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Review of the sustainable use of industrial waste to replace the fine aggregate used to prepare concrete

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Abstract— **U**sing industrial waste materials in concrete compensates for a lack of natural resources, addresses the waste disposal problem, and contributes to the development of alternative environmental protection strategies. Many industrial wastes are wholly or partially exchanged for coarse or fine aggregate. This research conducts a detailed evaluation of industrial waste materials that can be effectively used in concrete as a replacement for fine aggregate. The waste foundry sand, steel slag, copper slag, imperial smelting furnace (ISF) slag, blast furnace slag, coal bottom ash, ferrochrome slag, palm oil clinker, etc. were some of the industrial wastes that were covered in this essay.Out of these resources, waste foundry sand and copper slag have been the subject of the most trials; nevertheless, further research is still needed to determine whether other waste materials may substitute sand in concrete. Review and comparison of the various physical and mechanical characteristics of industrial waste as well as industrial waste concrete that substitutes natural sand. Study reviews for deflection and leaching are also conducted and contrasted.It can be seen that concrete that substitutes copper slag, imperial smelting furnace slag, or class F fly ash for sand demonstrates improved strength and durability properties, but that the slump of the concrete increases with copper slag replacement rate while it decreases with class F fly ash replacement rate. The use of ferrochrome slag and palm oil clinker as sand substitutes has received less study attention, thus it is thought that further thorough investigations are needed.

Keywords—**Industrial Waste, Fine Aggregate, Concrete, Sustainable use**.

I. INTRODUCTION

Concrete is the most often utilised construction material (Prabhu et al., 2014). Aggregate accounts for 70% of its volume and is used to manufacture 8 to 12 million tonnes of concrete globally each year (Devi and Gnanavel, 2014; Al-Jabri et al., 2009). Fine aggregate is described as having a particle size of 4.75 mm or less, whereas course aggregate has a particle size of 4.75 mm or larger. Sand, a major component of fine aggregate, is utilised in the production of concrete and mortar and plays an important role in design mixtures. Sand is an important component of concrete, and the amount and kind of sand used to form a certain concrete mix will determine the mix's properties.It has a considerable impact on the workability, lifetime, strength, weight, and shrinkage of concrete. Sand is typically used in greater quantities than cement. Sand may fill pores or holes in concrete, increasing the material's strength. Sand reduces the volume changes associated with the setting and hardening processes and provides a mass of particles capable of withstanding the action of applied stresses and exhibiting better durability than cement paste alone. As a result, sand is critical in assisting concrete to firm up and offer the essential strength. Because mortar and concrete are used so frequently, ordinary sand is widely used. Sand is therefore more necessary in developing nations to slow down the rapid infrastructure development.The lack of excellent quality sand due to the rising demand for it, particularly in India where natural sand supplies are depleting, poses a serious threat to the environment. Rapid sand removal from canal beds causes several problems, ranging from the loss of soil layers that hold water to the sliding of riverbanks (Sankh et al., 2014). The mining of sand from the canal raises sand prices and has had a significant negative impact on the building industry's capacity to make money. Finding a replacement for natural sand is therefore absolutely necessary.The amount of waste material produced is rising along with industrialization, creating an ecological problem that has to be addressed. According to Pappu et al. (2007), 290MT of the 960MT of solid trash that is produced in India each year is undesirable inorganic waste from the mining and manufacturing sectors. Regular resources are mostly depleting, while at the same time, created industrial wastes are growing rapidly. Efforts are being made to use industrial waste in concrete to save natural resources and lower the cost of construction materials in order to protect the environment.One environmental advantage that also improves the performance of concrete is the use of industrial waste as fine aggregate in the manufacturing of concrete. Reusing wastes is said to be the most environmentally friendly way to address the problem of waste disposal since it makes concrete more affordable (Bahoria et al., 2013

II.INDUSTRIAL WASTE PHYSICAL PROPERTIES AS FINE AGGREGATE

Grain size distribution, density, specific gravity and fine substance are physical characteristics of industrial wastes that assist determine their appropriateness and viability as a replacement for fine aggregate in concrete.

a) Bulk density

Waste foundry sand has a loose bulk density of 1690 kg/m^3, compared to a compacted bulk density of 1890 kg/m^3, according to Singh (2012). According to Chang-long et al. (2008), steel slag has a packing density of 1475 kg/m^3 and an apparent density of 2395 kg/m^3. The bulk density of granulated copper slag, according to Ambily et al. (2015), ranges from 1900 kg/m^3 to 2150 kg/m3. Bottom ash has a loose bulk density of 620 kg/m^3, but compacted bottom ash has a density of 660 kg/m^3 (Yuksel et al., 2007, 2011; Bilir, 2012; Yuksel and Genc, 2007). According to Yuksel et al. (2007, 2011; Bilir, 2012; Yuksel and Genc, 2007), the granulated blast furnace slag has a loose bulk density of 1052 kg/m^3 and a compacted bulk density of 1236 kg/m^3. According to Abdullahi et al. (2010), the bulk density of palm oil clinker fine aggregate is 1122 kg/m^3, however Mohammed et al. (2013) observed a bulk density of 1119 kg/m^3.

b) Particle gradation

Foundry sand with 78-94% components includes grains ranging in size from 0.6 mm to 0.15 mm, according to Khatib et al. (2013) and Basar and Aksoy (2012). Steel slag particle distribution is homogeneous, according to Qasrawi et al. (2009), with 83% of the material lying between 0.6 mm and 0.15 mm.

According to Sankh et al. (2014), the grain size distribution of copper slag comprises about 75% particles ranging in size from 1.18 mm to 0.3 mm. The particle size distribution of WFS is homogenous, with 85-95% of the materials lying between 0.6 mm and 0.15 mm, with roughly 5-20% of foundry sand being smaller than 0.075 mm (Singh, 2012).

c) Specific gravity

The specific gravity of various industrial waste products has been recorded by several studies. According to Singh and Siddique (2012)a, waste foundry sand has a specific gravity of 2.18. Siddique (2014) said that the range for the specific gravity of waste foundry sand is between 2.39 and 2.79. Devi and Gnanavel (2014) state that the steel slag had a minimum specific gravity of 3.0, however Qasrawi et al. (2009) state that the steel slag's specific gravity was 3.15. ISF slag has a 3.88 specific gravity, according to Morrison et al. According to Valcuende et al. (2015), blast furnace slag has a specific gravity of 2.45.

d) Shape and appearance

The slag from the blast furnace is granular and has smooth, black particles (Sankh et al., 2014). Foundry sand often has a subrakish to rounded form. In contrast to chemically bonded foundry sands, which are greyish in hue, green foundry sands are dark or grey in colour (Singh, 2012). The grain size distribution of the copper slag is similar to that of natural sand and it is granular in nature with black polished particles (Ambily et al., 2015). According to Tripathi et al. (2013), ISF slag is poisonous metal (lead and zinc)-containing, vitreous, and dark in shading. Coal bottom ash molecules are rakish, irregular, and porous with a rough texture (Siddique, 2014). According to Wahab et al. (2015), palm oil clinker (POC) has a porous character and a grey appearance.

III.CHEMICAL PROPERTIES

Chemical composition of industrial wastes is dependent on the kind of metal and combustible used. WFS have a high silica content and are coated with a thin layer of burned carbon, dust, and any lingering binder (resins/chemicals, bentonite, sea coal). Fe_2O_3 is present in copper slag in an amount of around 53.45% (Al-Jabri et al., 2011), but it is present in ISF slag in an amount of 38.33% (Morrison et al., 2003).Depending on the type of coal used and the burning procedure, bottom ash has different chemical compositions. According to Siddique (2014), the main components of bottom ash are silica, iron, and alumina, with minor amounts of magnesium, calcium, and other sulphates. The chemical composition of steel slag varies based on the kind of furnace, the grade of steel, and the pre-treatment technique. Steel slag's principal constituents, according to Yi et al. (2012), are SiO_2, CaO, Fe_2O_3, Al_2O_3, MgO, MnO, and P_2O_5. CaO is the major chemical component of blast furnace slag, accounting for 56.10% of the total. Siddique (2003) studied the chemical composition of class F fly ash and determined silicon dioxide as the primary element with a percentage of 55.3% and aluminium oxide with a percentage of 25.7%, according to ASTM C 311 (2013).

IV.FRESH PROPERTIES OF CONCRETE

a) Slump test

According to Aggarwal and Siddique (2014), the consistency of new concrete is a mix property that takes into account the various requirements of stability, mobility, compatibility, finishability, and placeability. In site work, slump test is widely utilised anywhere in the world. According to IS 456:2000, the recommended ranges for low, medium, and high workability of concrete are 25 mm–75 mm, 50 mm–100 mm, and 100 mm–150 mm, respectively.

b) Compaction factor test

The workability of the concrete is the quality that determines the amount of effort required to generate full compaction, according to the definition used in the compaction factor test.

Basically, the test involves compacting a standard amount of concrete with a standard amount of labour, then measuring the results. According to Panda et al. (2013), the compaction factor of concrete with ferrochrome slag in place of fine aggregate is between 0.88 to 0.92, indicating a workable range for concrete products. Aggarwal and Siddique (2014) conducted an investigation with a constant compaction factor of 0.78–0.83 by substituting natural sand with WFS and bottom ash, and they reported that the amount of water required increased when the amount of waste foundry sand and bottom ash was substituted for natural sand.

c) Air content

Siddique et al. (2009) revealed that the air content in concrete that substitutes three percentages (10%, 20%, and 30%) of used foundry sand for natural sand varies between 4.2% and 4.5%. While Aggarwal and Siddique (2014) found it in the range of 2.1- 3.4% in concrete where natural sand is replaced by waste foundry sand and bottom ash, Singh and Siddique (2012b) found it between 4.2% and 4.5% in concrete where natural sand is replaced by four rates (5%, 10%, 15%, and 20%).

V.LEACHING TEST

Leaching tests' main goal is to calculate the chemical species' mobility in waste or waste-based products at a particular leaching rate. In other words, a leaching test involves exposing a material to a leachant so that part of the substance's contents can be removed. According to Basar and Aksoy (2012), the inclusion of waste foundry sand increased the total organic carbon value, however the TOC values were still contained within EULFD class-III points of confinement.According to Tripathi et al. (2013), leaching of lead and cadmium from concrete with 70% natural sand replaced by ISF slag was below permissible limits of 5 and 1 ppm, respectively, although these limits were greater in the case of raw ISFS. The amounts of lead and zinc released from the ISF slag were focused by Morrison et al. (2003) in various solutions. They had come to the conclusion that the use of GBF slag and pulverised fuel ash might regulate the leaching of metal ions from the ISF slag.In a brief tank leaching test, Panda et al. (2013) used concrete specimens with varying percentages of ferrochrome slag as fine aggregate and sand, as well as normal distiled water with a pH value of 6.68 and toxicity characteristic leaching method extraction liquid pH 2.88.

They came to the conclusion that the findings of the chromium leaching investigation showed low level leaching and that the limits for Cr (VI) and total chromium were within the USEPA and Indian regulatory discharge standards. They claim that Portland cement made from blast furnace slag works best at neutralising both Cr (III) and Cr (VI).

VI. HARDENED CONCRETE PROPERTIES

a) Compressive strength

The compressive strength test is the most important of the several tests conducted on concrete since it provides insight into all of the properties of the material. By doing this specific test, one may ascertain if concrete construction has been completed legally or not. The compressive strength of the concrete immediately affects all other mechanical characteristics.According to Prabhu et al. (2014), foundry sand replaced concrete did not exhibit a slight increase in compressive strength, but the strength of the concrete mixture containing foundry sand up to 20% replacement was relatively close to that of the control mix. However, beyond 20% replacement, the concrete mixtures demonstrated lower strength than the control mix.According to Kaur et al. (2012), the reference concrete mix had a compressive strength of 33.10 N/mm^2 after 28 days of curing, whereas concrete containing 10%, 15%, and 20% untreated WFS had compressive strengths of 33.76 N/mm^2, 29.30 N/mm^2, and 27.80 N/mm^2 respectively.According to Devi and Gnanavel (2014), the concrete's compressive strength increased by 27.04% when 40% steel slag replaced the sand. According to Qasrawi et al. (2009), compressive strength was improved when fine aggregates were replaced by steel slag between 15% and 30%. However, beyond the 30% replacement level, the compressive strength of the concrete mix is lower than the reference concrete mix at ages of 28 days, 90 days, and 180 days.According to Tripathi et al. (2013), the reference control concrete's compressive strength was 41.70, 43.83, 45.77, and 48.20 N/mm^2 for each of the W.C ratios of 0.55, 0.50, 0.45, and 0.40. Compressive strength with increased W.C ratio 0.55 decreased with an increase in ISF slag, albeit this decrease was not appreciably felt for sand substitutes up to 60%. ISF slag concrete mixes with a W.C ratio of 0.45 had the same strength as the reference mix, but ISF slag concrete mixes with a W.C ratio of 0.40 had strength that was almost 5-16% higher.

b) Splitting tensile strength

A well-known derivative test for figuring out concrete's tensile strength is the splitting tensile strength test.

One of the most important and fundamental characteristics of concrete is tensile strength. A precise prediction of concrete's tensile strength can help prevent failure of concrete under tension, minimise cracking issues, and improve forecasting of shear strength (Singh, 2012). Basar and Aksoy (2012) estimate that the splitting tensile strength is 9-10% of the compressive strength. According to Prabhu et al. (2014), the tensile strength of concrete declines as the foundry sand replacement rate increases, yet the values of the mixes with a 20% replacement rate are approximately similar to the strength of reference concrete. When compared to the control mix, the tensile strength of the concrete mixes with 10%, 20%, and 30% foundry sand substituted was 4.53%, 6.03%, and 7.08%, respectively, at 28 days of curing. The split tensile strength of the control mix was 2.26 MPa, whereas the split tensile strength of the concrete mix using 40% steel slag in place of fine aggregate was 2.47 MPa, 9.29% higher than the control mix. According to Yuksel and Genc (2007), for replacements with granulated blast furnace slag, the split tensile strength declines as the rate increases, and there is no change up to a 10% substitute.

The reduction in split tensile strengths is 12% for the replacement of blast furnace slag with granulated blast furnace slag up to 30%.

c) *Flexural strength*

Flexural strength is a measurement of an unreinforced concrete beam or slab's resistance to failure in bending. Flexural strength in concrete is between 10% and 20% of compressive strength. According to Prabhu et al. (2014), the flexural strength of the concrete mixes, like compressive strength, was equivalent to the flexural strength of the reference concrete mix up to a 20% replacement rate, after which the flexural strength of the concrete began to dramatically fall. After 28 days, the control mixture had a flexural strength of 4.087 N/mm^2, while the mixtures with 10%, 20%, and 30% replacement levels of waste foundry sand had strengths of 3.986, 3.988, and 3.879 N/mm^2, respectively, which were only 2.47%, 2.42%, and 5.08% lower than the control mix. To examine the flexural strength of concrete where ISF slag was added as sand, Tripathi et al. (2013) selected four water cement ratios (0.55, 0.50, 0.45, and 0.40). Up to 60% ISF slag replacement, the flexural strength of all concrete mixes at all water cement ratios was comparable to or slightly greater than the strength of the reference concrete. However, beyond 60% replacement, the flexural strength of ISFS mixtures at all water cement ratios declines in all ages of curing.Concrete's flexural strength is significantly reduced when furnace bottom ash replacement is used, according to Yuksel and Genc's 2007 findings. Flexural strength for the control mix was 4.71 MPa, whereas it was 3.7 MPa, 3.66 MPa, and 3.72 MPa for replacements of 10%, 20%, and 30%, respectively. It's crucial to note that the results reveal a drop in tensile strength of about 10% for a 10% substitution of sand by furnace bottom ash. However, after that point, there is essentially no change in the tensile strength values.

d) *Modulus of elasticity*

The modulus of elasticity, commonly known as the Young's modulus, is a measurement of the stiffness of an elastic material that describes the elastic characteristics of objects when they are stretched or compressed. The Young's modulus of concrete is an essential consideration in the design of structural components. Waste foundry sand is the only industrial waste material on which the modulus of elasticity property has been studied. This E-value has been calculated by fewer researchers for one industrial waste concrete in which WFS has substituted sand. According to Basar and Aksoy (2012), the modulus of elasticity of concrete mixes including WFS in place of some of the typical sand decreased.According to Singh and Siddique (2012a), adding scrap foundry sand to concrete increased its elasticity modulus across the board.

When fine aggregate was substituted with 5% WFS, 10% WFS, 15% WFS, and 20% WFS, respectively, the modulus of elasticity of the concrete mix increased by 1.67%, 5.01%, 6.35%, and 4.35% above the control mixture's modulus of elasticity of 29.91 GPa after 28 days of curing.

According to Etxeberria et al. (2010), adding more leftover foundry sand to the concrete mix causes the modulus of elasticity to drop. Additionally, it was shown that the variance in modulus of elasticity increased linearly up to 15% before starting to decrease at 20% once natural sand was replaced with foundry sand.

VII. CONCLUSION

This article examined the use of various industrial wastes as a replacement for fine aggregate. All of the concrete's characteristics, including its physical and fresh and hardened states, were discussed and contrasted. Additionally examined and contrasted with conventional concrete was the microstructural examination of industrial waste-based concrete. A number of industrial wastes, including waste foundry sand, steel slag, copper slag, ISF slag, blast furnace slag, coal bottom ash, ferrochrome slag and class F fly ash, may be used as fine aggregate replacements in concrete with confidence. Several implications that may be drawn from the review are listed below.

1. All industrial wastes had essentially identical physical characteristics to those of natural sand, with the exception of the particle size distribution of foundry sand; steel slag did not fulfil ASTM C33 or IS-383-1970 grading criteria in terms of bulk density, specific gravity, or grain size distribution.

2. When copper slag and bottom ash are used in place of fine aggregate in concrete, the slump value increases by increasing the replacement ratio. Conversely, when waste foundry sand, steel slag, and palm oil clinker are used in place of fine aggregate in concrete, the slump value decreases by increasing the percentage of replacement. Slump value in concrete containing granulated blast furnace slag increases up to 20% of replacement level before declining beyond that.
3. 3. Up to 20% of the sand can be substituted with spent foundry sand without compromising mechanical or physical properties. The abrasion resistance of concrete mixes increased when WFS was added in place of fine aggregate. WFS increases USPV values while decreasing chloride ion penetration in concrete. This study also shows that adding fungal (Aspergillus spp.) treated 20% WFS-containing concrete leads in a 15.6% increase in compressive strength after 28 days.
4. The compressive strength, splitting tensile strength, flexural strength, and elastic modulus of concrete specimens were all higher than those of the reference concrete at all ages when sand replaced fly ash up to 50%.

In the conclusion, this comprehensive research found that industrial wastes may be used to the fullest extent possible in concrete innovations for a sustainable standard strength, durability, and eco-friendly concrete.

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