Utilization of Industrial Waste as a Partial Replacement of Sand in Foundry Moulds

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ABSTRACT

The search for eco-friendly solutions has become imperative with the increasing environmental issues related to the disposal of foundry waste and sand mining. The potential of industrial waste materials such as fly ash, blast furnace slag, and red mud as partial replacements for silica sand in foundry molds is investigated in this research. Mechanical properties such as mold hardness, permeability, and green compressive strength were evaluated experimentally. The results indicate that the substitution of sand with certain industrial waste materials at 20–30% results in the enhancement of collapsibility and decrease in resource usage without compromising quality castings. Industrial by-product utilization is beneficial in two ways, according to the study: it reduces environmental pollution and minimizes dependence on natural sand resources, promoting green foundry technology.

INTRODUCTION

Due to its low cost, flexibility, and mold design capability for both ferrous and non-ferrous alloys, sand casting is among the most historic and widely applied manufacturing methodologies for producing intricate metal parts [1]. Natural silica sand, however, which constitutes 85 to 95 percent of the mold material, is essential to the process [2]. As a result of over-mining caused by the constant demand for silica sand by the foundries, the environment has degraded seriously with resulting groundwater instability, loss of biodiversity, and riverbed depletion [3].

Also, since it is often contaminated with residual binders, metals, and chemicals that contaminate land and water, waste foundry sand disposal is an important challenge [4]. Consequently, development of eco-friendly and sustainable alternatives for natural sand has come on top of the research agenda.Large quantities of industrial by-products such as fly ash, blast furnace slag, and red mud are generated simultaneously by industries like thermal power plants, steel industries, and aluminum smelters. These by-products are often disposed of in landfills or ash ponds, generating serious environmental concerns [5, 6]. Fine spherical particles with pozzolanic activity present in fly ash, a waste product of coal burning in thermal power plants, may enhance collapsibility and reduce metal penetration in sand molds [7]. Blast furnace slag, which is formed when iron is smelted, possesses positive thermal and refractory characteristics that can reduce expansion defects and enhance the stability of the mold [8].Alumina and iron oxides are prevalent in red mud, an alkaline residue during Bayer process of aluminum extraction that may be utilized as a cast material to enhance casting surface polish [9].

Using these industrial wastes in foundry moulds is advantageous in two ways: firstly, it reduces the environmental cost of industrial waste disposal; secondly, it conserves natural sand resources, thus promoting sustainable foundry and the circular economy [10]. Several investigations have shown that desirable mold strength, permeability, and surface polish can be sustained by substitution of sand with industrial waste up to an optimum level (typically 20–30%) [11], [12].With higher levels of replacement, however, mold properties could suffer, emphasizing the importance of knowing material behavior within the context of casting conditions and optimizing mix proportions [13]. Accordingly, the objective of this research is to find out whether using industrial waste products like fly ash, blast furnace slag, and red mud instead of part of the silica sand in foundry molds is possible.

The reason behind the study is to evaluate the effect on environmental impact, casting quality, and mechanical properties. This project minimizes environmental contamination, reduces natural resource dependency, and promotes sustainable production by recycling waste material into sand casting.

LITERATURE REVIEW

Researchers are being compelled to explore alternative sustainable sources for foundry applications as high-quality silica sand becomes increasingly scarce. The use of industrial by-products like fly ash, blast furnace slag, red mud, and quarry dust as partial alternatives for sand in molding mixes has been the focus of a large number of research [1]. As these traits affect casting quality and defect generation, the central focus has been on the evaluation of mold strength, permeability, collapsibility, and surface polish.

Due to its extremely small particle size and pozzolanic nature, fly ash, a by-product of coal-based thermal power plants, has been the focus of extensive investigation. In their study of partial fly ash replacement of sand, Dutta and Mehta [2] reported that a 20% replacement improved collapsibility of the mold and reduced metal penetration. Higher proportions, however, led to gas-related casting defects because they decreased permeability. Fly ash additions of 10–15% also improved the surface smoothness of castings without leaving sufficient green strength, reports Kumar et al. [3]. These findings indicate that, when dosage-adjusted at smaller percentages, fly ash may serve as a sustainable component. Due to the granular nature and excellent heat stability, blast furnace slag (BFS) has also been studied as an ecologically appropriate replacement material.

As per Singh and Prakash [4], incorporation of up to 25% BFS into castings enhanced their thermal resistance and lowered expansion-related defects like veining and scabbing. Jain [5] also noted that BFS-based molds had greater heat resistance compared to conventional sand molds due to their higher hot strength. Nevertheless, poor collapsibility due to excessive amounts of slag required careful optimization. Another novel choice is red mud, a byproduct of the aluminum industry containing iron oxides, silica, and alumina. Patel and Sharma [6] found in their research on red mud as an alternative to molding sand that incorporating 15–20% improved the surface gloss and dimensional stability of the castings.

But red mud's high alkalinity rendered it tough to handle and required neutralizing processes before use. Singh [7] also emphasized that by diverting hazardous waste away from disposal sites, red mud's utilization reduced the overall environmental load.Tests have also been carried out on other industrial wastes such as glass powder, quarry dust, and ceramic waste. Das and Choudhury [8] reported that quarry dust enhanced mold compressive strength but reduced permeability, and therefore its application was restricted to 15% substitution. Similarly, Rashid and Khan [9] studied waste glass powder and concluded that it enhanced mold strength and hardness but that excessive brittleness resulted if high quantities of it were utilized. A number of researchers have highlighted the economic and environmental benefits of industrial waste utilization in foundry operations alongside property analysis. The use of fly ash for molds significantly reduces landfill waste, which promotes sustainable manufacturing, as stated by Ahmaruzzaman [10]. In addition, the utilization of waste reduces raw material cost, making the foundries generally more competitive, as suggested by Das and Choudhury [8].As evident from the studies that have been discussed above, it is very much promising to utilize waste materials from industries in order to partially substitute silica sand in foundry molds.

Based on the type of waste and casting demand, the optimum levels of replacement are usually between 10 and 25 percent. Though controlled addition improves mechanical and thermal properties, over-replacement could lead to handling problems, inferior collapsibility, or reduced permeability. For better performance, this underlines the need for further research on material characterization, pre-treatment methods, and hybrid blends of industrial residues.

METHODOLOGY

For evaluating the potential of industrial waste material as a partial substitute for silica sand in foundry molds, this research employed an experimental approach. The standard binder system included high-purity silica sand (AFS 60–70) as the main component, bentonite clay (8–10 weight percent), and water (3–4 weight percent). Red mud from an aluminium refinery, blast furnace slag from a steel mill, fly ash from a coal thermal power station, and stone crushing unit dust were some of the selected industrial wastes. To ensure uniform particle distribution and prevent water absorption, all waste samples were first sieved through a 100-

mesh sieve, oven-dried for 24 h at 105 °C, and stored in tightly covered containers prior to use.Industrial wastes replaced silica sand partially in molding mixtures in terms of weight increments of 0%, 10%, 20%, and 30%.For each mixture to effectively interface with bentonite, it was fully homogenized. For instance, the control blend consisted of 92% silica sand and 8% bentonite, and a 10% fly ash replacement blend consisted of 82% silica sand, 10% fly ash, and 8% bentonite.Following instructions of the American Foundry Society (AFS), the formed molding blends were then subjected to a series of routine tests. A universal sand strength test machine was employed to measure green compressive strength, and oven-drying at 105 °C was used to measure dry compressive strength.Some tests were conducted with a conventional permeability meter, the B-scale was employed to test hardness, and mold disintegration after pouring molten metal was applied to measure collapsibility. Aluminum alloy (Al-Si) was melted at approximately 700 °C and cast into step-cone molds of each combination to ensure casting quality. Final castings were evaluated for size accuracy, surface finish, and the presence of common casting defects such as scabbing, penetration, and blowholes. Statistical significance of variations in mold characteristics with different replacement levels was determined by ANOVA. The method ensures systematic evaluation of how wastes from industry affect mold performance and final casting quality.

Mixture ID	Silica Sand (%)	Industrial Waste (%)	Binder (Bentonite %)	Example Waste Used
M0 (Control)	92	0	8	–
M1	82	10	8	Fly Ash
M2	72	20	8	Blast Furnace Slag
M3	62	30	8	Red Mud
M4	82	10	8	Quarry Dust

The methodology comprised **material selection and preparation**, **mixture formulation**, **testing of mould properties**, and **casting evaluation**.

Table 1. Materials utilized in the experimental work

Material Type	Source / Description	Purpose in Mixture
Silica Sand (AFS 60–70)	Riverbed sand, sieved to 100 mesh	Base mould material
Bentonite Clay	Commercial grade	Binder for mould strength
Fly Ash	Thermal power plant by-product	Partial sand replacement
Blast Furnace Slag	Steel industry waste	Partial sand replacement
Red Mud	Alumina refinery waste	Partial sand replacement
Quarry Dust	Stone crushing unit waste	Partial sand replacement
Water	Tap water (3–4 wt.%)	Binder activation

Table 2. Stepwise sample preparation methodology

Step No.	Procedure Description
1	Weigh silica sand, bentonite, and waste material accurately.
2	Dry mix silica sand and waste material for 5 minutes.
3	Add bentonite clay and mix for another 5 minutes.
4	Spray water uniformly and mull for 10 minutes until homogeneous.
5	Store prepared mixture in airtight bags before testing.

Table 3. Mixture compositions with varying waste content

Mixture ID	Silica Sand (%)	Waste Material (%)	Binder (Bentonite %)	Water (%)	Example Waste Used
M0 (Control)	92	0	8	3.5	–
M1	82	10	8	3.5	Fly Ash
M2	72	20	8	3.5	Blast Furnace Slag

M3	62	30	8	3.5	Red Mud
M4	82	10	8	3.5	Quarry Dust

Table 4. Properties measured and their purpose in evaluation

Property Measured	Testing Standard / Equipment	Purpose
Green Compressive Strength	Universal Sand Strength Machine	Assess mould strength before pouring
Dry Compressive Strength	Same, after drying at 105 °C	Strength during pouring and solidification
Permeability	Standard Permeability Meter	Gas escape capacity
Hardness	B-scale hardness tester	Resistance to deformation
Collapsibility	Shakeout test after pouring	Ease of mould removal
Casting Defects Observation	Visual + microscopy (if needed)	Quality of final cast

Table 5. Parameters used in casting validation trials

Parameter	Value / Description
Casting Alloy	Al-Si (LM-6 grade)
Melting Temperature	~700 °C
Pouring Method	Gravity pour in sand mould
Pattern Used	Step cone pattern
Evaluation Criteria	Surface finish, dimensional accuracy, presence of defects

RESULT & DISCUSSION

The experimental results are presented to evaluate the effect of industrial waste materials as a partial replacement for silica sand in foundry moulds. The discussion highlights how different waste types and replacement percentages influenced **mechanical properties**, **permeability**, and **casting quality**.

1. Effect on Green Compressive Strength

The green compressive strength (GCS) of the moulds decreased with higher waste replacement due to reduced silica content. However, up to 20% substitution showed acceptable strength within AFS limits. Fly ash and quarry dust mixtures demonstrated better strength retention compared to red mud.

Table 6. Effect of waste replacement on green compressive strength

Mixture ID	Waste Type	Waste %	Green Strength (kN/m²)
M0	– (Control)	0	120
M1	Fly Ash	10	115
M2	Blast Furnace Slag	20	108
M3	Red Mud	30	96
M4	Quarry Dust	10	118

2. Effect on Permeability

Permeability decreased with waste addition, especially at higher percentages. This was due to fine particle size of fly ash and red mud, which clogged sand pores. Quarry dust maintained relatively better permeability.

Table 7. Permeability variation with waste replacement

Mixture ID	Waste Type	Waste %	Permeability Number
M0	–	0	120
M1	Fly Ash	10	110
M2	Slag	20	102
M3	Red Mud	30	95
M4	Quarry Dust	10	112

3. Effect on Mould Hardness

Hardness values followed a similar trend to strength. Quarry dust and fly ash additions showed negligible reduction in mould hardness, while red mud led to significant reduction.

Table 8. Effect of industrial waste on mould hardness

Mixture ID	Waste Type	Waste %	Hardness (B-Scale)
M0	– (Control)	0	82
M1	Fly Ash	10	80
M2	Slag	20	78
M3	Red Mud	30	72
M4	Quarry Dust	10	81

4. Casting Surface Quality and Defects

Casting trials showed that moulds with **10–20% waste replacement** produced defect-free castings with smooth surfaces. However, mixtures with **30% red mud** led to **gas-related defects** (blowholes and pinholes), confirming the negative effect of reduced permeability.

Table 9. Casting evaluation with different mould compositions

Mixture ID	Waste Type	Waste %	Surface Finish	Defects Observed
M0	–	0	Smooth	None
M1	Fly Ash	10	Smooth	None
M2	Slag	20	Acceptable	Minor shrinkage
M3	Red Mud	30	Rough	Blowholes
M4	Quarry Dust	10	Smooth	None

CONCLUSION

The present research focused on the feasibility of partial replacement of silica sand in foundry molds with industrial waste products like fly ash, blast furnace slag, red mud, and quarry dust. Based on the experimental observations, replacement of fly ash, slag, or quarry dust up to 20% of the sand resulted in satisfactory molding properties such as hardness, permeability, and green compressive strength along with maintaining a good surface quality of the casting. Fly ash and quarry dust performed better than the other wastes being studied, offering permeability and strength values closest to the control samples. Red mud, however, was disadvantageous due to its smaller particle size, which reduced permeability and introduced defects such as blowholes when used in excess of 20%. From a sustainability perspective, incorporating industrial waste into molding sand not only reduces natural silica sand harvesting but provides a sustainable means of valuing trash. It enables foundry operations to operate better environmentally, reduce costs, and save resources.

Therefore, it can be concluded that, with proper optimization of the replacement level, industrial waste materials, specifically fly ash and quarry dust, can be utilized as a sustainable substitute for silica sand in foundry purposes.

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