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Effect of foundry waste on the mechanical properties of Portland Cement Concrete

Anthony Torres [a,*], Laura Bartlett [b], Cole Pilgrim [a]

[a] Texas State University, San Marcos, TX 78666, United States
[b] Missouri University of Science and Technology, Rolla, MO 65409, United States

HIGHLIGHTS

- General foundry waste was used to partially replace natural aggregates in PCC.
- Coarse foundry waste had no impact on mechanical properties up to 30% by mass replacement.
- Fine foundry waste had no impact on mechanical properties up to 30% by mass replacement.
- Combined foundry waste had no impact on mechanical properties at 20% by mass replacement.
- Combined foundry waste had a negative impact on mechanical properties at 40% and 60% by mass replacement.

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ABSTRACT

Approximately 6–10 million tons of waste is produced annually by the ferrous and non-ferrous foundry industry in the United States and estimates have shown that only 15% of the waste produced is being recycled. The increasing scarcity of landfill space and disposal cost has fashioned a need for an alternative disposal method of this large industrial waste. Foundry waste can consist of many products such as used-foundry sand, slag, ash, refractory, coagulant, baghouse dust, pattern shop waste, and debris. Past researchers have presented an alternative disposal method by using spent sand and slag as constituents in concrete with positive results. This paper generalizes the foundry waste for use in Portland Cement Concrete (PCC) in order to increase the recycling percentage, by reducing processing time/cost and using all the waste produced by the foundry industry. This was done by partially replacing both fine aggregate and coarse aggregate of concrete with lightly processed foundry waste. Since foundry waste contains both fine and coarse materials, the as-received foundry waste was lightly processed and sieved to match the control concrete mixtures coarse and fine aggregate distribution. Both virgin coarse and fine aggregate were replaced by mass at 10%, 20%, and 30%. Two mixture groups replaced individual constituents separately (coarse and fine), and one mixture group replaced both coarse and fine in the same mixture. The compressive strength, splitting-tensile strength, flexural strength, and modulus of elasticity were measured for all groups at 7, 14, and 28 days. The results indicated that general foundry waste as either coarse, fine, or combined by mass replacement of natural aggregate has no impact on the mechanical performance of PCC up to 30% for individual replacement or 20% combined. This result not only demonstrates a possible avenue to increase the amount of foundry waste recycled annually, but it also reduces the demand for virgin aggregates for PCC.

1. Introduction

In the recent era of increased environmental impact attention on construction building materials, concrete has proven to be one of the leading sustainable construction building materials due to its efficient natural resource usage, its inert capability to contain recycled elements, and its durability. Due to concrete's inert nature a broad range of waste, including foundry waste can be incorporated into the concrete mixture with minimal impact to the properties of the concrete, with some waste actually providing an increase in concrete performance [1,2]. Foundry waste constitutes approximately 6–10 million tons of waste produced each year in the United States, of which only 15% is recycled [1–4].

* Corresponding author.
E-mail address: ast36@txstate.edu (A. Torres).

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Foundry waste can include constitutes such as used-foundry sand, slag, ash, refractory, coagulant, baghouse dust, pattern shop waste, and debris. Of the foundry waste, used-foundry sand and slag have shown to be the most promising by-products to improve concrete performance. The source of each waste results from different industrial practices and certain industries produce more of each type. The automotive industry are the major generators of used-foundry sand from its molding and casting operations [1]. Foundry sand is typically reused within the foundry many times before it becomes spent and unusable for metal casting. The classification of foundry sand depends upon the binder system during metal casting in which there exist two types: clay bonded systems (green sand) and chemically bonded systems; both are suitable for recycling in concrete [1]. When used-foundry sand is used in concrete it is typically used as partial replacement of the fine aggregate constituent, which is typically virgin sand. Slag, a metal manufacturing by-product, also consists of two distinct types, blast furnace slag (from iron making) and steel furnace slag (from steel refining) each consists of various combinations of calcium, magnesium and aluminum silicates. Slag is an inert material that is considered one of the most voluminous and reusable materials [5]. Unlike used-foundry sand, slag has been used as partial coarse aggregate replacement and as a supplementary cementitious material (SCM) in concrete [5–8]. An SCM is a material that partially replaces the cement in a concrete mixture, which also provides a beneficial cementing ability. The standard disposal method for foundry waste is in a landfill, with only 15% being recycled as road-bases, embankment material, cement production and concrete filler. This low recycling percentage is believed to be due to the cost of processing (separating, washing, crushing, storing, and analyzing). This paper demonstrates an alternative disposal technique that reduces the processing time and cost to prepare the foundry waste by generalizing waste for use in Portland Cement Concrete (PCC). The alternative disposal technique is to use general foundry waste to partially replace both fine aggregate and coarse aggregates in PCC. Since foundry waste contains both fine and coarse materials, as-received can be processed and sieved to match the control concrete mixtures coarse and fine aggregate distribution.

2. Literature review

Several researchers [1,2,9–16] have reported on the use of used-foundry sand in concrete primarily as partial replacement of fine aggregate in concrete. Other researchers [6–8,17,18] have focused on the use of slag in granulated powder form, commonly known as Granulated Ground Blast Furnace Slag (GGBFS) as an SCM or as coarse aggregate in concrete. These authors have shown positive results from including individualized foundry waste in concrete, which partially results in the 15% recycled foundry waste each year.

Siddique et al. [1] reported an increase in compressive strength, splitting-tensile strength, flexural strength and modulus of elasticity of with an increase in used foundry sand content. The fine aggregate replacement used in their study consisted of three percentages (10%, 20% and 30%). The increase in compressive strength varied from 8% and 19% depending upon the used-foundry sand replacement and the age of the specimens. The percent increase for the splitting-tensile strength varied from 6.5% to 14.5% and 7% and for the flexural strength. Lastly the recorded performance increase for the modulus of elasticity varied from 5% to 12%.

Naik et al. [10,11] produced brick, blocks, paving stones and pre-cast molded concrete products all with the partial replacement or inclusions of Class F fly ash (an SCM), coal combustion bottom ash, and used foundry sand. The fine aggregate and Portland cement was replaced in two percentages, with used-foundry sand and fly ash respectively. The results showed an improvement on strength and durability. In the pre-cast molded concrete the average compressive strength was 32% higher than the control samples.

Bikas et al. [12] incorporated used foundry sand in asphalt concrete with 4%, 7%, 10%, 14%, 17%, and 20% replacement of fine aggregate. Their tests measured the flow values and Marshall stability of the asphalt concrete. The results showed that a 10% replacement of fine aggregate with used-foundry sand is most suitable for asphalt concrete mixtures. Additionally reported is that used-foundry sand did not affect the environment around the deposition.

Fiore et al. [13] conducted a report on the reuse of foundry sand and recycling of various sizes. Their findings grouped used foundry sand into three categories according to particle size dimensions: less than 0.1 mm (0.0039 in.), between 0.1 mm (0.0039 in.) and 0.6 mm (0.023 in.), and above 0.6 mm (0.023 in). The fraction above 0.6 mm (0.023 in.) (metallic iron) may be reused in furnaces, while the fraction between 0.1 mm (0.0039 in.) and 0.6 mm (0.023 in.) may be reused in cores production, after retreatment. The smaller fraction, less than 0.1 mm may be recycled for use in the concrete industry. Additionally, the Fiore et al. [13] reported that the fraction below 0.025 mm could be reused in green molding operations, pending retreatment.

Yuksel et al. [17] used both bottom ash and non-ground blast furnace slag as 10%, 20%, 30%, 40% and 50% fine aggregate replacement, respectively. The results showed that both additives positively affect the durability properties of concrete, such as the resistance to high temperature and surface abrasion. This is due to the chemical and physical properties of the bottom ash and slag, as revealed by Scanning Electron Microscope (SEM) imaging. This work ultimately demonstrates that durable concrete can be produced with the addition of non-ground blast furnace slag and bottom ash.

Qasrawi et al. [18] uses both recycled concrete aggregate (RCA) and steel slag aggregate (SSA) as partial replacement in concrete. The results show a decrease in strength with full replacement, however a 67% replacement of SSA increased the properties of normal strength concrete. The use RCA had some adverse affects on the concrete such as workability, air content and modulus of elasticity, whereas the SSA replacement did not.

All of these studies demonstrate that the individual constituents of foundry waste can ultimately benefit the performance of PCC up to a certain percent replacement. These independent results provide credible insight into the use of foundry waste as a general constituent (combined) in PCC to not only increase the percent of foundry waste recycled each year, but to increase the performance of PCC.

2.1. Research significance

Currently only 15% of the 6–10 million tons of foundry waste is being recycled in the United States, which could be improved with minimal processing. There is extensive research investigating the use of individual foundry waste (used-foundry sand, slag, and bottom ash) in concrete, however many companies do not separate their foundry waste making it costly to process, which is a factor affecting the low recycling percentage. This paper generalizes the foundry waste for use in concrete production in order to increase the percent recycled each year and to potentially increase the performance of PCC. This was done by partially replacing both fine aggregate and coarse aggregate with lightly processed foundry waste. Since foundry waste contains both fine and coarse materials, the as-received waste was lightly processed and sieved to match the control concrete mixtures coarse and fine aggregate