Chapter 12
Investigating the Utilisation of Waste Sand from Sand Casting Processes for Concrete Products for Environmental Sustainability

Sirwan Faraj and Amin Al-Habaibeh

Abstract Concrete is one of the fundamental materials in the construction industry. Typically, concrete is composed of sand, cement, aggregate, and added water to the cement ratio. To enhance sustainability and reduce the negative effect on the environment from industrial waste, recycling waste material into the concrete mixture is becoming an area of research by substituting some of the concrete ingredients with some of the recycled waste material in order to reduce the amount of fine natural aggregate used in the construction industry, maximise the strength and minimise the overall weight of the concrete product. Waste foundry sand is a by-product of sand casting, a waste product of the metal casting industry. The improper disposal of this waste foundry sand (WFS) could cause environmental issues. Consequently, its possible use in building materials, product design, construction, and other fields is crucial for mitigating environmental limitations. To minimise negative environmental impacts, researchers have proposed reusing this waste foundry sand by replacing, fully or partially, some of the standard natural sand within the concrete mixture. This paper investigates the mechanical and physical properties of concrete cubes containing recycled sand-casting material by demonstrating the experimental work to determine the potential benefit or limitations of using this material within the concrete in the construction and product design industries. According to the experimental results, waste foundry sand, with a substitution ratio of up to 30%, had a compression strength of circa 23 N/mm^2 and reached up to 78% of the strength of a standard control sample within 7 days. The results hence suggest that waste foundry sand can be used in the production of concrete products when such reduction in strength is not critical. Such a range of products could include curbs, garden slabs, cycling pavements, gravel boards, etc. Additionally, utilising waste foundry sand will help

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to reduce the use of natural sand and the need for landfill sites, which has several advantages, including cost savings and environmental protection by reducing CO_2 emissions during transportation.

Keywords Waste foundry sand · Sustainability · Concrete · Recycling · Eco-friendly

12.1 Introduction

Concrete is a composite material that generally consists of numerous ingredients. It usually includes cement, water, coarse aggregate, sand, and other additives or polymers to enhance workability. Concrete is one of the most often utilised construction materials in the current economy. It can be unutilised structural products, paving material, pipes, drains, etc. [1]. Concrete is an expensive material in terms of cost and carbon emission. Solving this issue is ideal by substituting fine aggregate (sand) with industrial waste materials such as waste foundry sand (WFS). In sand casting, moulds made of uniformly sized, clean, high-silica sand are used in such industries. After the casting process is completed, foundries usually recycle and reuse the sand multiple times. However, after a specific number of cycles, depending on the products and their required specifications, the sand is discarded as waste foundry sand [2]. The environmental impact of this sand and its disposal problem can be mitigated if it can be utilised in other engineering applications. For example, it has been reported that each year Indian foundries produce approximately 1.71 million tonnes of waste foundry sand [3, 4]. Globally, it has been estimated that the foundry industry generates approximately 100 million tonnes of waste foundry sands (WFS) annually on a global scale [5]. Reusing the sand from the foundry reduces the need for landfill space or the use of conventional sand in engineering applications. This is expected to enable the development of environmentally sustainable use of such waste sand [6]. Figure 12.1 presents the waste foundry sand used in this paper.

Fig. 12.1 Waste foundry sand

The aim of this research is to explore the use and determine the potential strength of concrete products that contain waste foundry sand as a partial or complete replacement for normal sand.

12.2 The Methodology

In order to determine the potential strength of concrete products that include waste foundry sand as a partial or complete replacement for traditional sand, standard concrete cubes were made and tested under compressive stress. Concrete is usually tested in a laboratory environment. The primary objective of such tests is to ensure that the concrete meets the design specifications outlined in IS EN 206-1 or to compare the results relative to the benchmark. Because using different materials and ratios can cause varied effects, the standard helps to identify performance, production, and conformity. All applicable health and safety standards and regulations were followed during the laboratory work, and the appropriate personal protective equipment (PPE) was worn. Nine distinct concrete mixtures were created in one day for this test. Mould preparation starts by casting moulds (cubes) (100 × 100 × 100 mm) cast iron that must be rubbed with grease on the inner side to help the removal process. The specimen is properly compacted by vibration so that honeycombing formation does not occur. The cube test for compressive strength can be done in seven days. Having at least three specimens for testing from different batches is critical to calculating the average and any possible variation.

The concrete cubes are produced by placing the prepared concrete mix in the steel cube mould for casting. After it has been set for 24 h, the product (sample) is removed from the mould. The samples are then kept submerged underwater for seven days. The concrete samples must be dried and weighed prior to testing. The concrete cubes are placed on the compression machine for testing. The loading must be applied to the specimen axially without shock and increased at 140 kg/so cm/min until the specimen collapses.

12.3 The Selected Materials

This research study calculates and tests four designed mixes, each consisting of three cubes, making the total to be 12 samples. Table 12.1 contains the complete information about the proposed mixes. The ratio of 1:2:3 of Cement, Sand and Coarse Aggregate, respectively, was determined by the usual design process of the concrete type. The report's primary objective is to conduct compressive strength tests on the samples that have been cured under water. The results of the samples were analysed and compared. The models that include 100, 65 and 30% recycled waste sand were compared with the standard samples with 0% recycled sand (100% normal fine sand) as control samples, see Table 12.1.

Table 12.1 The 12 samples used in this paper and their composition

Replacement WFS (%)	OPC (kg)	WSF (kg)	Natural fine sand (kg)	Natural coarse agg (kg)	Water (l)	Number of samples
WSF (100)	1.2	2.4	0	3.6	9.66	3
WSF (65)	1.2	1.56	0.84	3.6	7.32	3
WSF (30)	1.2	0.72	1.68	3.6	7.14	3
WSF (0) (Control)	1.2	0	2.4	3.6	6.6	3

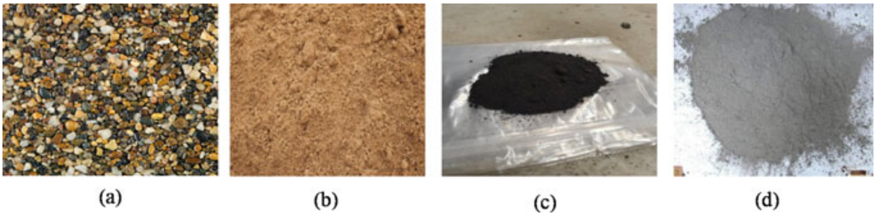

Fig. 12.2 The components of the mixture; **a** coarse aggregate, **b** fine aggregate, **c** waste sand and **d** Portland cement

The testing aggregate sample must comply with the BS EN 932-1:1997 standards as a benchmark. The rounded aggregate was used in this experiment with a size between 2 and 10 mm. Figure 12.2 shows the components sample used in this study for the concrete mix. Figure 12.2a presents the course aggregative, Fig. 12.2b presents the normal sand, Fig. 12.2c shows the recycled waste sand, and Fig. 12.2d gives the Portland cement used in this study.

To determine the samples' mechanical strength, the waste sand has been replaced with natural sand in proportions of 100, 65 and 30%. The water ratios used vary according to the mixing process. There are numerous types of cement on the market. This experiment used ordinary Portland cement with a compressive strength of 32 N/mm^2 according to the British standard (BS EN 1992-1-1). According to (EN 206-1-2000), the water/cement ratio is required to achieve the 30 MPa (M30). The water/cement ratio was determined to be 50% of the cement ratio. Plus, an additional 1% of added water because if the aggregate is dry, affecting the 'free water' needed. These values depend on the mixture of material proportions and conditions. The waste sand has high water absorption characteristics, increasing the water content by 15% to the sand ratio. At 28 days, concrete is expected to reach its maximum strength. Instead of checking the strength at 28 days, this research paper has tested the samples after 7 days, if concrete gains 65% of its target strength after seven days.

12.4 Experimental Results and Discussion

Table 12.2 presents the complete experimental data and results, including the compression tests. Figure 12.3 shows the average results of the samples at 7 days. It is clear from the data that the reduced sand reduced the compression strength of the samples. However, Fig. 12.3 will help design future products with specific strengths sufficient for the required applications from the product design perspective.

The three distinct concrete mixes were used, each with a different percentage of waste sand replaced with fine natural aggregates, such as 100, 65, and 30% in (kg). The results show that the average compressive strength of concrete cubes was reduced by roughly 64%, 46%, and 12%, respectively, compared to those made with fine natural sand. The maximum compressive strength cubes within seven days are shown in Fig. 12.3. The samples submitted to the compressive machine test for cubes made WFS, resulting in a satisfactory failure. The stress cracking that appears within the specimen is considered abnormal.

The specimens containing 30% WFS attained the desired compressive strength target. Figure 12.5 represents the compressive strength at 7 days and the calculated cube strength at 7 days (in %). However, according to the experimental results, the partial replacement of WFS should not exceed 30% in order to achieve the target strength. The samples were examined under the microscope following the testing process to reveal clear interfacial debonding between the aggregates and cement paste in some locations. The interfacial debonding (or separation) is clearly visible in Fig. 12.4 as the areas around the aggregates have micro-cracks caused by the direct axial force applied to the cubes. Except for sample (a) in Fig. 12.4, the crack propagation pattern is nearly the same throughout the remaining samples; binding difficulties cause this pattern. Figure 12.4a–d show no solid bond between coarse particles and cement paste. In this experiment, rounded form aggregates were used, which may have a negative effect on the total cube strength. Infiltration of water is another issue that might affect the strength of concrete. It was established during the cube testing procedure that the cubes made from recycled sand absorbed more water, causing the samples to collapse quicker under the compressive testing machine as stress was applied. The reason for these conclusions is unknown precisely. Therefore, additional study or testing is necessary to discover the cause.

12.5 Conclusion

This study aimed to evaluate the mechanical properties of recycled waste foundry sand and the impact of recycled material on the properties of concrete when used to replace the standard sand in the mixture. This study investigated introducing waste sand from sand casting processes to replace natural sand in concrete. In many sectors, recycling waste foundry sand instead of virgin materials can result in a slight decrease in the technical performances of the final products, which could still be acceptable

Table 12.2 The Experimental design and results

Sample (%)	Date of casting	Description of sample	Building number	Target grade of concrete	Number of cubes	7 days testing date	Weight of cubes (kg)	The average weight of cubes (kg)	Load in (kN)	Comp strength N/mm^2	Average comp. strength N/mm^2	Cubes strength %
WS 100	13/10/2021	Cube	1	n/a	1	21/10/2021	2.22	2.25	91.3	9.13	7.90	26.34
					2	21/10/2021	2.19		75.6	7.56		
					3	21/10/2021	2.21		70.2	7.02		
WS 65	13/10/2021	Cube	2	n/a	1	21/10/2021	2.24	2.28	127.5	12.75	13.28	44.28
					2	21/10/2021	2.28		132	13.2		
					3	21/10/2021	2.26		139	13.9		
WS 30	13/10/2021	Cube	3	n/a	1	21/10/2021	2.26	2.31	244.3	24.43	23.58	78.60
					2	21/10/2021	2.28		248.6	24.86		
					3	21/10/2021	2.28		214.5	21.45		
Control	13/10/2021	Cube	4	M30	1	21/10/2021	2.37	2.37	270	27	27.07	90.22

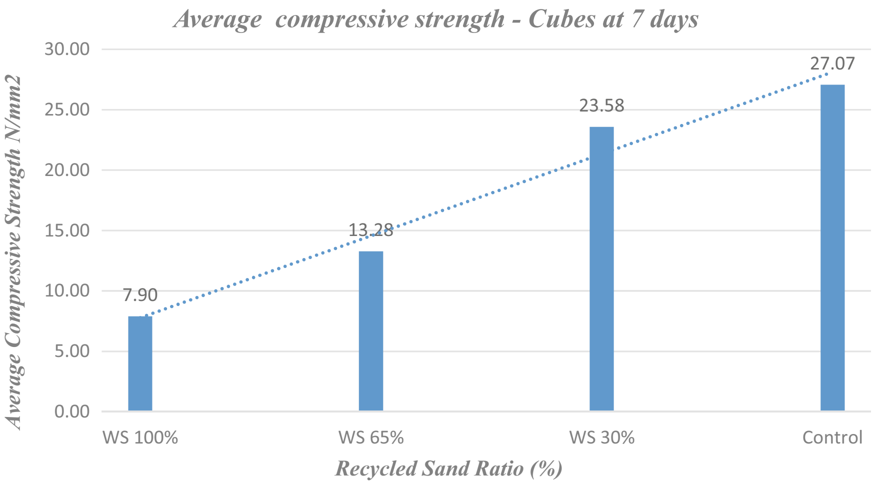

Fig. 12.3 Average compressive strength of the tested samples in comparison to the control samples

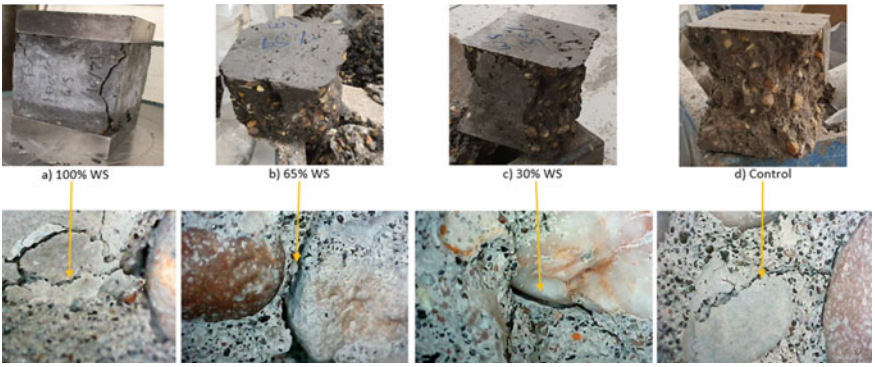

Fig. 12.4 Crack propagation within the concrete cubes after testing

depending on the needed application. Recycled waste sand could be used effectively as a partial or complete replacement of standard sand in suitable quality mortars and concretes. This will depend on the required design characteristics and the intended applications. Further work is still needed to evaluate the long-term effect and strength of concrete, including a full life cycle assessment (LCA).

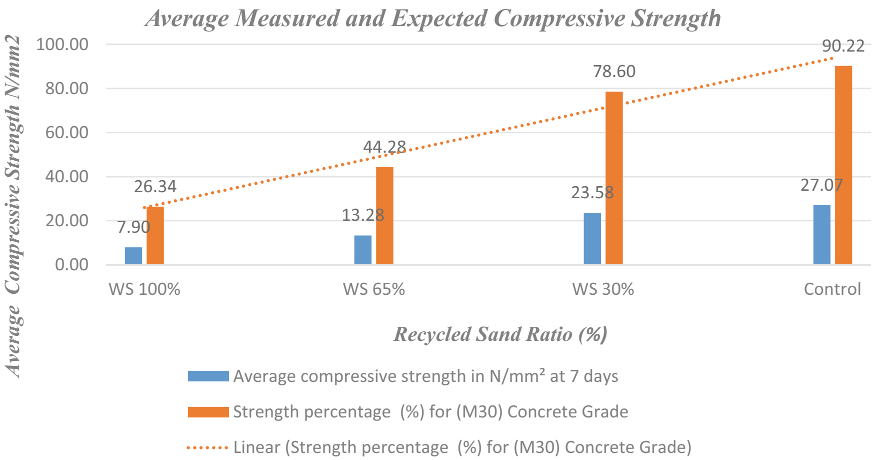

Fig. 12.5 Average compressive strength versus recycled sand ratio

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