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A Study on Role of Rock Dust in Resin Hardened Moulding Sand

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***Abstract*— In a casting process, the quality of the cast part depends on various physical and chemical properties of the sand mould like compressibility, shear strength, mould hardness, grain fineness number, setting/curing time, amount of resin and hardener used percentage of moisture content etc. Usually, the physical properties of the sand mould are completely dependent on the chemical properties of the moulding sand. This paper reports the analysis and investigation on the mechanical properties of the moulding sand when powdered granite is added as an additive. The mould hardness of the moulding sand specimen was analyzed and observed with the additive as powdered granite using the Taguchi (L9 orthogonal array) technique. The results of tensile strength, compressibility, permeability were optimum to the AFS (American Foundry Society) standards of the resin hardened sand mould. For the experiments, Phenolic resin and Hexamine were used as resin and hardener respectively. After certain observations in the tensile strength, compressibility, permeability and calculation of the percentage distribution through ANNOVA, it was observed that the amount of resin and powdered granite used were the significant factors for the mould hardness.**

Keywords*— *Compressibility, Permeability, Grain fineness number, setting/curing, Taguchi technique

I. INTRODUCTION

Sand Casting is one of the oldest and least expensive methods of manufacturing. The process of casting is usually practiced for creating products of metal with an efficient and economical manner. Sand casting is used to produce products with complex shapes and dimensional features, and is widely used for mass production. In this process, a pattern made out of wood, or metal is used to create an imprint for the mould cavity. The design of the product usually resembles that of the pattern but however not necessarily the same. The metal can be poured through manual pouring or auto pouring in sand casting. However, utilization of the auto pouring process gave an edge over the rate of production and decreased the rate of rejection [1]. Sand casting is used for producing small and medium sized parts to provide good properties in the final product. For achieving a better cast quality, it is imperative to understand the process knowledge on a particular technique or method of manufacturing [2]. Decomposed granite or powdered granite is usually obtained as by-products from quarry industries and granite polishing. Decomposed granite is widely known for its use as pozzolanic materials. The granules of the decomposed granite help in the reduction of micro voids present in the concrete mixture [3]. Addition of dried decomposed granite to chemical composites also proves to have a wide beneficial range of mechanical properties. Decomposed granite with the addition of certain amount of chemical coupling agent can lower the water absorption rate of the particular composite to which the mixture was added to [4]. Decomposed granite or granite powder is now used as a substitute for river sand in the preparation of concrete mixture, as it could increase its chemical resistance [5,6].

Fine and granular substances with an appreciable chemical resistance could be used to provide various beneficial chemical, thermal and mechanical properties [3,7]. However, not all finely granular particles provide a positive impact on a specimen's mechanical properties. Concrete containing fine bottom ash and slag gave a negative mechanical property by decreasing the specimen's compressive strength when added as fine aggregate [8]. Taguchi method has been reported to reduce the process variation through a robust DoE (Design of Experiments). This method is widely used for improving the design at a very low expense. Taguchi method achieves the robust products that are immune to all noise factors. It involves the construction of a product with a limited variation, with a close proximity towards the target factor [9]. Analysis through Taguchi approach provided, that the mould preheat temperature contributes as the most important factor for surface finish in sand casting and the mould hardness increases with the setting time and nature of the resin being used [9,10]. Typically, Taguchi's design with the L_9 orthogonal array is known to optimize and analyze the process parameters of a particular problem statement [11-13].

Optimal parametric compositions of green sand properties were obtained through Taguchi's approach using L_{18} orthogonal array [12]. Thus, this approach provides with a basic, systematic and efficient way for the optimization of

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various process parameters [14]. In experiments and analysis involving green sand casting, the method of trial and error is used to achieve the optimal process parameters. However, this method can highly exploit the usage of raw materials, time and cost [15]. Thus, keeping in mind the various factors involved in sand casting, the Taguchi's approach is followed to avoid and reduce defects due to parameter variation [16-18]. Resins are most widely used in foundries, to achieve the chemical bonding of the soil that needs to be moulded. However, certain resin, can also prove to create defects in the mould due to certain chemical composition in them [19]. Phenolic resins can be used on a wide range of materials or substances like wood, glass, fiber etc.

It is globally used to produce high performance materials by industries around the world. These resins are known to improve the mechanical and thermal properties of automotive and aerospace components as well [20]. Chemical hardeners are used in mould making to achieve the self-hardening property of the mould. Hexamine is one such hardener with an appreciable solubility in water. The compound is obtained when the reaction of formaldehyde and ammonia occurs in either gaseous or liquid phase [21]. Maximum mould hardness and its consecutive mechanical properties can be achieved through the integration of the process parameters provided by the use of Taguchi's approach and the advantages of the decomposed granite.

II. EXPERIMENTATION

Sand is the most important component used here in the system. Fresh silica sand with an optimum grain fineness number of about 55-60 is selected. Sand with the grain fineness number above the particular range wouldn't be able to attain the dimensional accuracy and the surface roughness of the specimen. Similarly, sand with a grain fineness number below the range would compromise the permeability criteria of the specimen and would lead to various blowhole and pin-hole defects. The sand was placed under sunlight to remove traces of moisture present in the sand to avoid defects in the specimen. Cashew nut shell oil Phenolic resin and Hexamine are used as resin and hardener respectively.

As per the industrial standards, the amount of resin to be added is from 1.8% to 2.2% weight of sand and amount of hardener is 20 to 22% weight of the resin. The composition and notation of the materials from Table 1 are quantified by percentage weight of sand, percentage weight of resin and time in minutes.
The measured quantity of sand is mixed for two minutes with metered quantity of resin and hardener with a standard sand muller. About 1 kg of silica sand is weighed and added in the sand muller along with the measured quantity of resin, hardener and decomposed granite. The quantity and proportion of the resin, hardener and decomposed granite varies for each group of the total analysis.

TABLE I. COMPOSITION AND NOTATION

S. No	Composition	Notations
1	Decomposed Granite (% wt of sand)	A
2	Resin (% wt of sand)	B
3	Hardener (% wt of resin)	C
4	Curing Time (in minutes)	D

TABLE II. PARAMETRIC VALUE

Levels	1	2	3
Resin	1.8	2	2.2
Hardener	20	22.5	25
Curing time	60	180	300
Decomposed Granite	10	20	30

TABLE III. STANDARD L9 ORTHOGONAL ARRAY AND VARIABLE SETTING

Test Number	Granite Powder (A)	Resin (B)	Hardener (C)	Setting Time (D)
1	1(10%)	1(1.8%)	1(20%)	1(60)
2	1(10%)	2(2%)	2(22.5%)	2(180)
3	1(10%)	3(2.2%)	3(25%)	3(300)
4	2(20%)	1(1.8%)	2(22.5%)	3(300)
5	2(20%)	2(2%)	3(25%)	1(60)
6	2(20%)	3(2.2%)	1(20%)	2(180)
7	3(30%)	1(1.8%)	3(25%)	2(180)
8	3(30%)	2(2%)	1(20%)	3(300)
9	3(30%)	3(2.2%)	2(22.5%)	1(60)

The variation is done on the basis of experimental design matrix as shown in Table III. To check the properties of the mould sand mixed with the decomposed granite, an analysis of their respective compressive strength, tensile strength and permeability. For testing these properties of the mould sand the specimens were made to be compatible for testing the respective properties.

'Test number 1' represents the 'level 1' composition of the specimen with 10wt% of decomposed granite, 1.8wt% of resin, 20wt% of hardener and a setting time of 60 minutes. 'Test number 2' represents the 'level 1' composition of decomposed granite of 10wt%, 'level 2' composition of resin with 2wt%, 'level 2' composition of hardener with 22.5wt% and 'level 2' setting time of 180 minutes. Similarly, the test runs were made with varying levels of composition of decomposed granite, resin, hardener, and setting time. After multiple attempts of specimen preparation according to the composition of Table II, an optimum composition was drawn by varying the amount of weight percentage of the resin used in each specimen.

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TABLE IV. OPTIMIZED PARAMETRIC VALUE

Levels	1	2	3
Resin	5.5	6	6.5
Hardener	20	22.5	25
Curing time	60	180	300
Granite Powder	10	20	30

TABLE V. OPTIMIZED STANDARD L9 ORTHOGONAL ARRAY AND VARIABLE SETTING

Test Number	Granite Powder (A)	Resin (B)	Hardener (C)	Setting Time mins (D)
1	1(10%)	1(5.5%)	1(20%)	1(60)
2	1(10%)	2(6%)	2(22.5%)	2(180)
3	1(10%)	3(6.5%)	3(25%)	3(300)
4	2(20%)	1(5.5%)	2(22.5%)	3(300)
5	2(20%)	2(6%)	3(25%)	1(60)
6	2(20%)	3(6.5%)	1(20%)	2(180)
7	3(30%)	1(5.5%)	3(25%)	2(180)
8	3(30%)	2(6%)	1(20%)	3(300)
9	3(30%)	3(6.5%)	2(22.5%)	1(60)

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As observed from Table IV, the optimized resin amount by weight percentage was utilized to prepare the appropriate specimen. The resin amount was modified to 5.5 wt%, 6wt%, 6.5wt% to levels 1,2 and 3 respectively. According to the optimization performed as per Table 4, an optimized standard L9 orthogonal array and variable settings were drawn to process the specimens according to their respective proportions and setting time (Table V). Table 5 represents the variation of composition on the basis of levels as discussed with the help of Table IV. According to the variation of composition observed from the table above (Table V), samples consisting of 6 cylindrical ASTM standard specimens and 3 dog bone specimens were produced to perform the respective analysis for each run.

III. RESULT AND DISCUSSION

As per the optimized parameters of the standard L9 orthogonal array and variable settings from Table-V, a series of specimen ranging with different composition of decomposed granite, resin, and hardener and setting time were produced through standard ASTM methodology.

A. *Tensile Strength*

The tensile strength for all nine different test runs were conducted through specimens with standard ASTM dimensions, with varying composition of decomposed granite, resin, hardener and setting time. A total of 3 separate tensile strength tests were performed on each test run specimen, to estimate the average of the respective mechanical property. The notations for the composition are mentioned as per Table-I, 'A' represents 'decomposed granite', 'B' represents 'resin', 'C' represents 'hardener' and 'D' represents the setting time.

TABLE VI. OBSERVATION OF TENSILE STRENGTH

Test Number	A (wt%)	B (wt%)	C (wt%)	D (wt%)	Tensile strength (kg/cm^2)		
					Run 1	Run 2	Run 3
1	10	5.5	20	60	7.5	7.4	7.5
2	10	6	22.5	180	6.0	6.0	5.9
3	10	6.5	25	300	7.9	7.8	7.8
4	20	5.5	22.5	300	6.9	7.2	6.8
5	20	6	25	60	5.8	5.6	5.7
6	20	6.5	20	180	4.3	4.0	4.2
7	30	5.5	25	180	0.5	0.7	0.5
8	30	6	20	300	2.4	2.5	2.5
9	30	6.5	22.5	60	7.2	7.2	7.3

Fig. 1. ASTM standard Tensile Strength Test Specimen

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Table VI represents the observation of tensile strength with various compositions on the scale of weight percentage and time in minutes. The resulting tensile strength of each specimen were noted on three different runs (Run 1, Run 2 and Run 3) on the unit of kg/cm^2, the average of which are obtained and discussed in the conclusion section below. Figure 1 and 2 shows the tensile test specimen and universal tensile strength machine that was used to perform the experiment.

Fig. 2. Testing of Tesnsile strength using Universal Strength Machine

B. Compressive Strength

The compressive strength for all nine different test runs were conducted through specimens with standard ASTM dimensions, with varying composition of decomposed granite, resin, hardener and setting time. A total of 3 separate compressive strength tests were performed on each test run specimen, to estimate the average of the respective mechanical property. The notations for the composition are mentioned as per Table 1, 'A' represents 'decomposed granite', 'B' represents 'resin', 'C' represents 'hardener' and 'D' represents the setting time.

TABLE VII. OBSERVATION OF COMPRESSIVE STRENGTH

Test Number	A (wt%)	B (wt%)	C (wt%)	D (wt%)	Compressive strength (kg/cm²)		
					Run 1	Run 2	Run 3
1	10	5.5	20	60	14.7	14.5	14.7
2	10	6	22.5	180	11.1	11.0	11.3
3	10	6.5	25	300	17.8	17.9	17.8
4	20	5.5	22.5	300	16.6	16.6	16.5
5	20	6	25	60	16.5	16.4	16.4
6	20	6.5	20	180	12.6	12.4	12.6
7	30	5.5	25	180	12.0	12.1	11.8
8	30	6	20	300	13.6	13.5	13.5
9	30	6.5	22.5	60	15.5	15.3	15.4

Fig. 3. ASTM standard Compressive and Permeability test specimens

Table VII represents the observation of compressive strength with various compositions on the scale of weight percentage and time in minutes. The resulting compressive strength of each specimen were noted on three different runs (Run 1, Run 2 and Run 3) on the unit of kg/cm^2, the average of which are obtained and discussed in the conclusion section below. Figure 3 and 4 shows the test specimen and the universal strength machine used to conduct the experiment.

Fig. 4. Compressive strength testing using Universal Strength Machine

C. Permeability

The permeability for all nine different test runs were conducted through specimens with standard ASTM dimensions, with varying composition of granite powder, resin, hardener and setting time. A total of 3 separate permeability tests were performed on each test run specimen, to estimate the average of the respective mechanical property. The notations for the composition are mentioned as per Table-I, 'A' represents 'decomposed granite', 'B' represents 'resin', 'C' represents 'hardener' and 'D' represents the setting time.

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Fig. 5. Testing of Permeability using Permeability Meter

TABLE VIII. OBSERVATION OF PERMEABILITY

Test Number	A (wt%)	B (wt%)	C (wt%)	D (wt%)	Permeability (1/min)		
					Run 1	Run 2	Run 3
1	10	5.5	20	60	80	83	81
2	10	6	22.5	180	73	72	73
3	10	6.5	25	300	65	65	65
4	20	5.5	22.5	300	76	75	76
5	20	6	25	60	68	69	68
6	20	6.5	20	180	71	73	70
7	30	5.5	25	180	78	77	77
8	30	6	20	300	75	74	75
9	30	6.5	22.5	60	70	70	71

Table-VIII represents the observation of permeability with various compositions on the scale of weight percentage and time in minutes. The resulting permeability of each specimen were noted on three different runs (Run 1, Run 2 and Run 3) on the unit of 1/min, the average of which are obtained and discussed in the conclusion section below. Figure 5 shows the permeability meter from which the samples were tested for its permeability.

IV. CONCLUSION

The resulting average values of the three separate observations for each test of mechanical properties are noted and corrected up to two decimal with their respective test numbers in the table below.

TABLE IX. OBSERVATION OF AVERAGE VALUE OF TENSILE STRENGTH, COMPRESSIVE STRENGTH AND PERMEABILITY

Test Number	Tensile Strength (kg/cm^2)	Compressive Strength (kg/cm^2)	Permeability (1/min)
1	7.47	14.63	81.33
2	5.97	11.13	72.67
3	7.83	17.83	65.00
4	6.97	16.57	75.67
5	5.70	16.43	68.33
6	4.17	12.53	71.33
7	0.57	11.97	77.33
8	2.47	13.53	74.67
9	7.23	15.4	70.33

Table IX represents the average calculated value of Tensile Strength, Compressive Strength and Permeability respectively. As observed from test number 5, 6 and 7, the mechanical properties are maximum at composition of 20wt% of granite powder, with varying resin amount of 5.5wt%, 6wt%, 6.5wt%. With the above observation of the ANNOVA table, three separate graphical representations of the mechanical properties can be obtained with the resin mixture at 20wt% of granite powder (200g of granite powder).

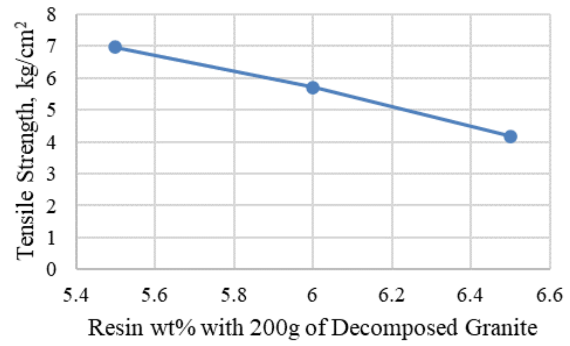

Fig. 6. Tensile Strength Graphical Representation (Tensile Strength vs Resin)

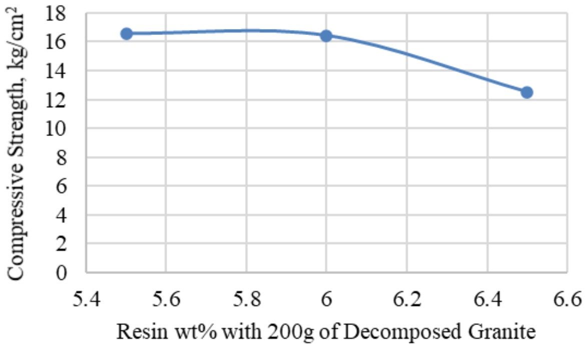

Fig. 7. Compressive Strength Graphical Representation (Compressive Strength vs Resin)

Figure 6 and 7 represent the trend with the relative increase in the resin wt% of 200g of granite powder with tensile strength and compressive strength. Figure 6 shows a constant decrease in the tensile strength of the specimen with increasing resin wt%. However, in Figure 7 the compressive strength of the specimen remains constant till the resin wt% reaches the mid-point, and slightly decreases with increase in the resin wt%.

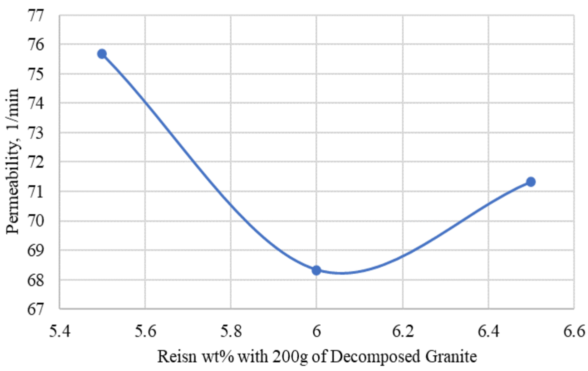

Fig. 8. Permeability Graphical Representation (Permeability vs Resin)

Similarly, in Figure 8 the permeability decreases and then reaches a critical point, and increases with the relative increase in the resin amount.

1. After several attempts, the optimized parameters were obtained on the basis of variation of the weight percentage amount of the resin from 1.8wt%, 2wt%, 2.2wt% to 5.5wt%, 6wt% and 6.5wt% for the levels 1, 2 and 3 respectively.

2. The set of maximum mechanical properties were observed in the range of specimen were the total added decomposed granite constituted for about 20wt% (200g) to levels 1, 2 and 3 of the specimen.

3. From Table-IX a conclusion was drawn that the resin and hardener are the dominant parameters and decomposed granite is suitable as a candidate material in Resin hardened sand moulding. The use of decomposed granite reduces the mould compressive strength and tensile strength and increases the permeability which is undesirable in this type of casting.

4. As the amount of decomposed granite increases the mould strength decreases.

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