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# A Review on the Usage of Recycled Sand in the Construction Industry

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## Abstract

The construction industry requires natural sand for many applications. The recycled sand obtained from industrial operations can also be utilized in construction activities. Many industries generate waste sand as a byproduct. The material generated from this discarded molds and cores is usually known as “used foundry sand,” “waste foundry sand,” or “spent foundry sand.” A vast quantity of used foundry sand is generating and heaping globally in a day-by-day manner. In this review article, an attempt is made to explore the characteristics and various utilizations of this recycled sand from the foundry industry as a valuable resource material in construction activities. From the analysis of the multiple types of research done so far on the reuse of waste foundry sand, it is found that the waste foundry sand is reusable in different civil engineering applications with added advantages. The advantageous applications of used foundry sand are ranging from the road base material to the substitute to fine aggregate in high-performance self-compacting concrete. More generally used foundry sand in the range of 10–30% is best suitable as a partial substitute to regular sand in mortar and concrete making. The use of recycled sand such as waste foundry sand in the construction industry can not only eliminate the problems of waste management and environmental impacts but also substantially boost up the sustainable developmental activities by way of reducing the consumption of natural resources.

**Keywords:** concrete, mortar, road base, used foundry sand, workability

## 1. Introduction

From the early civilization of humankind, as a construction material, sand is used extensively. In clay bricks, mud mortars, and lime mortars, the sand finds applications. When the concrete emerged as a construction material, the sand became an integral part of this versatile material. After the stone age, metals were used in making the tools and utensils. For the production of metal items, foundry operations are invariably required. For mold making, the sand has been used from the beginning of the usage of metals in the day-to-day life of the human being. The foundries utilize the sand for two critical applications of mold making and core making. As stated by Javed and Lovell [1], the mold is the outside container of the casting, and the core is the form for achieving the internal shape and cavities within the casted metal structure. Now also, the sand is the primary constituent matter of the mold or core making materials. Silica sand, along with binders

such as clay or sodium chemical binders, is used for the making of the mold for metal casting. Sand with clay is naturally available and is abundantly used in mold making. As per the Bureau of Indian Standards IS 3343 [2], original molding sand used in foundries has clay content varied from 5 to 20%. Dogan-Saglamtimur [3], from the research on the reuse of the waste foundry sand in the manufacture of geopolymer concrete, depicted that foundry sands have a loose structure in nature. After several cycles of reuses, the molding sand or foundry sand from the released molds and cores discarded and becomes industrial wastes. A large quantity of such industrial waste sand is generated from foundries all over the world. U. S. Department of Transportation [4] estimated that 1 ton of casting requires 1 ton of foundry sand approximately. American Foundry Society [5] reported that 100 million tons of sand are using and reusing in foundries per annum in the United States itself. The sand from industrial wastes can be recycled for applications in civil engineering and is called “used foundry sand,” “waste foundry sand,” or “spent foundry sand.”

As the quantity of the used foundry sand is so enormous, the disposal of used foundry sand in landfills is significantly affecting the ecology and the environment. Hence, the reuse of waste foundry sand in civil engineering applications other than a land filling is much beneficial to the society from both economical and environmental point of view. The research on the reuse of waste foundry sand in the construction industry is very much crucial as it is the largest consumer of the virgin sand. As a matter of fact, the natural sources of sand are being affected due to the overconsumption and now facing depletion. Every step toward reducing the use of natural sand by adopting waste foundry sand as a full or partial substitute to natural sand will lead to the preservation of the natural resources and the safe disposal of the industrial waste sand to a beneficial application safeguarding the ecology and the environment. In the following paragraphs, the used foundry sand and their properties are discussed in detail. Also, the utilization of used foundry sand recommended by various researchers in a variety of fields related to the construction industry is addressed with sufficient experimental findings. Since concrete plays a significant role in the construction industry, an extensive study of properties of concrete incorporating used foundry sand is also appended for the easy understanding of the applicability of the used foundry sand in concrete making.

## **2. Used foundry sand**

Used foundry sand (UFS), waste foundry sand (WFS), or spent foundry sand (SFS) is obtained from the released waste molds and cores from the foundries. The released molds' and cores' size and shape are different depending on the casting. The discarded molds and cores can be directly used for filling low lying areas. However, there may be a chance of contamination of the water sources due to the chemicals present in the waste foundry sand. To employ the used foundry sand for other civil engineering applications, further processing is required.

It should be noted that the waste foundry sand may contain metal and debris present in the discarded molds. However, as per the reports of the American Foundry Society [5], in most of the foundries, sand reclamation units are employed for the removal of metal particles and debris from the waste foundry sand for advanced applications. Two types of foundry sand are generated from foundries. These are named “green sand” and “chemically bonded sand,” depending on the binders used in the production of mold or core. About 90% of the used foundry sand comes under the category of green sand only. Processed used foundry sand as per Salim et al. [6] is shown in **Figure 1**.



**Figure 1.**  
*Used foundry sand.*

### **3. Properties of used foundry sand**

The used foundry sand has varied physical, chemical, and mechanical properties. In an examination of the characteristics of waste foundry sand and its leachate, Siddique et al. [7] emphasized that the physical and chemical properties of the used foundry sand mostly depend on the industrial segment for which the casting is made. The physical, chemical, and mechanical properties of used foundry sand are discussed in detail below.

#### **3.1 Physical properties**

The physical properties of used foundry sand are showing much diversity across the globe. The green sand and chemically bonded sand have different colors. As per the reports of Federal Highway Administration [8], the color of the green sand is gray or black, and the chemically bonded sand has an off-white or medium tan color. Usually, the size of the majority of the particles in the used foundry sand is in the range of 600–150 microns. The U. S. Department of Transportation [4] stated that the used foundry sand has moderately uniform particle size distribution, with just about 85–95% of the particles between 600- and 150-micron sizes and 5–12% of the particles having less than 75-micron sizes. Usually, the used foundry sand consists of subangular to round-shaped particles. The specific gravity of the used foundry sand depends on the properties of the virgin sand and the type of the binders used. Generally, the specific gravity of spent foundry sand has many variations from foundries to foundries. Javed and Lovell [1] stated that the specific gravity of spent foundry sand varies from 2.39 to 2.55. Bulk density of used foundry sand also depends on the properties of virgin sand and the materials used as binders. Naik et al. [9] reported that the bulk density of used foundry sand varies from 1052 to 1554 kg/m<sup>3</sup>. The percentage of the mass of water absorbed to the dry mass of the material is water absorption. As per the values of water absorption results from the earlier studies reported by Javed and Lovell [1], American Foundrymen's Society [10], and Johnson [11], the used foundry sand has water absorption of 0.45%. Later, it was revealed that the water absorption values of used foundry sand have much

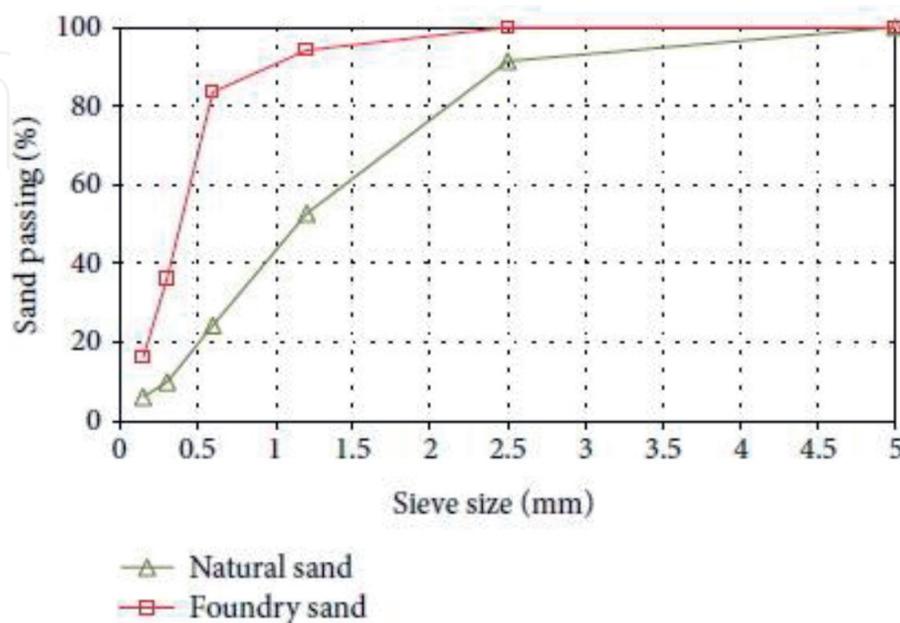
variation from sources to sources. Naik et al. [9] stated that the water absorption of used foundry sand is in the range of 0.38–4.15%. The fineness modulus of sand depends on the grading of the material. The surface moisture content of the sand can reduce the water requirement of the concrete and mortar mix. Most of the researchers did not report the fineness modulus and moisture content of the used foundry sand. However, Seshadri and Salim [12] and Kewal et al. [13] reported that waste foundry sand has a fineness modulus of 2.28 and 2.45, respectively. As per the physical properties stated by Guney et al. [14], the used foundry sand has a moisture content of 3.25%. A comparative graph of the gradation of natural sand and used foundry sand, as reported by Prabhu et al. [15], is shown in **Figure 2**.

### 3.2 Chemical properties

The chemical properties of used foundry sand depend on the type of binders used in the foundry sand mixture. Johnson [11] reported that the pH of used foundry sand varies from 4 to 8. The used foundry sand consists of different metal oxides. These include  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{SO}_3$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ,  $\text{TiO}_2$ ,  $\text{Mn}_2\text{O}_3$ , and  $\text{SrO}$ . Etxeberria et al. [16] stated that as far as the chemical constituents of used foundry sand were concerned, silicon dioxide constitutes the maximum contribution with 95.10% and the minimum by sulfur trioxide having a contribution of 0.03% of the total mass of used foundry sand. As per the chemical analysis of used foundry sand reported by American Foundrymen's Society [10], the spent foundry sand has a loss on ignition of 5.15%.

### 3.3 Mechanical properties

The spent foundry sand has excellent mechanical properties at par with the conventional sand. American Foundrymen's Society [10] stated that the spent foundry sand has an angle of internal friction varying from  $33^\circ$  to  $40^\circ$ , and the California Bearing Ratio (CBR) values range from 4 to 20%. As per the reports of the Ministry of Natural Resources [17], the Micro-Deval Abrasion Loss of used foundry sand is less than 2%, and Magnesium sulfate soundness loss varies from 5 to 15%.



**Figure 2.**  
Gradation of natural sand and foundry sand.

## **4. Applications of used foundry sand in the construction industry**

The used foundry sand can be used in partially or fully for all the purposes where the conventional sand is used. The used foundry sand can be used in a wide variety of applications such as road materials, cement concrete, geopolymer concrete, cement mortars, paver blocks, and masonry blocks.

### **4.1 Road materials**

The used foundry sand can be utilized as materials for road construction. Yazoghli-Marzouk et al. [18] studied the recycling of foundry sand in road construction. They found that treated used foundry sand with a 5.50% hydraulic binder did not show environmental impacts by leaching and has desirable mechanical properties and recommended the application of used foundry sand in the sub-base layer in road construction. The source of foundry sand was a stock of about 150,000 tons of foundry sand stock in Burgundy in France. Iqbal et al. [19] conducted studies on the operation of used foundry sand as a material for embankment, and structural fill further emphasized that sand replaced with 6% used foundry sand is best suitable for structural fill, embankment, and road sub-base material. Generally, it is believed that the compacted waste foundry sand can cause leaching of toxic constituents to the groundwater. But many pieces of research in this regard showed that waste foundry sand did not contaminate the surface water or groundwater. Arulrajah et al. [20] conducted the chemical composition analysis and leachate analysis of used foundry sand. They put forth the implementation of waste foundry sand in road embankment fill and pipe bedding applications. The waste foundry sand used in this research was provided by a recycling plant in Melbourne, Australia. The used foundry sand has superior qualities as that of conventional sub-base material for road construction, and the usage of waste foundry sand can reduce the thickness of the sub-base layer, and thereby, construction cost can be reduced. Guney et al. [21] studied the properties of highway sub-bases with used foundry sand mixtures. They highlighted that the incorporation of used foundry sand can reduce the thickness of the sub-base layer in the sub-base construction of roads.

In the construction of flexible pavements too, the waste foundry sand can be employed to a noticeable extent. The aptness of the waste foundry sand in asphalt mixtures depends on several properties of waste foundry sand, including gradation, particle shape, cleanliness, and surface texture. In a case study on the different methods other than the landfill for the disposal of spent foundry sand generated from the small to medium enterprises in the United Kingdom, Nabhani et al. [22] stated that both green sand and chemically bonded sand could be beneficially replaced with virgin sand in the manufacture of asphalt with an impending extension of its useful working life to about 60 years. Apart from the working life extension, cost savings can also achieve by the replacement of virgin sand by used foundry sand. The used foundry sand incorporated asphalt mixtures are environmentally safe material having no adverse effects on the surroundings. Bakis et al. [23] conducted experiments on the properties of asphalt mixtures made with used foundry sand by replacing the aggregate in different fractions. The environmental impact on the use of used foundry sand also examined. As per the research findings of the investigation on the properties of the used foundry sand incorporated asphalt mixtures, it is described that the use of waste foundry sand in asphalt mixtures did not considerably affect the surrounding environment and further suggested that 10% aggregates can be replaced with the waste foundry sand in the production of asphalt mixtures. Javed et al. [24] investigated the possibilities of the usage of green sand from gray iron castings in asphalt concretes by replacing the total aggregates

by 15, 20, and 30% by weight. The bulk-specific gravity, theoretical-specific gravity, Marshall stability, and Marshall flow tests were conducted on the asphalt concrete samples incorporating used foundry sand and control asphalt concrete sample. From the research analysis, it is confirmed that the aggregates in asphalt concrete can be replaced with green sand obtained from gray iron castings up to a replacement level of 15%.

For road foundations also, used foundry sand can be employed in an efficient manner. Pasetto and Baldo [25] investigated the properties of road foundation mixtures made using cement, waste foundry sand, and steel slag in different proportions. The samples were tested after different curing periods for Proctor, compressive strength, indirect tensile strength, and elastic modulus by static and dynamic tests. From the analysis of hydraulically bound mixtures made with waste foundry sand and steel slag, it is noted that the used foundry sand with cement and steel slag showed satisfactory results as per the norms of Italian Road Technical Standards, and the mixture containing 80% of steel slag and 20% of waste foundry sand gives the optimum characteristics. The used foundry sand can be employed in structural fill, embankment, road sub-base, and asphalt concrete mixtures either independently or with other materials like cement and steel slag.

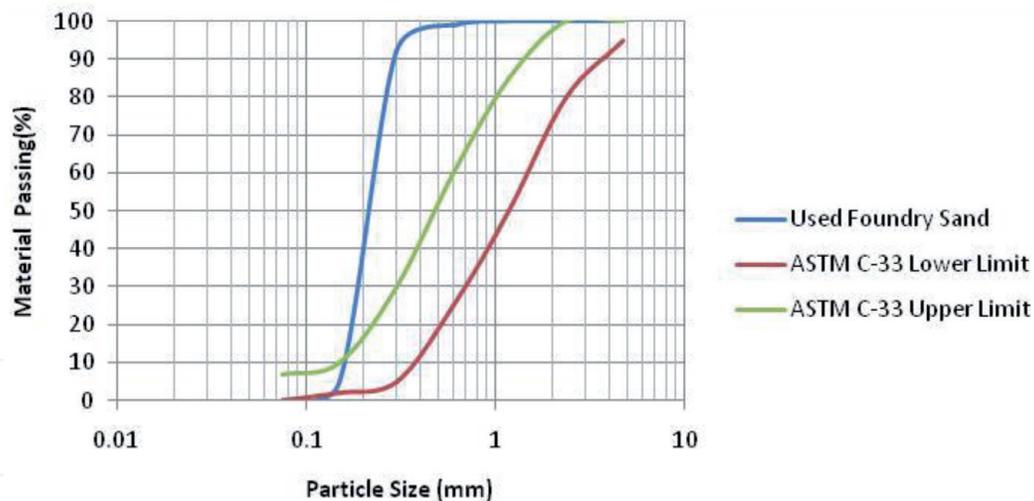
## **4.2 Cement concrete**

The waste foundry sand gradation is mostly outside the lower limits for fine aggregates used in concrete. It is worthwhile to note that the grading of used foundry sand is too fine to satisfy the specifications of fine aggregate. Hence, the waste foundry sand can replace the fine aggregates in cement concrete to some extent only. **Figure 3** shows the grading curve for used foundry sand as per the sieve analysis by Khatib et al. [26] and the gradation limits for fine aggregates as per ASTM-C-33 [27].

### *4.2.1 General concretes*

In general-purpose concretes, used foundry sand finds extensive applications. The used foundry sand is an effective substitute to fine aggregate in general-purpose concretes having strength parameters ranging from low strength to ultra-high strength. Many researchers found that used foundry sand is effective in reducing the usage of fine aggregate in common concretes to a greater extent. Manoharan et al. [28] investigated the characteristics of concrete with chemically bonded used foundry sand in concrete with characteristic compressive strength of 20 MPa having natural river sand replaced with 0, 5, 10, 15, 20, and 25% of used foundry sand and reported that the strength parameters of used foundry sand incorporated concrete containing 5–20% used foundry sand are similar to the control mix with 100% natural river sand of 4.75 mm maximum size as fine aggregate and 20 mm size crushed granite as coarse aggregate. The used foundry sand can reduce the cost of construction, too, to some extent. Bhimani et al. [29] stated that the concrete made with river sand and 20 mm downgraded crushed basalt rock aggregates with a 28th-day compressive strength of 20 MPa and a cost reduction of 3.39% could be achieved by replacing 50% river sand with waste foundry sand in the concrete mix.

In medium strength concrete with a characteristic compressive strength equal to or greater than 30 MPa, used foundry sand is an efficient replacement material to fine aggregates, without compromising on the qualities of the concrete produced. Sohail et al. [30] investigated the properties of concrete of a characteristic compressive strength of 30 MPa made with river sand as fine aggregate and



**Figure 3.**  
*Used foundry sand grading curve.*

20 mm nominal size crushed granite rock aggregates along with green sand from gray iron foundry as a substitute to river sand at 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% and reported that up to 70% river sand could be replaced with used foundry sand for the concrete with sufficient strength parameters. The abrasion resistance and the strength properties of concrete having 40 MPa compressive strength at 28 days made with 4.75 mm nominal size natural sand and 12.50 mm nominal size coarse aggregate with used foundry sand as a partial substitute to river sand at 0, 5, 10, 15, and 20% were investigated by Singh and Siddique [31] and reported in similar lines that up to 20% natural sand could be replaced with used foundry sand for the production of the concrete having desirable properties and further notified that the incorporation of used foundry sand increased the abrasion resistance of the concrete.

Natural fine aggregates can be replaced with waste foundry sand for the production of high strength concrete also. Guney et al. [14] investigated the application of waste green foundry sand in high strength concrete of compressive strength of 65 MPa at 28 days made with fine sand replaced with waste foundry sand at 0, 5, 10, and 15% by weight of fine sand. They reported that the high strength concrete made with a replacement of 10% of fine aggregates with waste foundry sand exhibited strength parameters at par with the control concrete made with fine sand as fine aggregate. In this research, it is further noted that the freezing and thawing reduced the physical and mechanical properties of concrete by the addition of waste foundry sand to the concrete; however, the strength parameters were found to be acceptable as per the norms fixed by the American Concrete Institute. Chandrasekar et al. [32] succeeded in developing high strength concrete with green sand by partially replacing river sand of 4.75 mm maximum size by 0, 10, 20, 30, and 40% with waste foundry sand and 12.5 mm nominal size coarse aggregate. Slump, compressive strength, split tensile strength, flexural strength, and modulus of elasticity were determined on the samples produced. The effects of the concrete on elevated temperature were also studied. Based on the analysis of the test results, it is confirmed that it is very much possible to replace the fine aggregates with used foundry sand in the range of 10–20% for the production of high strength concrete having a 28th-day compressive strength of 60 MPa for better strength characteristics than the control concrete.

Experimentally, it is proved that ultra-high-strength concrete can be made with used foundry sand as a partial substitute to fine aggregate. Torres et al. [33]

investigated the properties of ultra-high-strength concretes of 120 MPa compressive strength at 28 days made with 3.35 mm well-graded manufactured sand from limestone and river sand as fine aggregates and 6.35 mm size limestone and pea gravel as coarse aggregates along with spent foundry sand. In this research, fine aggregates were replaced by foundry sand at 0, 10, 20, and 30%. As an outcome of the study, it is noted that for optimum performance of the ultra-high-strength concrete, the river sand could be replaced with 10% spent foundry sand in the mix, which uses no coarse aggregates at all.

Nowadays, the requirements of fresh concrete in all the infrastructure projects are met with the ready-mixed concrete (RMC). By using the ready-mixed concrete of required grade, the quality of the concrete can be maintained better than the site mixed concrete. Many kinds of research were conducted on the feasibility of employing used foundry sand in the production of ready-mixed concrete also. Basar and Aksoy [34] conducted experiments on the effect of waste foundry sand as a partial substitute in 0, 10, 20, 30, and 40% of regular sand on the mechanical, leaching, and microstructural characteristics of ready-mixed concrete. The results of the various tests revealed that the typical regular sand in the replacement level of 20% with used foundry sand gives satisfactory mechanical and physical properties in the ready-mixed concrete incorporating used foundry sand.

#### *4.2.2 Special concretes*

The used foundry sand can be employed in special concretes like high-performance concrete, self-compacting concrete, high-performance self-compacting concrete, and lightweight concrete. Salim et al. [6] stated that high-performance concrete is high-strength concrete, having desired properties and uniform characteristics. Seshadri and Salim [12] investigated the features of high-performance concrete of design compressive strength of 60 MPa at 28 days with manufactured sand and 20 mm nominal size crushed stone aggregates as fine aggregates and coarse aggregates, respectively, in which fine aggregates were partially replaced by chemically bonded used foundry sand from 0 to 40% in 5% increments and found that up to 30% manufactured sand can be replaced with used foundry sand in the production of high-performance concrete with satisfactory strength characteristics. Ranjitham et al. [35] investigated the properties of 75 MPa characteristic compressive strength high-performance concrete made with 12.5 mm maximum size coarse aggregate and 4.75 mm maximum size river sand as fine aggregate with partial replacement of river sand by green foundry sand and reported that 10% addition of used foundry sand gives excellent strength properties than that of the control concrete without used foundry sand for high-performance concrete of 75 MPa characteristic compressive strength.

For the manufacture of self-compacting concrete also, the used foundry sand can be employed for the reduction in the consumption of the natural fine aggregates. The self-compacting concrete is a type of concrete that does not need external mechanical vibration for the compaction. The self-compacting concrete having strength characteristics in line with the concrete with conventional fine aggregates can be made with partial replacement of fine aggregates with used foundry sand. Siddique and Sandhu [36] reported that self-compacting concrete having a design characteristic compressive strength of 30 MPa made with 15% normal sand replaced by waste foundry sand and 10–12 mm maximum size coarse aggregate exhibited sufficient strength characteristics. Nirmala and Raviraj [37] conducted experiments on the optimization of the self-compacting concrete with used foundry sand as a partial substitute for manufactured sand (M-sand) using the Taguchi approach. The slump flow, V-funnel flow, U-box, L-box, and compressive strength

tests were conducted. On the basis of the results obtained, it is noted that for obtaining optimum strength properties for the self-compacting concrete, 20% of manufactured sand (M-sand) should be replaced with spent foundry sand.

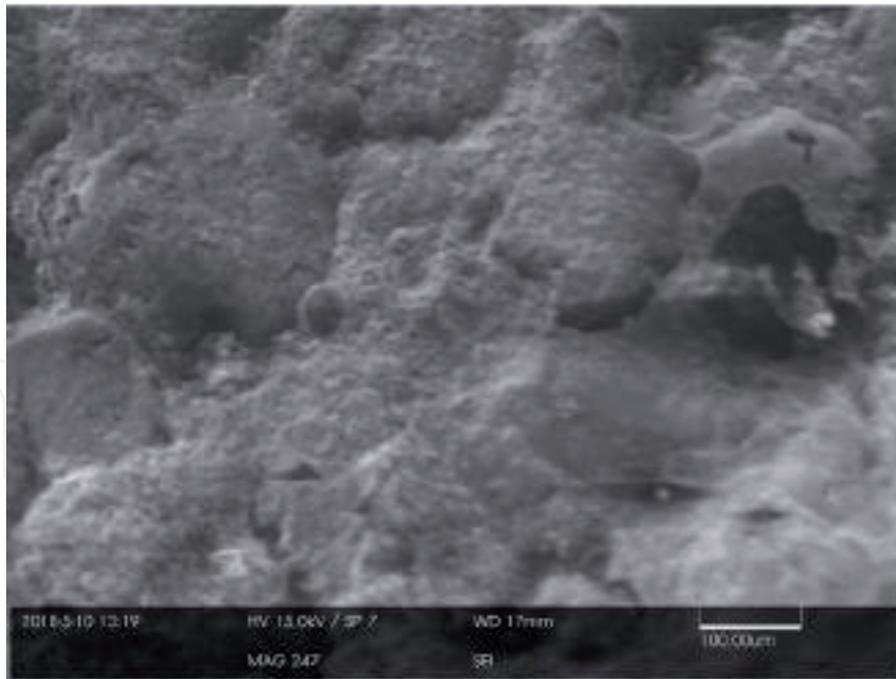
In modern construction practice, high-performance self-compacting concrete has great applications where the complicated molds are in use, and the reinforcement steels are very much congested. In this particular situation also, foundry sand waste can be employed with other materials in the production of self-compacting concrete. The high-performance self-compacting concrete has superior early as well as long-term durability and mechanical strength parameters. Makul [38] investigated the properties of high-performance self-consolidating concrete made with waste rice husk ash and foundry sand waste with water to binder ratios of 0.35 and 0.45 where the ordinary portland cement was replaced by rice husk ash in 10 and 20% by weight and the fine aggregate was replaced with foundry waste sand in 30 and 50% by weight. The foundry sand waste used was obtained from automobile part casting foundry. The slump flow, V-funnel flow, splitting tensile strength, and compressive strength tests were performed. Based on the test results, it is observed that the high-performance self-compacting concrete made with 30% replacement of fine aggregates with foundry sand waste and 10% cement replaced with rice husk ash has higher compressive and tensile strength than the conventional self-compacting concrete of the control mix.

Lightweight concrete is concrete, having less density than the regular concrete. In certain applications, regular concrete cannot be entertained due to its higher dead weight. In such situations, lightweight concrete can be effectively utilized. For the manufacture of lightweight concrete also, used foundry sand can be employed efficiently. Hossain and Anwar [39] reported that by the use of waste foundry sand and volcanic ash, lightweight concrete (LWC) can be made economically for the promotion of sustainable construction by reducing the disposal problems of waste foundry sand and volcanic ash.

### **4.3 Geopolymer concrete**

Geopolymer concrete is an innovation in the field of concrete in which cement is not a constituent. In geopolymer concrete also, the waste foundry sand can be used in place of fine aggregates in various replacement levels. Dogan-Saglamtimur [3] investigated the waste foundry sand usage in geopolymer concrete made with sodium hydroxide or sodium silicate for building material production and maximum compressive strength of 12.3 MPa obtained for waste foundry sand incorporated geopolymer concrete containing 30% sodium silicate when the samples were cured at 200°C. The waste foundry sand used in this research is of green sand, which contained bentonite. Based on the results obtained, it is confirmed that the geopolymer material produced with waste foundry sand is suitable for use as a building wall material. For the manufacture of geopolymer concrete cured in ambient temperature also, used foundry sand can be employed in place of fine aggregates. Bhardwaj and Kumar [40] studied the effect of green sand from the ferrous foundry on ambient cured geopolymer concrete. They stated that up to 60% replacement level of fine aggregates to waste foundry sand, the strength parameters are improved better than that of the conventional geopolymer concrete. Scanning electron microscope (SEM) image of concrete of compressive strength of 46 MPa containing 100% chemically bonded foundry sand (FS), as reported by Mavroulidou and Lawrence [41], is shown in **Figure 4**.

In another study on geopolymer concrete made with manufactured sand as fine aggregate with partial replacement of fine aggregate at 0, 5, 10, 15, 20, and 25% by weight of fine aggregate with foundry sand, Jerusha and Mini [42] studied the



**Figure 4.**  
*SEM image of concrete containing 100% FS.*

slump of the fresh geopolymer concrete and compressive strength of hardened geopolymer concrete samples at 3rd day, 7th day, and 28th day and found that the optimum replacement percentage of foundry sand to the fine aggregate is 15% for the geopolymer concrete made of foundry sand, and the maximum compressive strength obtained was 21.33 MPa.

#### **4.4 Cement mortars**

The used foundry sand can constitute as a raw material for the production of cement mortars efficiently. The use of used foundry sand can reduce the cost of the mortars to a considerable extent. Safi et al. [43] conducted experiments on self-compacting mortars made with foundry sand wastes replacing normal sand at 0, 10, 30, and 50% and reported that self-compacting mortars incorporating foundry sand wastes yielded good results at 30% of foundry waste sand in place of normal sand. By the addition of used foundry sand, the workability of the cement mortars gets reduced. However, the deficiency in the workability can be made good by adding a superplasticizer at a low dosage. Cevik et al. [44] investigated the characteristics of cement mortars incorporating waste foundry sand from Turkey steel manufacturer as a partial substitute to natural sand at 0–60%. Based on the compressive strength tests conducted on samples at 3, 7, and 28 days, it is found that the optimum percentage substitution of used foundry sand as a replacement of natural sand in cement mortar is 15%, which yields the maximum compressive strength. Another research study on the use of calcium aluminate cement for recycling green sand and chemically bonded sand conducted by Navarro-Blasco et al. [45] confirmed that by using calcium aluminate cement, mortars of strength higher than 10 MPa can be produced with regular sand replaced by waste foundry sand at 50%.

#### **4.5 Precast concrete products**

The used foundry sand can be incorporated in the concrete for the manufacture of precast concrete products like paver blocks and masonry blocks. Many researchers

conducted experiments on the applicability of used foundry sand in the production of paver blocks. Marchioni et al. [46] conducted experiments on paver blocks with spent foundry sand in Brazil. They reported that the paver blocks produced with 15% replacement of the fine aggregates with spent foundry sand gave acceptable strength parameters as per Brazilian standards ABNT NBR 9781. The incorporation of used foundry sand has shown a mixed response on the compressive strength of paver blocks. Kewal et al. [13] investigated the properties of paver blocks with geopolymer concrete incorporating used foundry sand and stated that the addition of used foundry decreases the compressive strength of paver blocks made with foundry sand-based geopolymer concrete. In another research on interlocking concrete paving blocks produced with foundry sand waste, Santos et al. [47] conducted compressive strength, measurement of dimension, and water absorption test paver blocks incorporating foundry sand waste. From the results, it is noted that the compressive strength of interlocking paver blocks produced with foundry sand waste is less than the compressive strength of paver blocks produced without foundry sand waste as per the specification laid by the Brazilian standards for the paver blocks. Tausif et al. [48], in a research study on foundry sand use in paver blocks, stated that paver blocks made with 12 mm maximum size coarse aggregate and 4.75 mm maximum size natural sand as fine aggregate with 0.3% synthetic fibers and foundry sand usage at 10% replacement of the fine aggregate showed a maximum compressive strength of 51.48 MPa at 28 days. In another research on the feasibility of used foundry sand in concrete pavers, Kulkarni and Katti [49] studied the properties of concrete pavers made with coarse aggregates of 10 mm maximum size and natural river sand as fine aggregate where the fine aggregates were replaced at 0, 25, 50, 75, and 100% with waste foundry sand from metal casting industries. Water absorption, compressive strength, split tensile strength, flexural strength, and abrasion resistance of the paver blocks were determined. From the test results, it is observed that water absorption increases with the percentage addition of waste foundry sand, whereas the compressive strength, splitting tensile strength, flexural strength, and abrasion resistance of paver blocks incorporating waste foundry sand decrease with the percentage addition of waste foundry sand. However, up to 50% replacements of natural river sand by waste foundry sand, the strength parameters of the paver blocks made are within the acceptable limits set forth by Indian Standard IS 15658 for paver blocks.

The waste foundry sand can be utilized in the production of masonry blocks also. Mahima et al. [50] studied compressive strength, water absorption, block density, drying shrinkage, and moisture movement of high-strength solid masonry blocks utilizing waste foundry sand as a replacement for fine aggregate and stated that at a replacement level of 20–30% of manufactured sand to waste foundry sand, the compressive strength and other parameters of the masonry blocks substantially improved over the regular masonry blocks. In this research, the control mix has a compressive strength of 23.78 MPa, whereas the blocks made with 20% fine aggregate replaced by used foundry sand yielded a compressive strength of 24.53 MPa. Naik et al. [51] studied the properties of concrete products like bricks, blocks, and paving stones incorporating recycled materials like used foundry sand, fly ash, and bottom ash. The brick samples were cast with regular sand, 9.5 mm maximum size crushed limestone chips, fly ash, bottom ash, and used foundry sand at 25 and 35% replacement of regular sand and tested for compressive strength, water absorption, density, and drying shrinkage. The test results confirmed that the concrete bricks with fine aggregates replaced with 25 and 35% ferrous green sand met with the compressive strength requirements as per ASTM C 55 for grade N concrete bricks.

A summary of the research studies described for different applications above is given in **Table 1** for easy reference.

Sl. No.	Researchers	Application of used foundry sand
1	Yazoghli-Marzouk et al. [18]	Sub-base layer in road construction
2	Iqbal et al. [19]	Material for embankment and structural fill
3	Arulrajah et al. [20]	Road embankment fill and pipe bedding
4	Guney et al. [21]	Highway sub-bases
5	Nabhani et al. [22]	Manufacture of asphalt
6	Bakis et al. [23]	Asphalt mixtures
7	Javed et al. [24]	Asphalt concretes
8	Pasetto and Baldo [25]	Road foundation mixtures
9	Manoharan et al. [28]	Concrete of compressive strength of 20 MPa
10	Sohail et al. [30]	Concrete of compressive strength of 30 MPa
11	Singh and Siddique [31]	Concrete of compressive strength of 40 MPa
12	Guney et al. [14]	High-strength concrete of compressive strength of 65 MPa
13	Chandrasekar et al. [32]	High-strength concrete of compressive strength of 60 MPa
14	Torres et al. [33]	Ultra-high-strength concrete of compressive strength of 120 MPa
15	Basar and Aksoy [34]	Ready-mixed concrete
16	Seshadri and Salim [12]	High-performance concrete of design compressive strength of 60 MPa
17	Ranjitham et al. [35]	High-performance concrete of design compressive strength of 75 MPa
18	Siddique and Sandhu [36]	Self-compacting concrete having a compressive strength of 30 MPa
19	Nirmala and Raviraj [37]	Self-compacting concrete
20	Makul [38]	High-performance self-consolidating concrete
21	Hossain and Anwar [39]	Lightweight concrete
22	Dogan-Saglamtimur [3]	Geopolymer concrete
23	Bhardwaj and Kumar [40]	Ambient cured geopolymer concrete
24	Jerusha and Mini [42]	Geopolymer concrete
25	Safi et al. [43]	Self-compacting mortars
26	Cevik et al. [44]	Cement mortars
27	Navarro-Blasco et al. [45]	Cement mortars
28	Marchioni et al. [46]	Paver blocks
29	Kewal et al. [13]	Paver blocks with geopolymer concrete
30	Santos et al. [47]	Paver blocks
31	Tausif et al. [46]	Paver blocks
32	Kulkarni and Katti [49]	Concrete pavers
33	Mahima et al. [50]	High-strength solid masonry blocks
34	Naik et al. [51]	Concrete products like bricks, blocks, and paving stones

**Table 1.**  
*Summary of research studies.*

## 5. Properties of fresh concrete made with used foundry sand

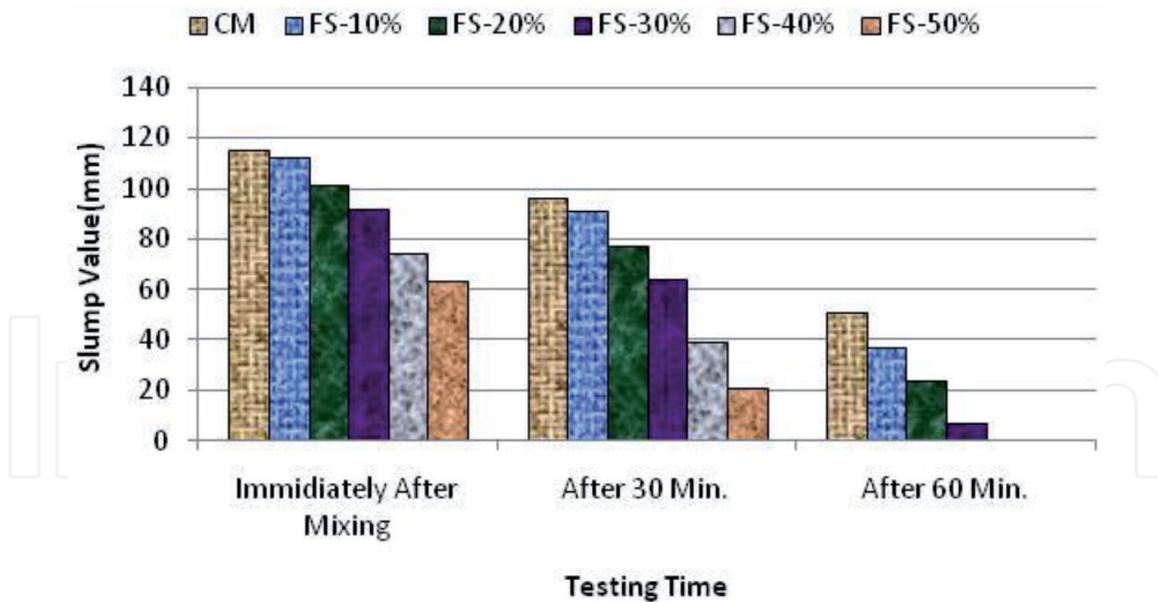
The properties of fresh concrete made with used foundry sand vary much to that of standard concrete with regular ingredients. The fresh properties of concrete include the workability, temperature, density, and air content.

## 5.1 Workability

The workability is an essential parameter of the fresh concrete. In most cases, the workability of the concrete made with used foundry sand decreases as the percentage of used foundry sand increases in the mix. As per Khatib et al. [26], the decrease in workability is attributed to the increase in the fineness of the fine aggregate in the mix. However, some researchers reported equal or slightly higher slump values in concrete made with used foundry sand. Mavroulidou and Lawrence [41] stated that the concrete having 20 MPa compressive strength at 28 days made with 100% chemically bonded waste foundry sand showed 160 mm slump as against 120 mm slump for concrete with regular concrete sand. From the research findings on the use of foundry sand in concrete production, Khatib et al. [26] remarked that the slump dropped approximately in a linear manner from 200 mm for the control mix to zero for the mixes containing 80 and 100% waste foundry sand as the replacement of ordinary sand. Manoharan et al. [28] also confirmed that the slump values of concrete having a design compressive strength of 20 MPa at 28 days made with partial replacement of natural river sand with chemically bonded used foundry sand in 0, 5, 10, 15, 20, and 25% showed a significant decrease in slump value when the used foundry sand content increased in the concrete mix. The same trend was also stated by Bhardwaj and Kumar [52] that the addition of waste foundry sand lowered the workability of geopolymer concrete, and the effect was rapid beyond 40% waste foundry sand replacement level. Some researchers noticed that for concrete incorporating used foundry sand, up to a certain percentage replacement of fine aggregates with used foundry sand, the slump value remains constant. After that, the slump value decreases. In the investigation on the effects of foundry sand as a fine aggregate in concrete production, Prabhu et al. [53] observed that up to 10% replacement of fine aggregate with waste foundry sand, the slump value remains constant as that of the control mix, and after that, the slump values decreased. As per Seshadri and Salim [12], the high-performance concrete of 60 MPa characteristic compressive strength prepared with the fractional replacement of manufactured sand with used foundry sand from 0% to 40% showed a decrease in slump values as the percentage of used foundry sand increased in the concrete mix. In this research, the slump obtained was 140 mm for the control high-performance concrete, and at 40% replacement, the slump value obtained was only 105 mm. Ranjitham et al. [35] observed that for 75 MPa characteristic compressive strength high-performance concrete with cement and fly ash, the slump values consistently reduced from 55 to 42 mm with 0–30% addition of foundry sand. From the research on the effect of used-foundry sand on the mechanical properties of concrete, Siddique et al. [54] stated that the concrete having 28.5 MPa characteristic compressive strength showed a decrease in the slump values when the percentage replacement of used foundry sand increased from 0 to 30%. The concrete mix containing used foundry sand normally requires higher dosages of superplasticizers to maintain the workability. The slump variation of the control mix (CM) and the concrete mix with foundry sand (FS) from 10 to 50% replacement of natural sand when tested immediately after mixing, 30 minutes after mixing, and 60 minutes after mixing as reported by Prabhu et al. [15] for 25 MPa characteristic compressive strength concrete mix is shown in **Figure 5**.

## 5.2 Temperature

Due to the inclusion of used foundry sand into the concrete mix, the temperature of the fresh concrete mix changes. Much research results are not available in this regard for the temperature variations. The temperature difference of the concrete



**Figure 5.**  
*Workability variation of foundry sand concrete.*

mix is attributable to the chemical action of the chemicals present in the used foundry sand with cement and water. In the research report on the application of used foundry sand in concrete production, Prabhu et al. [53] stated that for 20 and 30% replacement of fine aggregate with used foundry sand, the concrete showed an increase in temperature of 1°C from the room temperature. Some researchers observed no variations in fresh concrete temperature to that of room temperature by the addition of used foundry sand in the concrete mix. Manoharan et al. [28] reported that the concrete made with natural river sand replaced with used foundry sand from 10 to 25% in 5% increments had no difference between the room temperature and the fresh concrete temperature. Naik et al. [55] stated that the fresh concrete containing 25 and 35% used foundry sand showed the same temperature as that of room temperature, whereas the control mix showed a 2°C less temperature as that of room temperature. Seshadri and Salim [12] stated that for high-performance concrete made with partial replacement of fine aggregates with used foundry sand, the temperature of the fresh concrete was less than that of the room temperature for all the replacement from 0 to 40%, and the highest temperature difference observed for the replacement of 30 and 35% has a value of 3.5°C, whereas for the control mix, the value observed was 2.5°C.

### 5.3 Density

The specific gravity of the used foundry sand is normally less than the specific gravity of the fine aggregates. Hence, the density of the concrete incorporating used foundry sand may vary depending on the percentage of the used foundry sand in the concrete mix. Few researchers only reported the density of fresh concrete incorporating used foundry sand. Manoharan et al. [28] stated that the fresh density of concrete made with partial replacement of natural river sand with chemically bonded used foundry sand showed a marginal decrease in fresh density when the used foundry sand content increased from 0 to 25% in the concrete mix, the control mix has a fresh density of 2373 kg/m<sup>3</sup>, whereas the concrete containing 25% used foundry sand has a fresh density of 2355 kg/m<sup>3</sup> only.

In some cases, the addition of used foundry sand does not affect the fresh density of concrete. Siddique et al. [54] investigated the effect of used-foundry sand on the mechanical properties of concrete. They reported that the concrete made

with used foundry sand showed almost the same fresh density as that of the control mix for 10–30% replacement of fine aggregates with used foundry sand in which the control mix has a fresh density of  $2331 \text{ kg/m}^3$ , and the concrete with 10, 20, and 30% used foundry sand has a fresh density of  $2332 \text{ kg/m}^3$ . Naik et al. [55] also observed similar trends and confirmed that the control mix and concrete with 35% used foundry sand have the same fresh density, and fresh density of concrete with 25% used foundry sand has shown an increase in 1.30% over the control mix. For the ultra-high-strength concrete made with used foundry sand, also the fresh density has variation over the control mix. Torres et al. [33] investigated the properties of ultra-high-strength concrete made with silica fume, river sand, steel fibers, and green sand at 0, 10, 20, and 30% by weight of cement. They observed that the fresh density of ultra-high-strength concrete marginally decreased with the increase in the percentage of foundry sand in the mix from 2522 to  $2502 \text{ kg/m}^3$ .

#### **5.4 Air content**

A small quantity of air is entrapped in the concrete. Depending on the concrete mix and type of compaction, the entrapped air content may vary. Manoharan et al. [28] investigated the properties of chemically bonded used foundry sand incorporated concrete and reported that the air content of fresh concrete made with partial replacement of natural river sand with used foundry sand showed a marginal increase with an increase in the used foundry sand content in the concrete mix, the control mix has an air content of 5.2%, whereas the concrete with 25% used foundry sand has an air content of 5.7%. Siddique et al. [54] also observed similar trends in air content for the concrete made with used foundry sand and stated that the air content of the concrete with used foundry sand has a higher percentage of air content than the control mix in which the control mix has an air content of 4.2%, whereas the air content at 10% used foundry sand, the air content value was increased to 4.5%. In some cases, the air content of the concrete mix made with used foundry sand is found to be less than the air content of the regular mix. Naik et al. [55] observed that the air content of the concrete made with used foundry sand tends to decrease up to 25% replacement of fine aggregate with used foundry sand and remains constant further up to 35% replacement.

### **6. Properties of hardened concrete made with used foundry sand**

Many researchers reported the hardened properties of concrete made with used foundry sand at different curing periods. The mechanical properties include compressive strength, split tensile strength, flexural strength, and modulus of elasticity. The mechanical properties of hardened concrete made using waste foundry sand are discussed in detail in the following paragraphs.

#### **6.1 Compressive strength**

The concrete incorporating used foundry sand generally shows higher compressive strength than the normal concrete. In some cases, the compressive strength of concrete made with partial replacement of fine aggregates with used foundry sand was below or equal to that of the control mix. Siddique et al. [54] reported that the concrete having the 28th-day compressive strength of 28.5 MPa made with 0, 10, 20, and 30% replacement of sand with used foundry sand, the compressive strength was consecutively increased from 28.5 to 31.3 MPa. Manoharan et al. [28] reported the 28th-day compressive strength of concrete with 0 and 20% chemically bonded

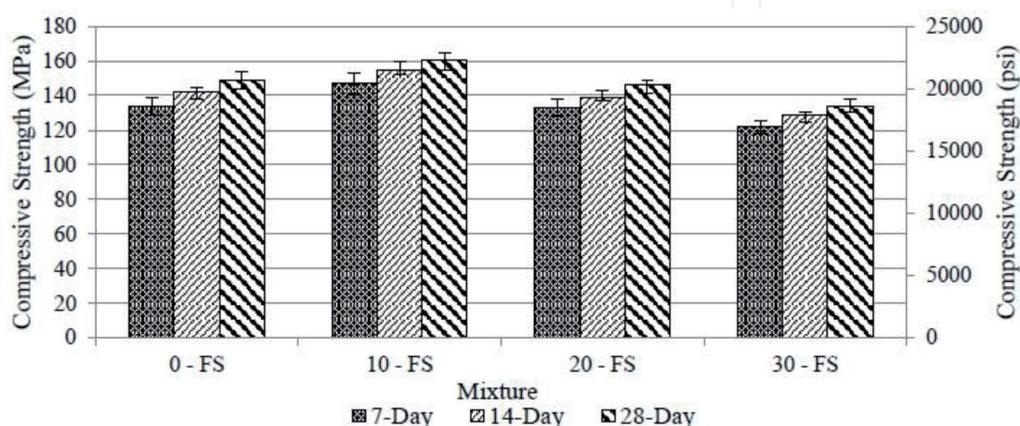
used foundry sand as 24.8 and 26.5 MPa, respectively, and for 25% used foundry sand, the compressive strength was below the compressive strength of control mix. In the majority of the research findings, the concrete containing used foundry sand has higher compressive strength than conventional concrete. As per Siddique et al. [54], the increase in compressive strength of the concrete made with used foundry sand may be due to the higher fineness of the used foundry sand than the regular sand, which resulted in the formulation of a denser concrete matrix along with the silica content present in the used foundry sand.

In some cases, the compressive strength of used foundry sand incorporated concrete is more or less the same as that of the control mix up to a certain percentage of used foundry sand content, and after that, the compressive strength decreases significantly. Prabhu et al. [53] stated that the concrete mix containing foundry sand up to 20% replacement of fine aggregate with foundry sand, the compressive strength observed was moderately close to the strength of the control mix, but beyond 20% replacement, the concrete mix showed lower strength than control mix. Some researchers pointed out specific reasons for the reduction of compressive strength of concrete made with used foundry sand beyond certain replacement levels of fine aggregate with used foundry sand. Singh and Siddique [31, 56] and Siddique et al. [57] pointed out that the compressive strength of concrete containing used foundry sand above a particular percentage gets reduced probably due to the increase in surface area of fine particles, which lead to the reduction of water-cement gel in the concrete matrix, and hence, the binding process of the coarse and fine aggregates does not take place properly. The graph of the compressive strength of ultra-high-strength concrete made with natural sand replaced by foundry sand at 0, 10, 20, and 30% at 7, 14, and 28 days as reported by Torres et al. [33] is shown in **Figure 6**.

## 6.2 Split tensile strength

Depending on the source of used foundry sand, the concrete incorporating used foundry sand shows inferior or at par or superior split tensile strengths than the regular concrete.

In some cases, the split tensile strength of concrete made with used foundry sand increases with the percentage increase in used foundry sand in the concrete mix up to a certain level and decreases afterward. Sohail et al. [30] described that up to 40% replacement of river sand with waste foundry sand from a gray iron foundry, the split tensile strength of concrete at 28th day increases, and further, it reduces consistently up to 100% replacement. Patil et al. [58] confirmed that the split

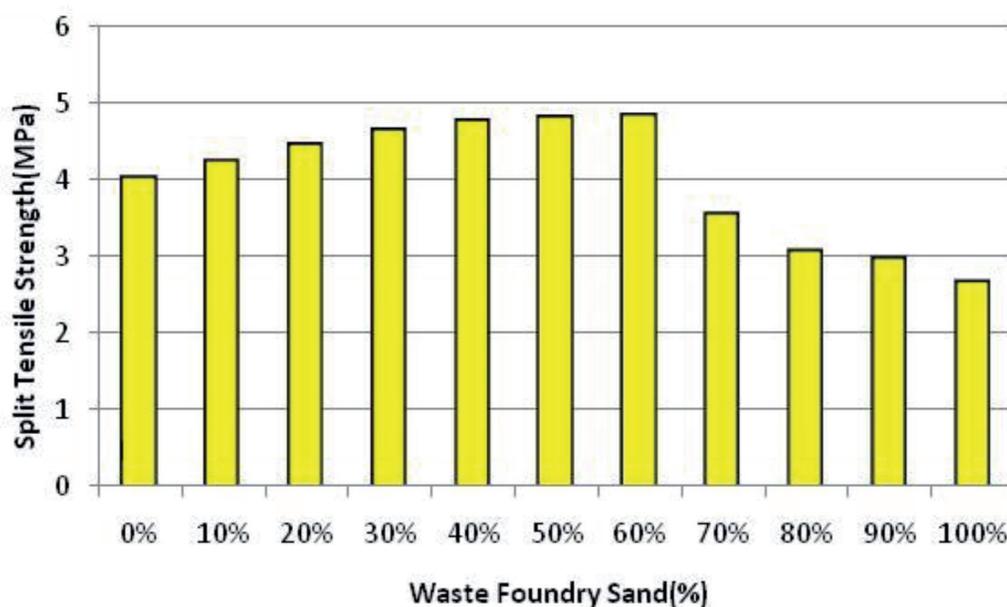


**Figure 6.**  
Compressive strength vs. % foundry sand.

tensile strength of concrete of 30 MPa characteristic compressive strength made with partial replacement of fine aggregates with waste foundry sand increases up to 10% replacement, and further, it decreases in which the control concrete has a split tensile strength of 3.30 MPa, whereas at 10% waste foundry sand content, the split tensile strength increased to 3.87 MPa. Siddique et al. [54] reported that for concrete of 28.5 MPa characteristic compressive strength, the splitting tensile strength was consistently increased from 2.75 to 3.00 MPa from 0 to 30% replacement of regular sand with used foundry sand. In some research findings, the tensile strength of concrete with used foundry sand was found decreasing as the used foundry sand content increases. Seshadri and Salim [12] observed that, for the high-performance concrete with partial replacement of fine aggregate with used foundry sand, the split tensile strength was decreased with the increase in the percentage of used foundry sand from 0 to 40%; at 0% used foundry, the concrete has a split tensile strength of 6.30 MPa, whereas at 40%, the split tensile strength of concrete reduced to 4.40 MPa. Prabhu et al. [53] reported that the split tensile strength of concrete containing foundry sand at 20% substitution of fine aggregate with used foundry sand showed almost equal splitting tensile strength as that of control mix, and the tensile strength in general marginally decreases with an increase in the percentage of foundry sand in the concrete mix. Bhardwaj and Kumar [40] reported that the split tensile strength of ambient cured geopolymer concrete of 40 MPa compressive strength at 28 days made with waste foundry sand increases up to 60% replacement of natural sand with waste foundry sand from the ferrous foundry and decreases afterward for further increase in waste foundry sand percentage. A graphical representation of the split tensile strength of geopolymer concrete of 40 MPa compressive strength at 28 days made of waste foundry sand at different percentage replacements as per Bhardwaj and Kumar [40] is shown in **Figure 7**.

### 6.3 Flexural strength

The flexural strength of the concrete containing used foundry sand shows marginal variations with the addition of used foundry sand. The flexural strength of concrete incorporating used foundry sand usually increases marginally to that of normal concrete. In the research on the properties of concrete with used foundry



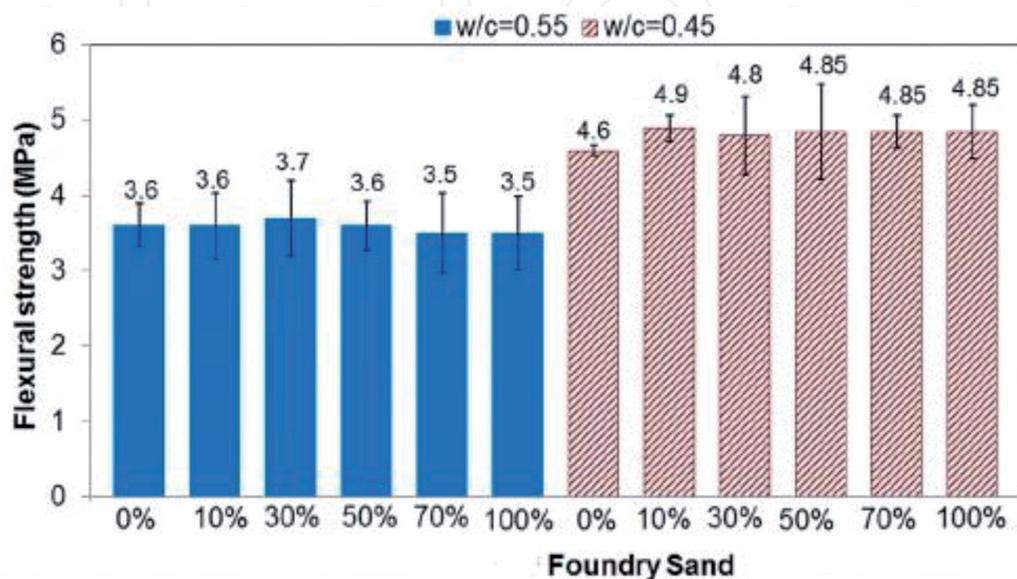
**Figure 7.**  
*Split tensile strength vs. % waste foundry sand.*

sand, Siddique et al. [54] observed that the flexural strength of 28.5 MPa characteristic compressive strength concrete consecutively increased with the percentage increase of used foundry sand up to 30% replacement level in which the flexural strength of control mix was 3.41 MPa and the flexural strength at 30% replacement was 4.18 MPa.

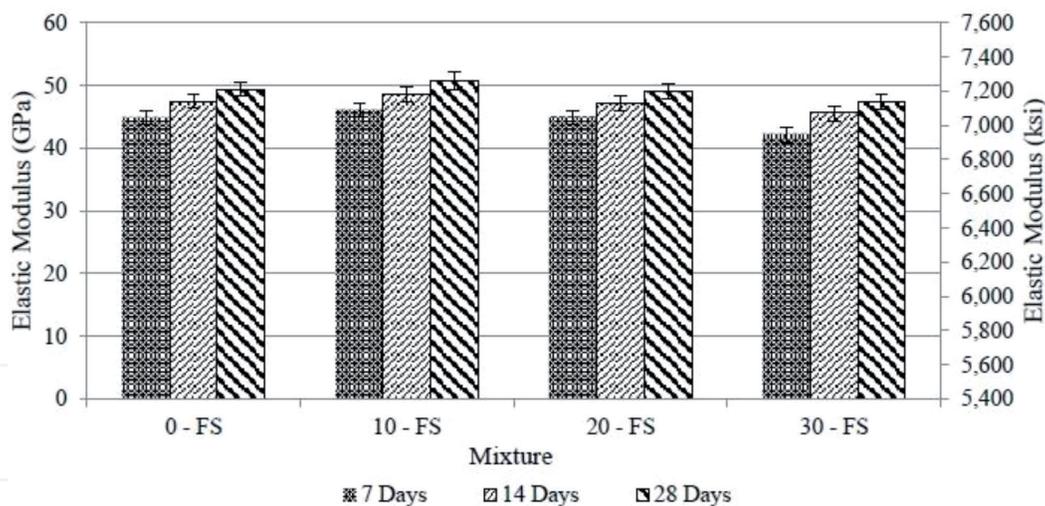
In some cases, the flexure strength seems to decrease with the increase in percentage addition of used foundry sand. Seshadri and Salim [12] reported that the high-performance concrete having 60 MPa characteristics compressive strength showed a decrease in flexure strength on the increase in replacement of fine aggregate with used foundry sand, in which the control mix has a flexural strength of 10.05 MPa, and at 40% used foundry sand content, the flexural strength decreased to 7.05 MPa. As per Torres et al. [33], at 10% replacement of fine aggregate with foundry sand, the ultra-high-strength concrete showed an increase in flexure strength, and further, it showed a consecutive decrement in flexure strength for 20 and 30% replacement of fine aggregates with foundry sand. Prabhu et al. [53] observed that the flexural strength of concrete with foundry sand content up to 20% of fine aggregates has similar results as that of the control mix; further, the flexural strength decreases after 20% replacement level. The flexural strength variation of concrete having 36.5 and 46 MPa compressive strength at 28 days made with regular sand replaced at 0, 10, 30, 50, 70, and 100% to chemically bonded foundry sand with water to cement ratio 0.55 and 0.45 as reported by Mavroulidou and Lawrence [41] is shown in **Figure 8**.

#### 6.4 Modulus of elasticity

Generally, the modulus elasticity of concrete containing used foundry sand increases up to certain percentage content of used foundry sand and then tends to decrease with further increase in the used foundry sand content. Manoharan et al. [28] observed that the modulus of elasticity of concrete increased with percentage replacement of natural river sand with used foundry sand from 0 to 20%, and further addition of used foundry sand decreased the modulus of elasticity, the modulus of elasticity of control concrete was 23.60 GPa, whereas at 20% replacement of river sand with used foundry sand, the elastic modulus increased to 25.40 GPa. As per the research findings of Prabhu et al. [53], the replacement of fine aggregate



**Figure 8.**  
Flexural strength vs. % foundry sand.



**Figure 9.**  
*Elastic modulus variation of foundry sand concrete.*

with used foundry sand slightly improved the modulus of elasticity of concrete mix. Some researchers observed marginal reduction of modulus of elasticity by the addition of used foundry sand. Basar and Aksoy [34] stated that the waste foundry sand content in the ready-mixed concrete reduces the modulus of elasticity. The variation of modulus of elasticity of ultra-high-strength concrete made with foundry sand at 7, 14, and 28 days for foundry sand percentages of 0, 10, 20, and 30% as reported in the research findings of Torres et al. [33] is shown in **Figure 9**.

## **7. Absorption and permeability characteristics of concrete made with used foundry sand**

The absorption and permeability characteristics of concrete include water absorption, rapid chloride permeability, sorptivity, and carbonation. The absorption and permeability characteristics of concrete incorporating used foundry sand are discussed in detail in the following paragraphs.

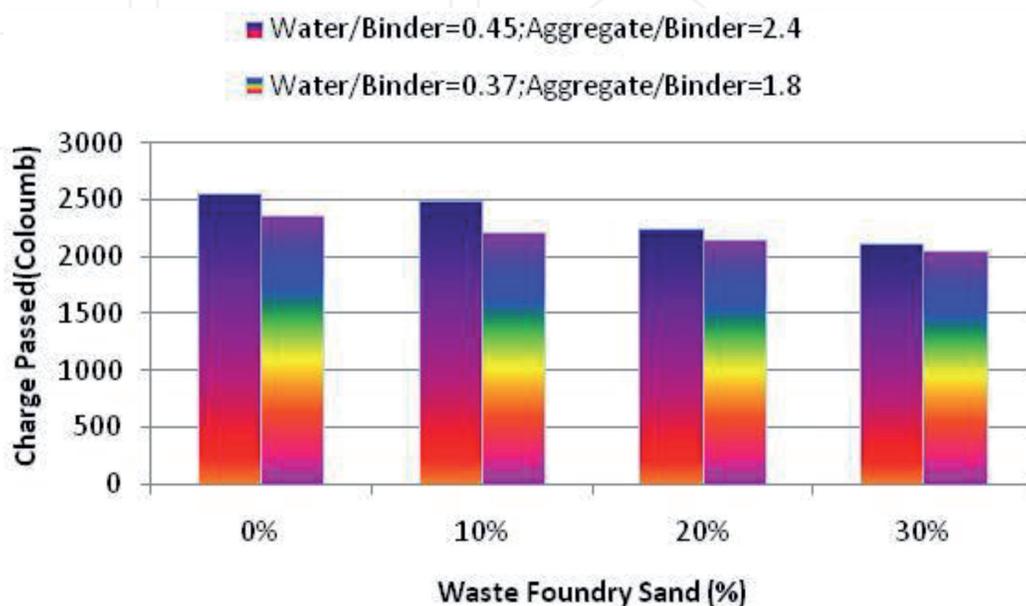
### **7.1 Water absorption**

The concrete made with used foundry sand is generally more permeable than the normal concrete. However, some researchers reported that the inclusion of used foundry sand has no impact on the water absorption of the concrete. The water absorption is somewhat related to the compressive strength also. As per Basar and Aksoy [34], the concrete having higher water absorption has lower strengths. The water absorption of the hardened concrete has a significant effect on the durability characteristics of concrete. Khatib et al. [26] reported that water absorption of the concrete mix containing used foundry sand, the control mix showed the least and increased for 20, 40, 60, 80, and 100% replacement of fine aggregates with foundry sand. It is further confirmed that the water absorption of 56 days cured concrete samples also followed the same trend. Ready-mixed concrete with used foundry sand also showed similar behavior on water absorption. Basar and Aksoy [34] stated that the water absorption of ready-mixed concrete containing waste foundry sand increased with the increase in percentage replacement of fine aggregate with waste foundry sand. Some researchers observed a marginal decrease in water absorption of the concrete containing used foundry sand over the normal concrete. Salokhe and Desai [59] reported that the foundry waste sand had no apparent impact on

the water absorption of concrete; however, at 20% ferrous foundry waste sand, the water absorption showed a decrease over the water absorption of the control mix, the control mix has water absorption of 1.91, and at 20% used foundry sand, the water absorption value was 1.13%.

## 7.2 Rapid chloride permeability

Rapid chloride permeability test (RCPT) is an important test to ascertain the durability of concrete. In this test, as per ASTM C 1202-19 [60], the higher the charge passed through the samples, the concrete is more permeable. The penetration of chlorides through the concrete can affect the reinforcement steel, and the corrosion takes place. Hossain and Anwar [39] studied the rapid chloride penetration of lightweight concrete samples of 20 and 28 MPa compressive strength at 28 days made of waste foundry sand and volcanic ash from Papua New Guinea and reported that the chloride permeability of lightweight concrete decreases with the increase in the percentage content of waste foundry sand. As per the observations of Siddique et al. [57], for 20 and 30 MPa characteristic compressive strength concrete with regular sand partially replaced with spent foundry sand, the charge passed was found to be decreasing with the increase in spent foundry sand content in the concrete mix. In some cases, the chloride permeability decreases up to a certain percentage of used foundry sand in the concrete mix, and further, it increases. Singh and Siddique [31, 56] reported that the chloride permeability of concrete incorporating waste foundry sand decreases up to 15% substitution of fine aggregate with waste foundry sand, and further, it increases. In some cases, the used foundry sand content in the concrete increases the chloride permeability. Aggarwal and Siddique [61] stated that the concrete samples passed charges of 578, 628, 616, 600, 664, 652, and 741 coulombs for 0, 10, 20, 30, 40, 50, and 60% replacement of fine aggregates with waste foundry sand, respectively. As per ASTM C 1202-19 [60], all the above samples have very low permeability as the charges passed were between 100 and 1000 coulombs. A graphical representation of the charges passed through the samples on rapid chloride permeability test (RCPT) at 56 days conducted by Hossain and Anwar [39] on lightweight concrete samples made with waste foundry sand and volcanic ash is shown in **Figure 10**.



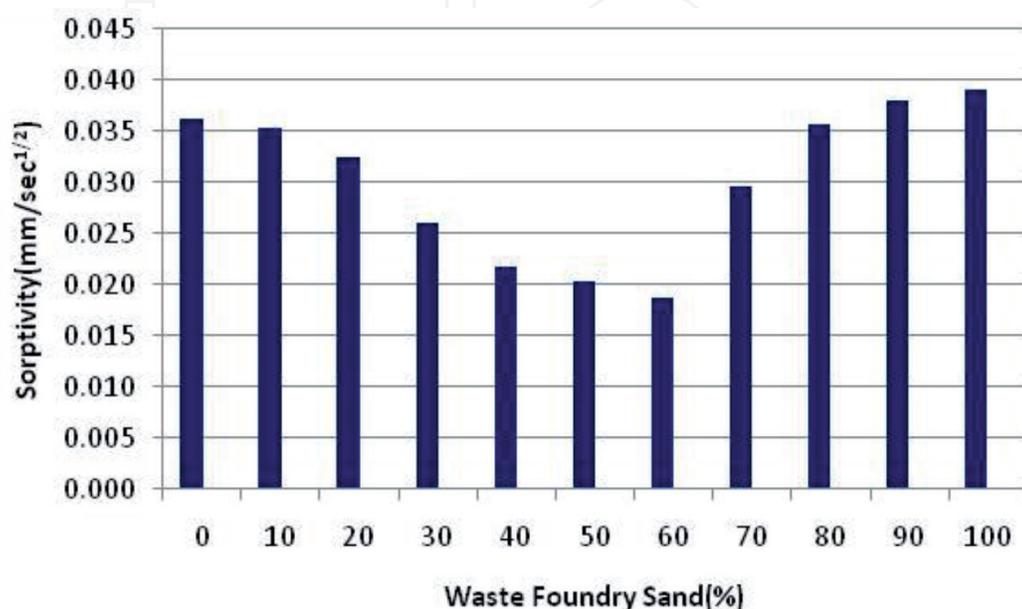
**Figure 10.**  
Chloride penetration of lightweight foundry sand concrete.

### 7.3 Sorptivity

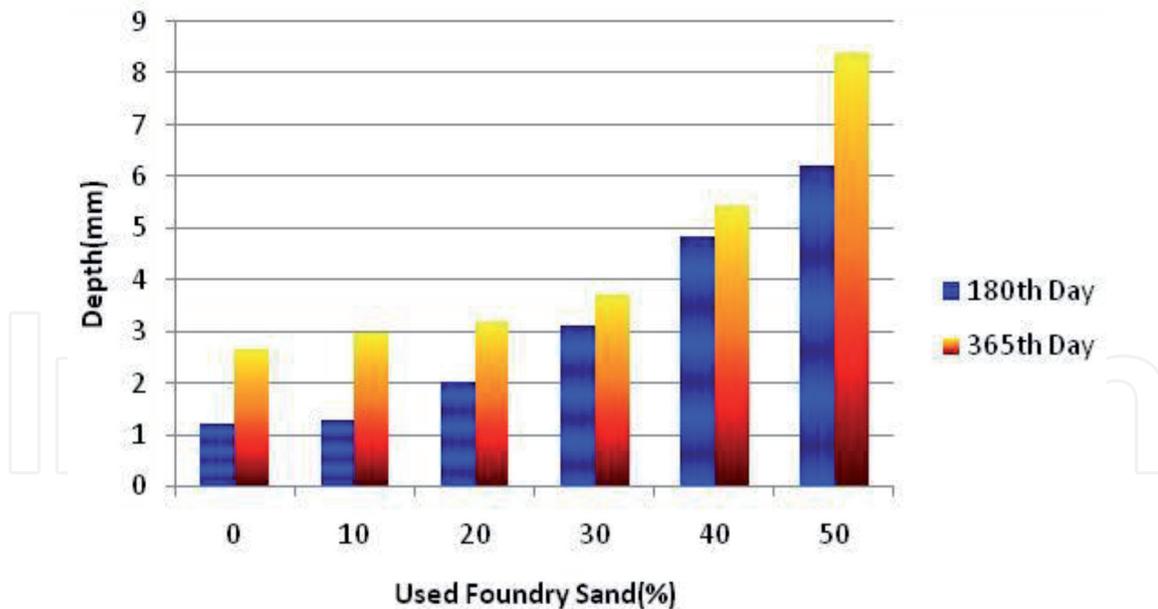
The sorptivity of the concrete is due to the capillary rise of water from the bottom of the concrete specimen. Some researchers reported a decrease in sorptivity up to certain percentage content of used foundry sand and an increase in sorptivity after that. Bhardwaj and Kumar [40] reported that the sorptivity of geopolymer concrete made with waste foundry sand tends to decrease from 0 to 60% substitution of fine aggregate with waste foundry sand, and further addition of waste foundry sand in the mix increased the sorptivity. It is also observed that for the concrete having up to 80% of waste foundry sand, the initial rate of absorption (IRA) is less than the IRA of the control mix. Khatib et al. [62] reported that for the concrete made with natural sand replaced with used foundry sand at 0, 30, 60, and 100%, waste foundry sand (WFS) exhibited a consecutive increase in water absorption by capillary action when the WFS content increased in the concrete mix. A graph of the sorptivity variation of geopolymer concrete made with waste foundry sand as per Bhardwaj and Kumar [40] is shown in **Figure 11**.

### 7.4 Carbonation

Carbonation is the reaction of carbon dioxide in the atmosphere with the calcium hydroxide in the cement paste. This reaction produces calcium carbonate and lowers the pH to a value of around 9. The carbonation affects the durability of the concrete. Generally, the used foundry sand content in the concrete mix increases the carbonation depth. Prabhu et al. [15] reported that the carbonation depth on 180 days of the concrete made with used foundry sand increased with the percentage increase in used foundry sand in the concrete mix. At 365 days also, the carbonation depth observed was increasing with the percentage increase in used foundry sand. Siddique et al. [63] stated that the carbonation depth of concrete made with 0, 10, 20, 30, 40, and 50% used foundry sand at 90 and 365 days increased with the used foundry sand content in the mix. The carbonation depth variation at 180th and 365th days as per Prabhu et al. [15] for 25 MPa characteristic compressive strength concrete made with used foundry sand is shown in **Figure 12**.



**Figure 11.**  
*Sorptivity vs. % waste foundry sand.*



**Figure 12.**  
Carbonation depth vs. % used foundry sand.

## 8. Ultrasonic pulse velocity (UPV) tests on used foundry sand concrete

The ultrasonic pulse velocity (UPV) test is one of the nondestructive tests (NDTs) to check the quality of the concrete. In this test, the quality and strength of concrete are evaluated by noting down the velocity of an ultrasonic pulse passing through a concrete body. A very few research results are only published on the UPV tests on concrete containing waste foundry sand. Khatib et al. [26] reported that the concrete specimens cured for 28 days showed a consistent decrease in ultrasonic pulse velocity values when the fine aggregates in the concrete mix were replaced with foundry sand in the range of 0, 20, 40, 60, 80, and 100%. The same trend was observed for the specimens cured for 56 days also. Prabhu et al. [15] also stated that the increasing amount of waste foundry sand in the concrete systematically decreases the ultrasonic pulse velocity of concrete made with natural sand replaced with 0, 30, 60, and 100% of waste foundry sand.

## 9. Long-term strength characteristics of concrete made with used foundry sand

Many research findings are available on the long-term strength characteristics of concrete made with used foundry sand. Siddique et al. [54] studied the long-term strength characteristics of concrete incorporating used foundry sand and reported that the compressive strength, split tensile strength, flexural strength, and modulus of elasticity were improved much at 365 days over the strength at the 28th day for the concrete incorporating used foundry sand. It is to be noted that no detrimental effects were noticed in the strength parameters on aging due to the incorporation of used foundry sand in the concrete mix. Generally, the long-term strength characteristics increase up to certain percentage content of the foundry sand, and the further increase of foundry sand content, the strength decreases. Siddique et al. [63] stated that at 365 days, the compressive strength of concrete increases with percentage replacement of 10, 20, and 30% fine aggregates with foundry sand and decreased for 40, 50, and 60% foundry sand content.

## **10. Leaching in concrete and mortars made with used foundry sand**

The used foundry sand is a nonhazardous material. However, the chemicals present in the used foundry sand can leach into the groundwater and may affect the groundwater quality. As per Siddique et al. [7], the liquid drains or leaches from a landfill are called leachate. The leachate test is essential to assess the suitability of the used foundry sand for certain applications. Very few research observations are available on the leachate analysis of the concrete/mortars made with used foundry sand. Monosi et al. [64] conducted dynamic leaching tests on mortar samples as per Italian standards. They reported that the mortars made from used foundry sand do not release leachate higher than the values specified by Italian standards, and the pH of the leachate was found to be alkaline during the entire testing period. Fero et al. [65] observed that the concentrations of organic compounds in groundwater leached from an iron foundry landfill were below their respective detection limits.

In some cases, the used foundry sand may contain heavy metals. Navarro-Blasco et al. [45] reported that in mortars with used foundry sand, the used foundry sand appeared to be contaminated with heavy metals. In another research conducted by Kaur et al. [66] performed a metal analysis of the leachate obtained from concrete made with untreated and fungal treated waste foundry sand and indicated that waste foundry sand is the contributor of the concentration of leachable metals in concrete containing waste foundry sand. Results from the above research further showed that metal concentration in leachate obtained from fungal treated waste foundry sand incorporated concrete is less than the leachate of untreated waste foundry sand concrete.

## **11. Conclusion**

The foundry industries all over the world generate an enormous quantity of waste sand every year. Many investigations conducted on the reuse of waste foundry sand over the years suggested that the sand discarded from the foundry industries as waste material can be recycled and utilized for beneficial applications in road embankment formation, structural fill, pipe bedding, asphalt concrete, mortars, and different types of concretes. But horizons are still open for the researchers for further innovations in the application of used foundry sand mainly related to the needs in the construction industry where better strength and durability properties are of the paramount concern. In most of the research findings, it suggested that 10–30% fine aggregates can be replaced with used foundry sand for the manufacture of concrete and mortars with sufficient strength parameters with reduced cost. Some researchers estimated that the cost reduction is much significant if the waste foundry sand can be employed in making concrete or concrete products near the foundry industries itself. Due to fine particles present in the used foundry sand, the workability of used foundry sand admixed concrete is profoundly much less than the workability of regular concrete having the same water to binder ratio. However, the researchers suggested that this deficiency can be overcome by adding superplasticizers to the mix. Some researchers pointed out that by performing some inexpensive treatments to the used foundry sand, the strength parameters of used foundry sand incorporated concretes and mortars can be enhanced further. Most of the researchers are in the view that the used foundry sand is a nonhazardous material. However, some researchers suggested that it is better to conduct leachate analysis in advance to avoid the chances of corrosion of the reinforcement if the used foundry sand is proposed to be utilized in the production of concrete for RCC

structures. From the analysis of the research works done so far, it can be established that the use of waste foundry sand in the construction industry can not only eliminate the problems of waste management and environmental impacts but also substantially boost up the sustainable developmental activities by way of reducing the consumption of natural resources. However, the feasibility of employing used foundry sand in civil engineering applications in the construction industry will invariably depend on the local cost and the availability of the used foundry sand in the required quantities where the construction work is to be executed. Amidst many research findings and suggestions, the beneficial use of used foundry sand in civil engineering applications is only a bare minimum at present. A collective effort from the researcher community, academicians, and industrialists is highly needed for the full utilization of the recycled used foundry sand from the industrial wastes in the construction industry soon.

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