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Partial Replacement and Utilization of Industrial Waste in Production of Quality Casting

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Abstract: Red mud is a solid waste which is generated in the process of alumina production and is of highly alkaline. Red mud has very complex compositions but contains a variety of rare and valuable metals. In addition, its high alkalinity is a severe pollution to water, land, air and environment, which has been one of the main factors to affect the sustainable development of aluminum industry. Bayer Red mud which is a waste by product of Aluminum extraction process is dumped in large areas near the sea or nearby ponds. Bayer Red mud is dumped after the neutralization process. Neutralization is done by mechanics of seawater treatment. The mud is actively mixed with the seawater for a period of around 30 minutes to enable the reactions to take place. Clay content had significant effect on permeability, hardness or GCS while moisture content had a little effect. Through this project an attempt is made to carry out different experiments by making red mud a constituent in mold sand in different proportions and to manufacture castings and compare the resulting casting with regular casted component. Taguchi's process is used to optimize the process parameters which come into account in the experiments**.**

***Index Terms* - Green sand, Casting, Red Mud, Bentonite, Permeability**

I. INTRODUCTION

Aluminium is a light weight, high strength and recyclable structural metal. It plays an important role in social progress and has a pivotal contribution in transportation, food and beverage packaging, infrastructure, building and construction, electronics and electrification, aerospace and defense. It is the third abundant element in the earth's crust and is not found in the free state but in combined form with other compounds. 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: Mining of bauxite, followed by refining of bauxite to alumina by the Bayer process (invented by Karl Bayer in 1887) and finally smelting of alumina to aluminium (Hall – Hoult process). Production of alumina is basically a chemical enrichment process. It is a process of separating alumina from undesired components like oxides of iron, titanium, silicon, calcium, vanadium, manganese etc. in bauxite. The Bayer process of extraction of alumina from bauxite remains the most economical process till date. 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. Red mud is a mixture of compounds originally present in the parent mineral, bauxite and of compounds formed during the Bayer process. As the bauxite has been subjected to sodium hydroxide treatment, the red mud is highly caustic with a pH in the range of 10.5 to 12.5. Bauxite ore mined globally amounts to be around 205 million tones per year for 2008 and 201 million tones per year for 2009, posing a very serious and alarming environmental problem. Considerable research and development work for the storage, disposal and utilization of red mud is being carried out all over the world.

II. ORIGIN OF BAUXITE:

The name bauxite was derived from the French province Les Baux and is widely used to describe aluminium ore containing high amounts of aluminium hydroxides. Bauxite is a member of the family of lateritic rocks. It is characterized by a particular enrichment of aluminium-hydroxide minerals, such as gibbsite, boehmite and/or diaspore. Bauxite forms by weathering of aluminous silicate rock (lateritic bauxite) and less commonly of carbonate rock (karst bauxite) mainly in tropical and sub-tropical climate. Bauxite forms by weathering under conditions favorable for the retention of alumina and the leaching of other constituents of the parent rock. Bauxite rock has a specific gravity between 2.6 to 3.5 kg/m3 . It is usually, an amorphous or clay like substance which is, however, not plastic. The usual color of bauxite is pink but if of lower iron content it may tend to become whitish in color and with increase in iron it is reddish brown in color.

III. PRODUCTION AND CLASSIFICATION OF BAUXITE:(World and Indian Context)

As mentioned in table 1, Bauxite resources are estimated to be 55 to 75 billion tons, located in Africa (33%), Oceania (24%), South America and the Caribbean (22%), Asia (15%), and elsewhere (6%). The worldwide metallurgical bauxite production for the year 2008 and 2009. Based on the production data from the International Aluminium Institute, world alumina production during the first two quarters of 2008 increased by 4% as compared to the same period in 2007. Expansions of bauxite mines in Australia, Brazil, China, and India accounted for most of the increase in worldwide production of bauxite in 2008 . Reduced output from bauxite mines in Guinea, Guyana, Jamaica, Russia and Suriname was partially offset by increases in production from new and expanded mines in Australia, China, Brazil and India and accounted for most of the slight decrease in worldwide production of bauxite in 2009 as compared to 2008. Bauxites can be classified in function of the ore type. Alumina occurs in 3 phases defining ore type: gibbsite (γ-$Al(OH)_3$), boehmite (γ- $AlO(OH)$) and diasporic (α-$AlO(OH)$).. The mineralogical characteristics of the bauxite ore determine the type of process needed for alumina production.

(Table 1 Worldwide Bauxite mine production)

Country	Mine production (x 1000 tonne)		Country	Mine production (x 1000 tonne)	
	Year 2008	Year 2009		Year 2008	Year 2009
Australia	6,1400	6,3000	Russia	6,300	3,300
China	3,5000	3,7000	Venezuela	5,500	4,800
Brazil	2,2000	2,8000	Suriname	5,200	4,000
India	2,1000	2,2300	Kazakhstan	4,900	4,900
Guinea	1,8500	1,6800	Greece	2,200	2,200
Jamaica	1,4000	8,000	Guyana	2,100	1,200
			Other countries	6,550	5,410

India has confirmed 3 billion tones of bauxite reserves out of the global reserve of 65 billion tones. India is self-sufficient in bauxite. Bauxite deposits are mostly associated with laterite, and occur as blankets or as capping on the high plateaus in peninsular India. India has the fifth largest bauxite reserves which are 7% of world deposits. India's share in world aluminium capacity rests at about 3%. India has large resources of high-grade bauxite deposits of the order of 3037 million tones (proved + probable + possible). The recoverable reserves are placed at 2525 million tones. The proved and probable reserves are 1218 million tones, placing the country 5th in rank in the world, next only to Australia, Guinea, Brazil and Jamaica About 89% of the recoverable reserves of bauxite are of metallurgical grade. Orissa is the largest bauxite producer (43.6 per cent of total production in 1998-99) followed by Jharkhand (19.2 per cent), Maharashtra (13.3 per cent) and Madhya Pradesh/Chhattisgarh (11.4 %).

Production from Gujarat, Andhra Pradesh and Tamil Nadu is also worth mentioning. Bauxite is found in Gujarat, the Kutch Jamnagar belt, in the east coast bauxite belt covering Andhra Pradesh and Orissa, Ratnagiri in Maharashtra, the Madhya Pradesh bauxite belt covering Amarkantak-Phutkapahar, Jamirapat-Mainpat etc. besides this, bauxite mines are also found in the Satna-Rewa belt (Madhya Pradesh), the Netarhat plateau and adjoining areas in Gumla and the Lohardaga district of Bihar. Distribution of bauxite in India Indian bauxite deposits are grouped into five major geological geographical areas; they are as follows: Eastern Ghats, Central India, West Coast Gujarat, Jammu & Kashmir. Based on the mineralogy and order of preference, Indian bauxite can be divided into 4 types:

1. Gibbsite bauxite (Eastern ghats, Gujarat and coastal deposits of western India)
2. Mixed gibbsite- boehmite bauxite (boehmite < 10%, diaspore < 2%; parts of Western Ghats and Gujarat deposits
3. Boehmite bauxites (boehmite > 10 and diaspore < 2%; Central Indian bauxite
4. Diasporic bauxites (diaspore > 5%; J&K and some part of Central Indian and Gujarat deposits

Typical compositions of industrially used bauxite are Al_2O_3 (40-60%), combined H_2O (12-30%), Fe_2O_3 (7-30%), SiO_2 free and combined (1-15%), TiO_2 (3-4%), F, P_2O_5, V_2O_5 and others (0.0.5-0.2%).

3.1 Production and Main Characteristics of Red Mud/Bauxite Residues:

Output of Bauxite Residues: About 1 tonne of alumina is produced from 3 tones of bauxite and about 1 tonne Aluminium is produced from 2 tonne of alumina. Depending on the raw material processed, 1-2.5 tons of red mud is generated per ton of alumina produced. Chemical and Mineral Compositions of Red Mud: Chemical analysis shows that red mud contains silicium, aluminium, iron, calcium, titanium, sodium as well as an array of minor elements namely K, Cr, V, Ba, Cu, Mn, Pb, Zn, P, F, S, As, and etc. The variation in chemical composition between red mud worldwide is high. Typical composition of red mud. Typical chemical composition of red muds generated by Indian alumina plants is

Table 2: Typical composition of red mud Composition Percentage

Fe_2O_3	Al_2O_3	SiO_2	Na_2O	CaO	TiO
30-60%	10-20%	3-50%	2-10%	2-8%	2%

Mineralogically, red mud has a very high number of compounds present. Red mud is a very fine- grained material. Typical values for particle size distribution are 90 weight % below 75 microns. The specific surface area (BET) of red mud is between 10 and 30 m2 /g, depending on the degree of grinding of bauxite.

3.2 Environmental Issues:

Red mud is disposed as dry or semi dry material in red mud pond or abandoned bauxite mines and as slurry having a high solid concentration of 30-60% and with a high ionic strength. The environmental concerns relate to two aspects: very large quantity of the red mud generated and its causticity. Problems associated with the disposal of red mud waste include:

- Its high pH (10.5-12.5)
- alkali seepage into underground water
- Instability of storage
- alkaline air borne dust impact on plant life
- Huge land areas consumed

Up to 2 tons of liquid with a significant alkalinity of 5-20 g/l caustic (as Na_2CO_3) accompany every ton of red mud solids.

IV. Literature Review:

Red Mud is the residue generated in the process of alumina production from Bauxite by Bayer's Process of Extraction of alumina. Enormous Quantity of Red Mud is generated worldwide every year posing a very serious and alarming environmental problem. As bauxite is subjected to sodium hydroxide treatment, red mud is highly caustic. Considerable research and development work for the storage, disposal and utilization of red mud is being carried out all over the world. Use of Taguchi method makes it easy to experiment to get the expected output. Taguchi Method of process optimization reduces both cost and time of the experiments. Below are some of the research findings.

As per Experiment is carried out by Smith [1] et al. studied and comes to a conclusion that Red Mud may be partly substituted with sand casting in the preparation of mould for the production of aluminium castings. Micro-structural Differences were observed between pure silica mould and red mud- silica sand mould. Faster cooling rates were observed when Red Mud is used in Molding. Porosity was not sensitive to levels above 25% red mud mixture.

Apoing [2] et.al has carried out experimentation and concluded that Red Mud has very complex composition, but contains verity of rare and valuable metals like Titanium & Silicon. Kamble [3] et.al experimented and concluded that RM can be used as Moulding material. Saravana Kumar [4] et.al has studied and concluded that Taguchi Method will result in reduction of casting defects and increase the yield percentage of the accepted casting without any additional investment. Quality of casting can be improved by aesthetic look, dimensional accuracy, quality, etc. Tiwari [5] et.al conducted a case study of Cast iron sand casting through An Application of Taguchi's method for optimization of Parameters Study and Concluded that Taguchi's method for optimization of process is simple and effective in terms of time and cost of overall experiments, research and manufacturing. John [6] et.al resulted that An optimization procedure for sand casting process parameters based on the Taguchi method is described. While keeping other casting parameters constant, for aluminum alloy casting. K. S Anastasiou [7] has studied and found that Considerable reduction in porosity formation can be obtained by Taguchi technique implementation in the die casting process. Plotting Graph of Experiments conducted gives the direct relation between the process parameters and the result obtained.

Mekonnen[8] et.al has used Taguchi used to improve the quality of casting product by reduction in cause without eliminating it. Graphs of the changes in levels of process parameters gives the relation of effect of parameter in output obtained and at the same time it gives an idea what changes are needed to be made. Rasik and Rupesh [9,10] et.al has concluded that many different factors like Moisture content, Grain size, clay percentage, etc affect the casting quality. Defects in the casting can be reduced by experimenting with changing levels of different process parameters by plotting orthogonal array chart. Neutralization and utilisation of red mud for its better waste management. Suchita Rai [11] et. al has carried out work for the Reahabilitation of Red mud. Saravana kumar [12] et. al., has used Taguchi approach capture the effect of signal to noise ratio of the experiments based on the orthogonal array used to find the optimum condition. Manjunath [13] et. al has experimented and found Possibility of replacing the part of Portland cement by Red mud and Fine Aggregates by Used foundry sand. Amol [14] et. al has experimented sand casting and used DoE, signal-to-noise (S/N) ratio and analysis of mean to investigate the effect of the selected process parameter and their level on the casting defects. Reddy [15] et. al. reviewed that RM disposal and reuse is complicated by its extreme alkalinity, which is also noticed to be influencing multiple engineering properties. But with selected pH amendments, the treated RM is found to have significant potential to be used as an effective and sustainable geomaterial. Sujeet Kumar [16] et. al found that red mud is generated from the processing of bauxite is not only highly alkaline but also contains toxic metals. Parameters controlling strength of red mud-lime mix. Suchita Rai [17] et. al. has observed that the alkaline constituents in the red mud impose severe and alarming environmental problems. Yanju Liu [18] et.al overviewed current techniques employed for iron recovery from red mud. Information on the recovery of other valuable metals is also reviewed to provide an insight into the full potential usage of red mud as an economic resource rather than a waste. Khairul, Jafar [19] et.al demonstrated the different methods and techniques recently analyzed or suggested for the consumption of bulk red mud to maintain a sustainable environment.

V. Selection Of Process Parameters:

An effort has been made to find optimal settings of the green sand casting process parameters that yield the optimum quality of cast iron casting .The process parameters considered are moisture content, green strength, permeability and mould hardness. An experimental examination to the process parameter effect was offered to establish the optimum arrangement of design parameters for performance, quality and cast. The range of red mud percentage varies from 20-50 in total five steps. Silica sand percentage weight varies from 50-70, Bentonite percentage varies from 2-4. Whereas the other percentage parameter likes coal dust remain constant.

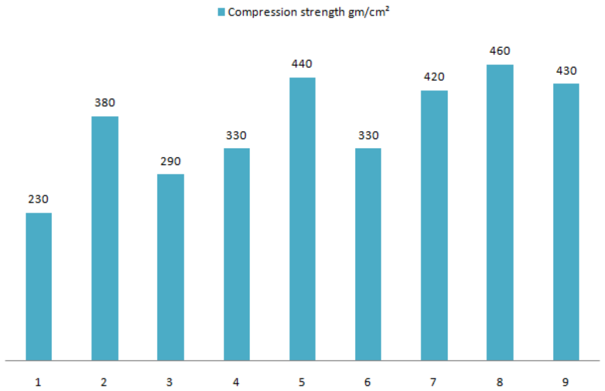
a) Red mud percentage varied from 20- 50%.
b) Silica Sand percentage weight varied from 50-75%.
c) Bentonite percentage varied from 4%. (constant)
d) Other parameters remain constant.

5.1 Design Of Experimentation And Its Validation:

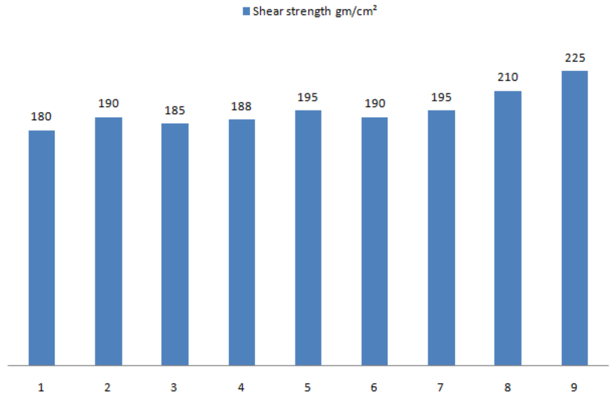
Casting processes involve the use of molten material, usually metal. This molten material is then poured into a mould cavity that takes the form of the finished part. The molten material then cools, with heat generally being extracted via the mould, until it solidifies into the desired shape. For aluminum alloys, the optimum pouring temperature range is 700°C to 750°C. At temperatures higher than this range, the casting results in large crystals, low strength and gases are entrapped in the castings, leading to defects known as blowholes. After melting of aluminium, we pour it into the mould cavity which leads to the casting.

(Table 3 Details of Experimental trail and sand parameters)

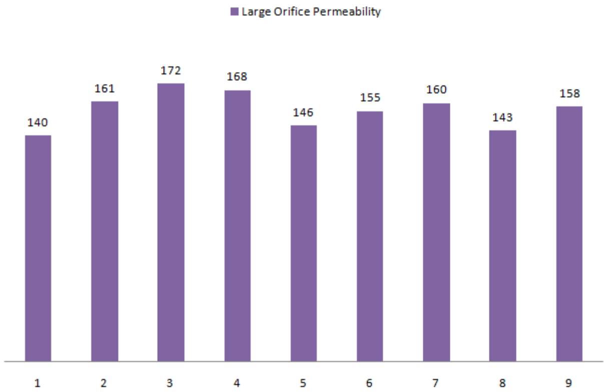
Exp Trial	% Red Mud	% Silica sand	% Moisture	% Bentonite	Compression strength gm/cm²	Shear strength gm/cm²	Permeability	
							Large Orifice	Small orifice
1 (A)	20	68	6	4	230	180	140	17.1
2 (B)	23	67	6	4	380	190	161	15.4
3 (C)	27	63	6	4	290	185	172	14.9
4 (D)	30	62	8	4	330	188	168	13
5 (E)	33	59	9	4	440	195	146	12.2
6 (F)	35	57	7	4	330	190	155	12.7
7 (G)	40	54	7	4	420	195	160	13.1
8 (H)	45	41	8	4	460	210	143	11.2
9 (I)	50	44	7	4	430	225	158	9.7



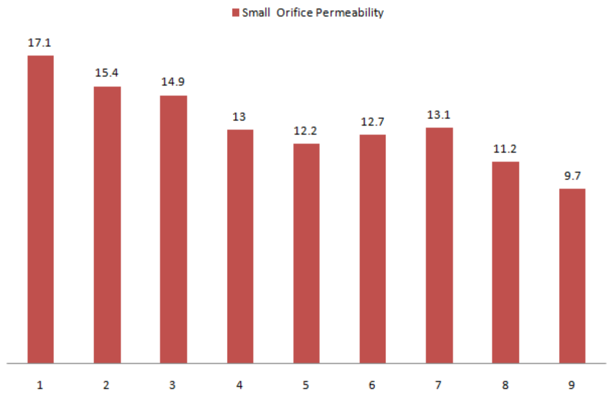
Graph 1. Effect of percentage of red mud on Green compressive strength of molding sand



Graph 2. Effect of percentage of red mud on Green Shear strength of molding sand



Graph 3. Effect of percentage of red mud on large orifice permeability



Graph 4. Effect of percentage of red mud on small orifice permeability

As shown in graph 1, there is positive correlation for red mud percentage against green compression strength. From the trend in the graph, it can be concluded that Green Compression strength of the molding sand mixture goes on increasing gradually with increase in red mud percentage. As shown in graph 2, a positive correlation for red mud percentage against green shears strength. From the trend in the graph, it can be concluded that green shear strength of the molding sand mixture goes on increasing gradually with increase in red mud percentage. As shown in graph 3, no correlation for red mud percentage against permeability number through large orifice. From the trend in the graph, it can be concluded that permeability through large orifice of the molding sand mixture does not show any relation with change in red mud percentage. As shown in graph 4, a negative correlation for red mud percentage against permeability through small orifice. From the trend in the graph, it can be concluded that permeability number through small orifice of the molding sand mixture goes on decreasing gradually with increase in red mud percentage.

Fig.1 Casting quality obtained after experimental trials as mentioned in Table 3

VI. Results Obtained and Discussion

From the experiment it is observed that with the increase in red mud percentage the defects go on increasing. High moisture content in the red mud result in mold wall movement and dimensional variations are observed. When molten metal is poured into the mold it heats up the green sand. The high moisture content of red mud creates steam, causing air to become entrapped in the mold. Permeability number through small orifice goes on decreasing with increase in red mud and hence the gas gets entrapped in the mold cavity resulting in blow holes defect. Metal penetration is observed with increase in red mud percentage. Sand inclusion is also observed. Mulling time of the green sand mixture increases and proper mulling is not possible in green sand mixtures with high percentage of red mud. Grain size of red mud is small and due to high moisture content, granules of red mud are formed which bind together. Hence the tendency of red mud to mix with other contents in the green sand is less.

Among all the experiments, experiment no.2[B] with 23% Red Mud, 67% Silica Sand, 4% Bentonite (binder) and 2% Coal Dust, as green sand content is found best for producing aluminium castings. When compared with reference casting (from molding sand without Red Mud) better surface finish and dimensional accuracy was observed.

VII. Conclusion:

In this experimental work neutralized Red Mud is reused in molding sand of Aluminium foundry. This will help to solve the alarming disposal problem of the waste. Reading indicates experimental trial parameters and observed readings of mold permeability, green and shear strength of mold. The casting obtained with experimental trial 2[B] gives satisfactory and reliable results in quality of casting. Among experimental trial 1 to 9, most of castings are defective because of blow hole, shrinkage, gas holes, pinholes, rough surface finish. The possible causes for defects are too high Moisture content of sand, or water released too quickly, too low gas permeability of the sand. The red mud had significant effect on green compressive strength and green shear strength. It didn't show much effect on permeability number through large orifice but it showed a significant effect on the permeability through small orifice. To achieve the same, different mixtures of Red Mud and Silica Sand has been tested for defects in casting and mixture of 23% Red Mud, 67% Silica Sand, 4% Bentonite (binder) and 2% Coal Dust, is found best for producing aluminium castings. A comparison of reference casting (from molding sand without Red Mud) and the results obtained with casting obtained from molding sand with Red Mud confirmed the potential of neutralized Red Mud for using it as a constituent in molding sand with better surface finish and dimensional accuracy.

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