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Micro-structural and metal leachate analysis of concrete made with fungal treated waste foundry sand

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HIGHLIGHTS

- ▶ Paper presents study micro-structure and metal leachate of concrete made with fungal treated WFS.
- ▶ Concrete is made with 0%, 10%, 15% and 20% WFS as partial replacement of sand.
- ▶ *Aspergillus niger* removes above 90% metal content in treated leachate samples.
- ▶ SEM & EDS confirms biomineral formation by fungus results in concrete improvement.

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ABSTRACT

Waste foundry sand (WFS) is a byproduct of metal casting industry which results from the mold and core making processes. Land filling is not considered to be a good option because it leads to the risks associated with the environment as it generates leachate which may contain heavy metals and organic contaminants. Its beneficial use in construction materials results in reducing the cost of construction materials' ingredients and also helps in reducing disposal problem. Leaching characteristics are essential in understanding the environmental impact or toxicity, disposal and potential development of beneficial applications of WFS. This study aimed to presents micro-structural and metal analysis of fungal treated leachate obtained from concrete made with various percentages of WFS (0%, 10%, 15% and 20%).

Metal concentrations of untreated and fungal treated leachate obtained from concrete made with WFS were analyzed for 15 metals including (Ba, Be, Cd, Cr, Co, Cu, Fe, Hg, Li, Mo, Mg, Mn, Ni and Zn) by using ICP-MS and compared with world Health organization (WHO) standard limits and ground water quality standards (GWQSs). Metal analysis indicates that WFS contribute to the concentration of leachable metals in concrete containing WFS. Results show the reduction in the metal concentration in leachate obtained from fungal treated concrete. In fungus (*Aspergillus niger*) treated WFS (10%) containing concrete, the metal concentration in Cd, Cr, Fe, Mo, Mn, Ni and Pb were reduced to significant levels. Micro-structural analysis confirms the improvement of concrete by inclusion of fungal treated WFS in concrete due to the formation of calcium rich biomineral in the pores of concrete.

1. Introduction

There are more than 5000 foundry units in India and majority of them falls under the category of small-scale industry [1]. These foundry units generate approximately 17,10,000 t (1.71 MT) waste foundry sand per year. Foundry sand is high quality silica sand with uniform physical characteristics. It is a by-product of ferrous and non-ferrous metal casting industries, where sand has been used for centuries as a molding material because of its thermal conductivity. Foundries successfully recycle and reuse the sand many times in a foundry. When the sand can no longer be reused in the foundry, it is removed from the foundry and is termed as WFS. It can be reused in various applications as an alternative to sending it to landfill, and reuse options are well established in England, Europe and North America. Reuse options include cement manufacture, asphalt, concrete, bricks and free-flow fill for certain construction applications. WFSs are an excellent substitute for virgin sands that are currently used in manufactured soils and geotechnical applications. Dungan [2] studied trace metals and EPA-priority polycyclic aromatic hydrocarbons (PAHs) and phenolics in ferrous and non-ferrous SFSs over a one-year period. This suggested that the majority of SFSs are not hazardous in nature, except those that use olivine sands or are from brass foundries,

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due to the presence of elevated concentrations of Ni or Cu, Pb, and Zn, respectively. Classification of foundry sands depends upon the type of binder systems used in metal casting. Two types of binder systems are generally used, and on the basis of that foundry sands are categorized as: clay-bonded sand (green sand) and chemically bonded sand.

WFS are generally sub-angular to round in shape. Green sand is generally black, or gray, and chemically bonded sand is typically a medium tan or off-white color. The grain size distribution of Waste foundry sand is uniform, with 85–95% of the material between 0.6 mm and 0.15 mm, 5–12% of foundry sand can be smaller than 0.075 mm. The specific gravity of foundry sand varies between 2.39 and 2.55 [3]. Chemical composition of the WFS depends on the type of metal molded at the foundry, type of binder and combustible used. The chemical composition of the foundry sand may influence its performance [4]. It consists primarily of silica sand, coated with a thin film of burnt carbon, residual binder (bentonite, sea coal, resins/chemicals) and dust. Silica sand is hydrophilic and consequently attracts water to its surface [5].

It can serve as a potential silica source as a substitute to virgin sand in road bases, structural fill, flowable fill, soil amendments or as the fine aggregate portion of concrete or hot-mix asphalt. Significant efforts have been made in recent years to use foundry sand in civil engineering construction. Several researchers have investigated the utilization of WFS in civil engineering application such as concrete and concrete related products [6–11] and geotechnical applications [12] and leachability characteristics of WFS [13–19]. Some of the application areas included highway bases and retaining, landfill liners, asphalt concrete and pavement bases [12]. Use of WFS in concrete related products like bricks, blocks and paving stones has been reported by Khatib and Ellis [8], Naik et al. [9], Fiore and Zanetti [10], and Siddique et al. [11].

Beside the various benefit aspects regarding its use in concrete, it also brings some environmental problems. Earlier Ham and Boyle [20] concluded that (i) leaching potentials greatly influenced by the process temperature; (ii) constituents of the leachate depended upon the type of foundry sand, which reflected the difference in the binder materials present in the waste materials. Naik et al. [13] evaluated the performance and leaching of controlled low strength materials (CLSMs) incorporating foundry sand may also contain hazardous constituents depending upon their source. They concluded spent foundry sand met all parameters of enforcement standards (ESs), but it exceeds the preventive action limits (PALs) for lead and chromium. Ji et al. [14] presented the chemical analysis and leaching characteristics of waste foundry sand of four sand types (green sands, Furan/acid sand, phenolic sands and silicate sands). It was found that all spent/waste foundry sands contain poly aromatic hydrocarbon (PAH) compounds.

Dungan and Dees [19] studied total metal concentrations in molding sands and the leached metals were assessed via TCLP, SPLP and ASTM water leach test. It was concluded that total metal concentrations in the majority of the waste molding sands were at the low end of range measured in the agricultural soils. With the exceptions of few sands, only Co, Cu and Ni were above the range found in the soils. Douglas [18] showed that TCLP extracts of used foundry sand without any additives contain high concentrations of copper, lead and zinc lead well over the regulatory limits for hazardous waste of 5 mg/l. Deng [17] analyzed the leaching characteristics of WFS by three leaching protocols, namely, TCLP, SPLP and ASTM D 3987. According to the mean and median middle levels or most metallic chemicals in TCLP leachates are higher than those in SPLP or ASTMD3987 leachates by varying factors up to 50, which was thought associated with TCLP was more aggressive than other two protocols. These components when leached out from WFS, it may shows harmful effects on the environment. So, lack of land filling and the negative environmental impact of leachate come out from WFS have led to the investigative bioleaching technology as an alternative in the removal of heavy metals.

The ability of microorganisms (such as bacteria and fungi) to transform solid compounds and result in soluble and extractable elements which can be recovered [21]. Microbially heavy metals extraction processes are usually more eco-friendly and economical. Fungi are efficient bioleachers due to their acid (oxalic acid, citric acid and gluconic acid, etc.) producing potentials by using carbon source and compounds with at least two hydrophilic reactive groups (e.g. Phenol derivatives) into the culture medium as metabolic products which leads to dissolving the heavy metals by forming salts and chelates [22]. Bioleaching of fly ash by *Aspergillus niger* was first reported by Bosshard et al. [23]. The experiment was conducted in shake flasks and the leaching of different metals such as Al, Cd, Cr, Cu, Zn and Mn present in fly ash were determined.

Ezzouhri et al. [24] reported that the filamentous fungi isolated from heavy metal contaminated soil belonging to the genera *Aspergillus* and *Penicillium*, have high level of resistance to a number of metals which makes them attractive potential candidates for further investigations regarding their ability to remove metals from contaminated waste water. Fungal biomass provides a metal sink, either by metal biosorption to biomass (cell walls, pigments and extracellular polysaccharides), intracellular accumulation and sequestration, or precipitation of metal compounds onto and/or around hyphae. Fungi are highly effective biosorbents for a variety of metals including Ni, Zn, Ag, Cu, Cd and Pb. Fungi can precipitate a number of inorganic and organic compounds, e.g. oxalates, oxides and carbonates.

The application of the fungi resolves the problem of land filling and water contamination with toxic compounds has received increasing interest because fungi are ubiquitous in the natural environment and dominant microorganism in soil with low pH values and having important component of their role is the ability to solubilize, transform and uptake of metal species [25]. So, the main concern of the present research work is to reduce metal toxicity of WFS by using fungal culture (*A. niger*) and to study the effects of fungal treated waste foundry sand on concrete properties.

2. Experimental programme

2.1. Material used

2.1.1. Cement

IS mark 43 grade cement (IS mark 43 grade means compressive strength of cement is 43 MPa) of Brand-Ambuja cement was used for all mixes. Testing of cement was done as per IS: 8112 [26] (Table 1).

2.1.2. Coarse and fine aggregate

Locally available coarse aggregates having the maximum size of 12.5 mm was used in this work. Testing of fine and coarse aggregates was done as per IS: 383 [27]. The sand used for the experimental programme was locally procured and conformed to Indian Standard Specifications IS: 383 [27]. The sand was first sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm and remove the dust. Properties of the coarse and fine aggregate used in the experimental work are tabulated in Table 1.

2.1.3. Waste foundry sand

WFS were collected from the Delux foundry, Mandi Gobindgarh (Punjab). Sample was collected from different places randomly and stored in bags. For the isolation of fungi, soil and WFS samples were collected from the areas near to the

Table 1
Properties of cement, coarse and fine aggregates.

Characteristics	Cement	Coarse aggregate	Fine aggregate
Initial setting time (min)	90 min	–	–
Final setting time (min)	255 min	–	–
Fineness (%)	3.5%	2.0	2.28
Specific gravity	3.12	2.62	2.57
Water absorption (%)	–	0.80	1.02