factors must be made such that it nullifies the effect of noise factors [**9**]. Taguchi Method involves identification of proper control factors to obtain the optimum results of the process as shown in Table 3. Orthogonal Arrays (OA) are used to conduct a set of experiments as shown in Table 4. Results of these experiments are used to analyze the data and predict the quality of components produced.

Table 3: Selected factors and their levels

Factor	Levels		
	1	2	3
Red Mud (%)	70	75	80
Temperature (°C)	1100	1175	1250
Time (Hours)	3	3.5	4

Table 4: Orthogonal array (OA) L9

Experiment No.	**Control factors**		
	1	**2**	**3**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

The various methods have been used for neutralization of red mud are by adding liquid carbon dioxide, saline brines or seawater, Ca and Mg-rich brines, soluble Ca and Mg salts, acidic water from mine tailing, fly ash, and carbon dioxide gas **[10].** The neutralized red mud is utilized for environmental benefits. These processes are costly and hardly any industry takes the steps to neutralize the red mud. It was recorded from Chemline digital pH meter (CL- 110), that the pH of red mud procured from site is alkaline with pH value ranges from 10.4 to 11.5. It is necessary to reduce the alkalinity of red mud pH=10.7 (50 gm of red mud was stirred with 100 mL of distilled water for 30 min) for further use **[11]**. Neutralization was achieved in two ways:

2.1 Neutralization

2. 1 .1. Acid Neutralization: pH = 6.91* - R.M + RO water + HCl {1:6:3}
2. 1. 2. Sea Water Neutralization: pH= 7.97*- R.M + Sea water {1:6}
* Both stirring @ 600 rpm for 15 min.

2.2. Trials with as-received red mud

In order to make proper utilization of red mud without adopting the costly process of neutralization, conventional route was preferred namely preparation of wet mix with a foundry waste, binder clay/slurry of suitable consistency with varying compositions. Red mud is a material which does not have any bonding property in the wet condition. In order to develop the bonding property in the green state one type of foundry waste (obtained as a waste from reclaimed sand used in No-bake sand system) having high silica content & some bonding characteristics was mixed with red mud. Figure 1 shows the SEM image of untreated red mud samples.

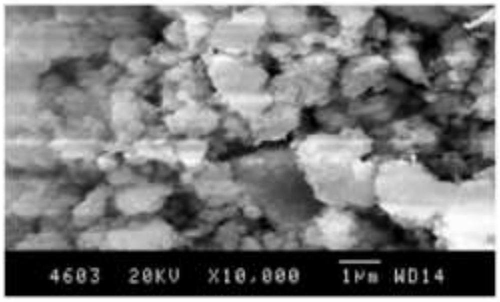


Fig. 1: SEM image of untreated red mud

Fig. 2: Solid cylindrical compact

Proper dry mix was done followed by wet mixing with addition of water to get a mineral mixture of red mud & foundry waste.

2.3 Steps involved for making solid cylindrical compacts

- Making cylindrical pallets of uniform size.
- Drying in oven for 2 hours at 110°C shown in Fig. 2.
- Heating at 1100°C for 3 hours.
- Determination of compressive strength: The maximum compressive stress under gradual applied load on a given solid material will sustain without fracture.
- Determining water absorption (W.A): The amount of weight gain (%) experienced in a material after immersion in water for a specific duration of time under controlled environment.

$$\text{W.A (\%)} = \frac{(\text{soaked wt} - \text{Dry wt})}{\text{Dry wt}} * 100 \tag{2}$$

- Determining apparent porosity (A.P): It refers to the amount of void within a volume of a porous solid.

$$\text{A.P (\%)} = \frac{(\text{soaked wt} - \text{Dry wt})}{\text{Soaked wt} - \text{Dry wt}} * 100 \tag{3}$$

2.4 Conducting the Matrix Experiment

In accordance with the above OA mentioned in Table 4, experiments were conducted with their factors and their levels as mentioned in Table 3. The experimental layout with the selected values of the factors is shown in Table 5.

Table 5: OA with control factors

Experiment No.	Control factors		
	Red mud (%)	Temperature (°C)	Time (hours)
1	70	1100	3.00
2	70	1175	3.50
3	70	1250	4.00
4	75	1100	4.00
5	75	1175	3.00
6	75	1250	3.50
7	80	1100	3.50
8	80	1175	4.00
9	80	1250	3.00

III. RESULTS and DISCUSSION

3.1 Compressive strength

The Table 6 shows the measured values of compressive strength obtained from different experiments.

Table 6: Measured compressive strength

Experiment No.	Measured values of compressive strength (kg/sq.cm)			
	1	**2**	**3**	**Mean**
1	428.70	486.50	512.30	475.83
2	903.80	984.30	667.70	851.93
3	377.40	302.30	356.70	345.47
4	462.10	272.40	449.20	394.57
5	810.80	967.80	776.80	851.80
6	479.30	459.20	426.30	454.93
7	438.40	508.20	412.80	453.13
8	1013.70	1027.20	1044.40	1028.43
9	349.10	571.20	757.20	559.17

For calculating the values of Δ1, Δ2, Δ3 etc & Cr1, Cr2, Cr3, the measured values of compressive strength in Table 6 are considered, where Δk is the S/N ratio corresponding to experiment k. Similarly it has done for Porosity and apparent density.

Table 7: S/N ratios for compressive strength (Δk)

Experiment No.	S/N ratio (dB_1)
1	20.92
2	14.28
3	1.093
4	11.42
5	18.44
6	24.61
7	19.25
8	36.50
9	8.74

The S/N ratio for the individual control factors are shown in table 7 and calculated as given below:

Cr1 = (Δ 1+Δ 2+Δ 3), Cr2 = (Δ 4+Δ 5+Δ 6) & Cr3 = (Δ 7+ Δ8+Δ 9) [For control factor of red mud]

Ct1 = (Δ 1+Δ 4+ Δ7), Ct2 = (Δ 2+Δ 5+Δ 8) & Ct3 = (Δ3+Δ 6+ Δ9) [For control factor of Temperature]

Ci1 = (Δ 1+Δ 5+Δ 9), Ci2 = (Δ 2+Δ 6+ Δ7) & Ci3 = (Δ 3+ Δ4+Δ 8) [For control factor of Time of sintering]

Average S/N ratio corresponding to red mud at level 1 = Cr1/3

Average S/N ratio corresponding to red mud at level 2 = Cr2/3

Average S/N ratio corresponding to red mud at level 3 = Cr3 /3, j is the corresponding level each factor. Similarly, Ctj and Cij are calculated for temperature and time.

The average of the signal to noise ratios is shown in Table 8. Similarly S/N ratios can be calculated for other factors.

Table 8: Average S/N ratio for each factor

Level	Red mud		Temperature		Time	
	Sum(C_{rj})	Avg S/N ratio	Sum(C_{tj})	Avg S/N ratio	Sum(C_{ij})	Avg S/N ratio
1	36.3	12.1	51.6	17.2	48.12	16.04
2	54.48	18.16	69.24	23.08	58.14	19.38
3	64.5	21.5	34.44	11.48	49.02	16.34

For calculating the compressive strength the objective function, "Nominal-is-best" type was used as shown below.
S/N Ratio for this function:

$$\eta = 10 \log\left(\frac{y^{-2}}{s^2}\right) \quad (4)$$

Where y = mean responses for the given factor.
s = standard deviation of the responses for the given factor level combination.

The factor levels corresponding to the highest S/N ratio were chosen to optimize the condition. From these linear graphs it is clear that the optimum values of the factors and their levels are as shown in Fig. 3.

Parameter	Optimum Value
Red Mud (%)	80
Temperature (^{0}C)	1175
Time (hrs)	3.5

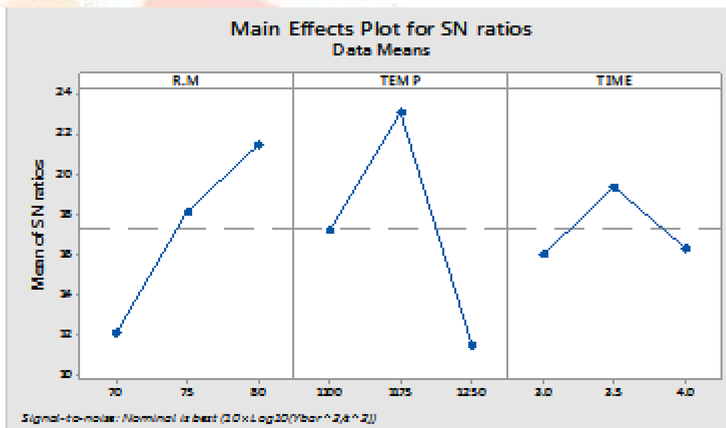


Fig. 3: Optimum values of factors and S/N ratio for compressive strength

3.2 Apparent Porosity

The water absorption and apparent porosity of the samples were calculated and results are shown in Table 9.

Table 9: Calculated value of absorbed water and apparent porosity

Sample No.	Dry wt.(gm)	Soaked wt (gm)	Suspended wt(gm)	Water Absorption (%)	Apparent Porosity (%)
1	6.01	6.64	4.02	10.48	24.05
2	6.64	7.34	4.51	10.54	24.73
3	6.52	7.27	4.37	11.5	25.86
Avg. 1	6.39	7.08	4.3	10.84	24.88
1	6.18	6.2	3.76	0.32	0.82
2	6.09	6.32	3.84	3.78	9.27
3	5.87	5.98	3.62	1.87	4.66
Avg. 2	6.05	6.17	3.74	1.99	4.92

1	5.79	5.87	3.06	1.38	2.85
2	5.92	6.14	3.63	3.72	8.76
3	5.88	5.97	3.42	1.53	3.53
Avg. 3	5.86	6.01	3.35	2.55	5.81
1	6.58	7.1	4.38	7.9	19.12
2	5.95	6.54	3.91	9.92	22.43
3	5.98	6.66	3.85	11.37	24.2
Avg. 4	6.17	20.3	12.14	29.19	65.75
1	5.6	5.73	3.53	2.32	5.91
2	5.57	5.69	3.51	2.15	5.5
3	5.81	5.93	3.66	2.07	5.29
Avg. 5	5.66	5.78	3.57	2.18	5.57
1	6.02	6.05	3.18	0.5	1.05
2	5.6	5.63	2.92	0.54	1.11
3	5.57	5.62	3.05	0.9	1.95
Avg. 6	5.73	5.77	3.05	0.64	1.37
1	6.25	6.76	6.74	8.16	20.48
2	6.13	6.74	4.25	9.95	24.5
3	6.12	6.67	4.24	8.99	22.63
Avg.7	6.17	6.72	4.25	9.03	22.54
1	6.74	6.83	4.19	1.34	3.41
2	6.75	6.85	4.21	1.48	3.79
3	6.12	6.23	3.85	1.8	4.62
Avg. 8	6.54	6.64	4.08	1.54	3.94
1	6.83	6.95	3.84	1.76	3.86
2	6.84	6.92	3.85	1.17	2.61
3	6.59	6.7	3.65	1.67	3.61
Avg. 9	6.75	6.86	3.78	1.53	3.36

For the objective function (apparent porosity) Smaller-the-better type of control function was used in calculating the S/N ratio. The S/N ratios of all the experiments were calculated and tabulated in Table 10.

Table 10: S/N ratios for apparent porosity

Experiment No.	S/N ratio (dB_2)
1	-27.92
2	-15.58
3	-14.52
4	-26.86
5	-14.92
6	-3.084

7	-27.08
8	-11.98
9	-10.63

The S/N ratio for the individual control factors are calculated as given below:

Pr1 = (Δ 1+ Δ2+Δ 3), Pr2 = (Δ 4+Δ 5+Δ 6) & Pr3 = (Δ 7+Δ 8+Δ 9) [For control factor of red mud]

Pt1 = (Δ 1+ Δ4+ Δ7), Pt2 = (Δ 2+ Δ5+ Δ8) & Pt3 = (Δ 3+ Δ6+Δ 9) [For control factor of temperature]

Pi1 = (Δ 1+Δ 5+ Δ9), Pi2 = (Δ 2+ Δ6+Δ 7) & Pi3 = (Δ 3+ Δ4+Δ 8) [For control factor of time of sintering]
Average S/N ratio corresponding to Red Mud at level 1 = Pr1/3

Average S/N ratio corresponding to Red Mud at level 2 = Pr2/3

Average S/N ratio corresponding to Red Mud at level 3 = Pr3 /3, j is the corresponding level each factor. Similarly, Ptj and Pij are calculated for temperature and time.

Table 11: Average S/N ratio for each factor

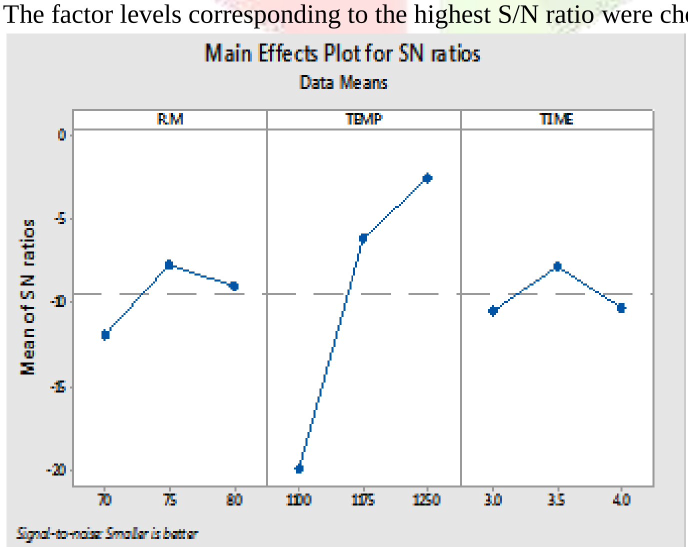
Level	Red mud		Temperature		Time	
	Sum(P_{rj})	Avg S/N ratio	Sum(P_{tj})	Avg S/N ratio	Sum(P_{ij})	Avg S/N ratio
1	-58.02	-19.34	-81.86	-27.29	-53.47	-17.82
2	-44.86	-14.95	42.48	-14.16	-45.74	-15.25
3	-49.69	-16.56	28.23	-9.41	53.36	-17.78

For calculating the apparent porosity, the objective function "Smaller-the-better" type was used as shown.

$$\text{S/N Ratio for this function: } \eta = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \qquad (5)$$

Where y = responses for the given factor level combination.
n = number of responses in the factor level combination.

The factor levels corresponding to the highest S/N ratio were chosen to optimize the condition.



Parameter	Optimum Value
Red Mud (%)	75
Temperature (⁰ C)	1250
Time (hrs)	3.5

Fig. 4: S/N ratio for apparent porosity & optimum values of factors

The factor levels corresponding to the highest S/N ratio were chosen to optimize the condition. From these linear graphs it is clear that the optimum values of the factors and their levels are as given in Fig. 4.

3.3 Water Absorption

The water absorption of the samples was calculated and results are shown in Table 9.

For the objective function (water absorption), Smaller-the-better type of control function was used in calculating the S/N ratio. The S/N ratios of all the experiments were calculated and tabulated in Table 13.

Table 12: S/N ratios for water absorption

Experiment No.	S/N ratio (dB_3)
1	-20.71
2	-7.75
3	-7.193
4	-19.85
5	-6.78
6	3.50
7	-19.14
8	-3.81
9	-3.83

The S/N ratio for the individual control factors are shown in table 12 calculated as given below:

Wr1 = (Δ 1+Δ 2+Δ 3), Wr2 = (Δ 4+Δ 5+Δ 6) & Wr3 = (Δ7+ Δ8+Δ 9) [For control factor of red mud]

Wt1 = (Δ 1+Δ 4+Δ 7), Wt2 = (Δ 2+Δ 5+Δ 8) & Wt3 = (Δ3+Δ 6+Δ 9) [For control factor of temperature]

Wi1 = (Δ 1+ Δ5+Δ 9), Wi2 = (Δ2+ Δ6+ Δ7) & Wi3 = (Δ 3+ Δ4+ Δ8) [For control factor of time of sintering]

Average S/N ratio corresponding to red mud at level 1 = Wr1/3

Average S/N ratio corresponding to red mud at level 2 = Wr2/3

Average S/N ratio corresponding to red mud at level 3 = Wr3 /3, j is the corresponding level each factor. Similarly, Wtj and Wij are calculated for temperature and time.

The average of the signal to noise ratios is shown in Table 13. Similarly S/N ratios can be calculated for other factors.

Table 13: Average S/N ratio for each factor

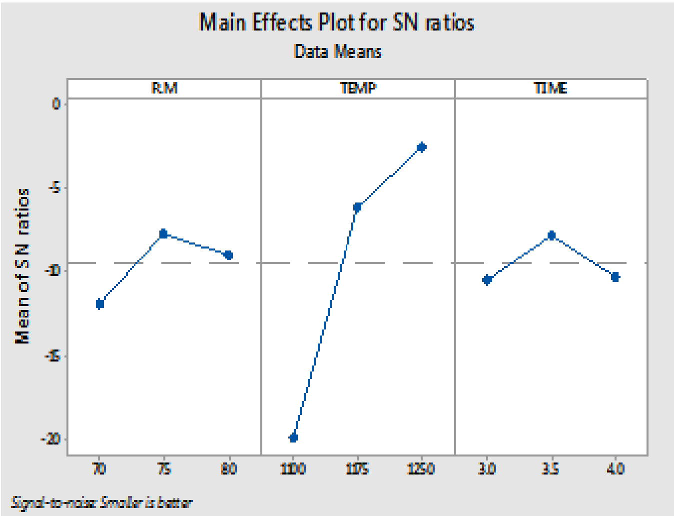
Level	Red Mud		Temperature		Time	
	Sum(W_{rj})	Avg S/N ratio	Sum(W_{tj})	Avg S/N ratio	Sum(W_{ij})	Avg S/N ratio
1	-35.655	-11.885	-59.709	-19.903	-31.320	-10.440
2	-23.139	-7.713	-18.342	-6.114	-23.400	-7.800
3	-26.778	-8.926	-7.524	-2.508	-30.855	-10.285

For calculating the water absorption the objective function, "Smaller-the-better" type was used as shown.

S/N Ratio for this function: $\eta = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$ (6)

Where y = responses for the given factor level combination.

n = number of responses in the factor level combination.



Parameter	Optimum Value
Red Mud (%)	75
Temperature (^{0}C)	1250
Time (hrs)	3.5

Fig. 5: S/N ratio for water absorption & optimum values of factors

The factor levels corresponding to the highest S/N ratio were chosen to optimize the condition. From these linear graphs it is clear that the optimum values of the factors and their levels are as given in Fig. 5.

3.4 Confirmation Experiment-I

The following Table 14 shows confirmation experiment conducted using 80% red mud, 1175°C, 3.5 hrs. Compressive strength of samples was checked. It can be seen that the results are consistent.

Table 14: Confirmation experiment 1

Sample No.	Compressive strength(kg/sq.cm)
1	1052.40
2	1033.20
3	1024.60
4	1027.40
Mean	**1034.40**

3.5 Confirmation Experiment-II

Table 15 shows confirmation experiment conducted using 75% red mud, 1250°C, 3.5 hrs. Water absorption and apparent porosity of samples was checked. It can be seen that the results are consistent.

Table 15: Confirmation Experiment- II

Sample No.	Dry wt (gm)	Soaked wt (gm)	Suspended wt (gm)	W.A. (%)	A.P. (%)
1	6.55	6.59	3.57	0.61	1.32
2	6.31	6.35	3.49	0.64	1.40
3	6.33	6.37	3.46	0.63	1.37
4	6.49	6.53	3.54	0.62	1.34
Mean	**6.42**	**6.46**	**3.52**	**0.62**	**1.36**

IV. ANOVA and its Significance

Analysis of variance (ANOVA) is used to evaluate the response magnitude in (%) of each parameter in the orthogonal experiment. It is used to identify and quantify the sources of different trial results from different trial runs (i.e. different parameters). The basic property of ANOVA is that the total sums of the squares (total variation) is equal to the sum of the SS (sums of the squares of the deviations) of all the condition parameters and the error components, i.e. adding the variations of each factors,

$$SS_T = SS_R + SS_T + SS_I + SS_e \quad (7)$$

$$SS_T = \sum_i^n y_i^2 - \frac{G^2}{n} \quad (8)$$

Where, G = is the sum of the resulting data of all trial runs; and n is the total number of the trial runs

$$SS_k = \sum_{j=1}^{t} \left(\frac{Sy^2{}_j}{t}\right) - \frac{G^2}{n} \quad (9)$$

Where k represents one of the tested parameters; j is level number of this parameter; Sy_j is sum of all trial results involving this parameter k at level j; n is the total number of trial runs. Table 16 shows the results of the ANOVA for compressive strength, apparent porosity and water absorption respectively.

It is seen from Table 16 that for the compressive strength (C.S.), the contribution of firing temperature (89.92%) is more significant than red mud content which is (5.91%). These factors are more significant than the holding time (3.43%). It is clear that the effect of noise factor (0.72%) on compressive strength is very low as compared to the control factors.

It is also seen from Table 16 that for the apparent porosity (A.P.), the contribution of firing temperature (65.42%) is more significant than holding time which is (12.70%). These factors are more significant than the red mud content (11.42%). It is clear that the effect of noise factor (10.45%) on apparent porosity is less compared to the control factors. For the water absorption (W.A.), the contribution of firing temperature (63.03%) is more significant than holding time which is (13.50%). These factors are more significant than the red mud content (12.24%). It is clear that the effect of noise factor (11.20%) on apparent porosity is less compared to the control factors.

Table 16: Sum of all squares of all deviations for compressive strength, apparent porosity and water absorption

Parameter	Compressive strength			Apparent porosity			Water absorption		
	DOF	SS	SS%	DOF	SS	SS%	DOF	SS	SS%
Red Mud, R	2	28395	5.92	2	393.90	11.42	2	83.04	12.25
Temperature, T	2	431631	89.92	2	2256.20	65.42	2	427.36	63.04
Time, I	2	16479	3.43	2	438.00	12.70	2	91.57	13.50
Noise, e	2	3494	0.72	2	360.60	10.45	2	75.97	11.20
Total	8	480000	100.00	8	3448.70	100.00	8	677.94	100.00

V. CONCLUSION

The study revealed that the sintered product obtained from the compacts of red mud and waste foundry sand aggregate had a pH of 8.17 which is very close to neutral value. For compressive strength with the objective function, "Nominal- is-best" it was found that 80% red mud with 1175°C sintering temperature for 3.5 hrs sintering time gave highest values of 1034.40 kg/cm2. For water absorption and apparent porosity, with the objective function, "Smaller- the-better", and the optimized condition was 75% red mud with 1250°C sintering temperature for 3.5 hrs sintering time gave lowest value for water absorption of .62 and for apparent porosity was 1.36. With the study of all controlling factors, for the compressive strength, it is found that the sintering temperature (89.92%) is more significant than red mud content (5.91%); sintering time (3.43%) and noise factor (0.72%), for water absorption and apparent porosity, factors affecting contribution are listed in ascending order as sintering temperature > sintering time > red mud (%) > noise factor. Sintering temperature and sintering time are the two independent variables which have a significant effects on the properties compared to composition variation, on the mechanical properties.

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