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# EXPLORING THE POTENTIAL OF WELD SLAG AS AGGREGATE REPLACEMENT IN CONCRETE FOR SUSTAINABLE CONSTRUCTION: A REVIEW PAPER

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**ABSTRACT:** *Concrete is the most globally used material in the construction industry, with over ten billion tons produced annually, and its aggregates making 70 to 80% of its quantity. The aggregates production leads the natural sources of these aggregates to deplete in a high rate and with a significant carbon footprint. Consequently, industries are generating waste output in a large quantity which is posing problems to the environment and leading to economic challenges. This review explores the potential of using industrial waste such as weld slags, steel slags, and glass powder as substitutes to traditional concrete aggregates. The integration of these wastes solves the problems of waste disposal, resource depletion and environmental pollution. The review is to also to encourage the reuse, recycling and reduction of waste production to reduce pollution. This practice will help ensure resource conservation, environmental protection and enhanced sustainability. Furthermore it underscores the importance of further research on the durability and practical applications of concrete containing industrial slags such as steel slags, weld slags, glass powder etc. to establish effective and sustainable construction practices.*


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## INTRODUCTION

The most versatile material used in the construction industry is concrete. For thousands of years, humans have been using concrete for different construction purposes; the main constituents in it are the aggregate which makes 70 to 80% of its volume. The history of concrete's ingredients is dated back to ancient Egypt. Till today, concrete production is high—over ten billion tons per year. This massive production of concrete leads to the exhaustion of natural resources and an enormous carbon footprint (Zehra et al., 2021).

An artificial stone-like material is concrete; it is obtained by properly designing its constituents (i.e., the cement, fine aggregate, coarse aggregate and water), mixing, casting, and curing, to the required shape and dimension of the desired structure (Sawant, 2018).

Environmental degradation is caused by high production of waste from industries and other sources and this serves as an economic challenge and a cause of environmental destabilization (Zehra et al., 2021).

The high volume of aggregate used in the construction industry leads to the depletion of natural resources worldwide, while concurrently, the industries are generating a huge amount of wastes (M. Ramesh et al., 2014).

The global increase in industrialization leads to high waste material production, which requires urgent attention for proper management to prevent ecological issues (Asokan Pappu, 2007).

To compensate for the lack of natural resources (aggregates), industrial waste materials are utilized and this solves the problem of waste disposal and serves as a technique of safeguarding nature. Industrial wastes are utilized either as a partial or full replacement of coarse aggregate or fine aggregate (Dash et al., 2016).

To ensure environmental sustainability, resources must be retrieved (Muhedin & Ibrahim, 2023). This sustainable practice includes recycling of industrial waste and reuse of renewable resources (Dash et al., 2016).

Several wastes are produced in industries, e.g., coal ash, metal slags, industrial sludge, pulp, paper, mine tailings, leather, food and agriculture, etc. These wastes pose challenges of storage, disposal, land space for filling and environmental pollution. Hence, these waste are incorporated in concrete production (Bergonzoni et al., 2023a).

Reuse, recovery and recycling of waste materials is a closed loop system promoting circular based economy, which helps to cause low pollution, reduce carbon emission and solve the problems of resource scarcity. Building construction, infrastructure and industrial construction are where more than the 50% of nonrenewable resources are used in the human economy (Bergonzoni et al., 2023b).

Environmental sustainability is in high demand to address the current needs of resources in the construction industry, without harming the ability of future generations to address their own needs too (Althoey & Hosen, 2021).

Proper management of solid waste is an extremely important issue that is posing a crucial challenge to the society worldwide (Premalatha & Srinivasan, 2019), and it is the biggest


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challenge of both big or small cities (Abdel-Shafy & Mansour, 2018). India is one of the countries that is facing a great challenge in waste management to ensure a clean environment and a growing economy (Manoranjan et al., 2016). In this barren setting, there is a significant demand for giving attention to the different wastes generated in industries (Rojina & Devender, 2023).

As an alternative to the dumping of these industrial wastes, researchers are more interested in them as substitute materials in concrete aggregate during construction, and this approach is better as it protects the environment (Al-Jabri et al., 2011).

Developing countries like India are suffering from the challenge of waste management; a large quantity of waste is produced due to the rapid industrialization and increase in population, resulting in an unhealthy environment during landfills (Premalatha & Srinivasan, 2019).

Large volumes of weld slags are generated in fabrication during the welding process; the weld slag can be used in concrete as a partial replacement of the aggregate to some extent, as a means of finding an alternative solution to its dumping (Manoranjan et al., 2016).

Improper dumping of weld slags has shown significant toxic symptoms in humans, animals and plants due to their direct or indirect exposure to it. This is due to the presence of heavy metals in slags which leads to the elevation of metal levels in plants and animal cells (Abdullahi & Sani, 2020).

One of the difficult tasks today is to ensure the fulfillment of human needs and economic advancement while preserving life's foundation, environment security and prosperity (Althoey & Hosen, 2021). The need for recycling is not just for economical purposes but also for conservation of ecology; this is because it uses less energy than using raw materials (Rojina & Devender, 2023).

Arc welding produces quality welds in ferrous, stainless steels and even some non-ferrous metals. During the weld process, the flux is used to cover the weld joint and to protect welding operations from atmospheric contamination. This flux is partially melted, resulting in a liquid protective slag layer generating a waste material known as submerged arc welding slag. In general, one kilogram of flux is consumed for every kilogram of weld metal deposited. About 2,500 tons of slag are generated in India, which rise to 10,000 tons during increases. Hence, the weld slag can be effectively utilized. Use and recycling of steel and weld slag from the steel manufacturing industry is an important issue (Brothers, 2018).

Welding slag is the hardened layer left on the top of weld made during flux-cored welding (FCAW), shielded metal arc welding (SMAW), submerged arc welding (SAW) and other welding and brazing processes, and this can have a slightly different makeup depending on the process or product. Slags in welding are meant to protect the weld from oxidation and contamination from the atmosphere. As the junction cools, it also keeps the pool of molten weld there. Welding slag removal involves the use of chipping hammers, wire brushes or wheels, or needle scalers. On the other hand, some filler metals are designed with self-peeling slag, which separates the slags from the weld automatically.

Not much work has been reported on the use of steel slag and weld slag in concrete related to durability (Bhuvaneswari & Nirmalkumar, 2018).


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## USES OF WELD SLAG

The importance of weld slag in welding work is a twofold. It protects the weld from oxidation and contamination from the atmosphere; it also keeps the molten weld in the joint as it cools to prevent the weld from being out of position (Brothers, 2018).

## PROPERTIES OF WELD SLAG

Weld slag is light black, red or black in color; it melts on the welding zone due to the flux (solid shielding materials) materials used in the welding process. During the process, the molten weld undergoes a thermodynamic process through which the molten weld pool causes all elements that are not included in the pool to be forced out to solidify on the surface to form slag. The characteristics of the weld slag depend on the material used in the flux; it contains elements like carbon, silicon, nitrogen, hydrogen titanium dioxide, aluminum, calcium oxides, etc. (Brothers, 2018).

## ENVIRONMENTAL IMPACT OF WELD SLAGS

During the welding process, metal fumes are generated, due to the fluxes or shielding gasses being used, from the metals being welded and also from the fillers being used. These fumes are released into the atmosphere and can lead to the pollution of air, land, and water, which has an effect on the life of people or animals in the environment (The Environmental Impact: Sustainable Welding Practices in Industry, 2023).

## LITERATURE REVIEW

The study of Dash et al. (2016) on sustainable use of industrial waste as a partial replacement of fine aggregate suggested that of the various tests conducted on concrete, the most important test that provides vital information on the concrete's qualities is the compressive strength test. This test alone can show whether a concrete work has been done legitimately or not, while other mechanical properties are dependent on the compressive strength.

S. T. Ramesh et al. (2013) studied the use of furnace slag and welding slag. Weld slag and furnace slag concretes showed better performance towards compressive strength. At 28 curing age, the compressive strength of the concrete is optimum at 5% replacement of sharp sand with weld slag, and it is seen to increase by 27.4% above the normal mix, while for sharp sand replacement with furnace slag, the optimum compressive strength is at 10% replacement, with 23.2% compressive strength increment above the normal mix. For percentage replacement above these, the compressive strength reduces significantly.

Shewalul (2021) studied the effect of waste steel scrap as a reinforcing material. The compressive strength of concrete is increased by incorporating 0.5% and 0.75% steel scrap by 26.8% and 30.7% respectively; however, the compressive strength is reduced by 5.3% for 1.5% steel scrap. The test result shows that the inclusion of steel scrap increases the compressive strength compared to the conventional concrete. And the optimum percentage is 0.75% by volume of concrete.

Arunachalam and Jayakumar (2016) in their study on the influence of weld slag aggregate in high performance concrete showed that there is a significant increase in the compressive


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strength of the HPC to 10% replacement of fine aggregate with weld slag aggregate by 6.94%, while for 20, 30, 40 and 50% replacement, the strength decreases gradually by 4.35, 16.75, 29.8 and 42.23% respectively. Similarly, the relationship of compressive strength against flexural strength is also observed to be linear, and that 10% replacement is acceptable for most structural applications while 20% to 50% replacement can be applied to nonstructural members such as compound wall, partition wall, flooring wall and so on. For the fresh concrete properties, the inclusion of the weld slags leads to a significant loss of slump; as suggested, this might be due to the moisture content loss by the weld slag during welding (heating) and that leads to the reduction of the concrete workability. Henceforth, the water absorption of the concrete with up to 10% replacement with weld slag is less than that of the control mix, while for replacement above ten percent, the water absorption increases gradually.

Althoey and Hosen ( 2021), in their study on the effect of iron waste as a partial replacement to fine aggregate, showed that the replacement of fine aggregate with iron waste demonstrated a significant influence on the compressive strength of concrete. The enhancement of compressive strength with the substitute of 5%, 10%, 15%, and 20% fine aggregate in sustainable concrete of iron waste expressed 5%, 13%, 31%, and 38% respectively, higher than the reference sample.

Muhedin & Ibrahim (2023) conducted an experiment to study the effect of waste glass powder as a partial replacement of cement and sand in concrete; in this experiment it was observed that the two parameters controlling the compressive strength of the concrete are the percentage of waste glass powder and the curing day. The compressive strength for the specimens increases by increasing the WGP to 5% replacement. On the 7th day, the compressive strength of the concrete with 5% WGP is increased by 10.7% above the normal mix. Henceforth, for replacement above 5%, the compressive strength decreases significantly.

Jangid and Sharma N.D., in their experiment to replace cement, sand and aggregate with waste material generated from construction and deterioration work, discovered that 28 days of curing concrete with 15%, 30% and 45% replacement of coarse aggregate with glass powder has an increase strength of 3.3%, 5.9% and 8.4%, greater than the conventional concrete.

Manoranjan et al. (2016), in their experiment to study the replacement of coarse aggregate with weld slag in M25 concrete at 7 days curing, observed that the compressive strength of the concrete with 10%, 20% and 30% replacement was increased to 33%, 29%, and 30% respectively, greater than the conventional concrete.

Premalatha and Srinivasan (2019), in their experiment on the properties of concrete with waste glass powder (GP) as fine aggregate replacement for M30 with 10%, 20% and 30% replacement, showed that concrete has an increased compressive strength of 2.4%, 2.9% and 3.7% respectively, while 40% and 50% have a reduction of 1.1% and 3.9% reduction respectively, compared to the conventional concrete.

Ananthi and Karthikeyan (2015), in their experiment on the properties of industrial slag as fine aggregate in concrete, concluded that the compressive strength of concrete by replacing 10% bottom ash at 7 days increases by 1.2 $N/mm^2$ and at 28 days increases by 1.5 $N/mm^2$;


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hence, the compressive strength of concrete by replacing 10% weld slag at 7 days increases by 1 N/mm$^2$ and at 28 days increases to by 0.3 N/mm$^2$.

The above reviews are proof that the incorporation of certain industrial waste for certain percentages in concrete mix helps in adjusting the properties (fresh or harden) of the concrete.

## METHODOLOGY

Weld slags as a replacement of aggregates in a concrete:

**Material Collection:** Weld slags are obtained from welding industries or welding shops; the weld slags are removed from the welded area of jointed metals. The removal is done manually by using chipping hammers, wire brushes or using power tools such as using angle grinders, wire brush wheels, etc. Some filler metals are formulated with self-peeling slag that releases from the weld on its own.

**Material Testing:** The collected sample of weld slags should be tested for their particle size distribution, moisture content, and specific gravity. These tests should be carried out using standard laboratory testing equipment, e.g., sieve analysis, moisture testing equipment, etc. as per the provision and guide of standard codes.

**Concrete Mix Design:** Once the physical and mechanical properties of the weld slag have been determined, the next step is to design the concrete mix containing weld slags as an aggregate. The mix design process would involve determining the optimal proportion of weld slag and other aggregates, as well as the appropriate binder content and gradation to achieve the optimal concrete characteristics.

**Concrete Testing:** The designed concrete mix, after casting and curing for the desired curing age, should be tested for their mechanical and performance properties, such as compressive strength, flexural strength and tensile strength, etc. Similarly, the concrete at its fresh stage should be tested for slump; this is to define the consistency and workability of the mix design.

## RESULTS AND FINDINGS

1. The compressive strength of concrete with weld slag as fine aggregate replacement has shown an improvement within some certain percentages.
2. The optimum percentage replacement of fine aggregate with weld slag is 5 to 10%.
3. The flexural strength of concrete with weld slag aggregate is proportional to its compressive strength.
4. For structural applications, fine aggregate can be replaced to 10% while for non-structural applications, it can be replaced to 30% by weld slag.
5. Inclusion of weld slag aggregate leads to the loss of slump of concrete.


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6. Water absorption of concrete with 10% weld slag replacement of aggregate is less than that of the control mix, and for percentages above 10%, the water absorption of the concrete gets increased.

7. The specific gravity of weld slag is greater than that of fine aggregate and coarse aggregate.

8. Within the 10% replacement with weld slag, the weld slag has some cementitious contributions to the concrete due to the presence of silicon in it.

**Life Cycle Assessment**

Finally, the research study should involve the in situ strength assessment of the concrete (structural element). This can be done by several in situ testing techniques, which include rebound hammer test, penetration resistance test (ASTM 803), ultrasonic pulse velocity (ASTM 597), etc. These techniques are to check the present strength of the concrete and to be compared with the previous strength to correlate and assess the time variation in strength due to the partial replacement of the concrete aggregate with weld slags, to ensure the serviceability and safety of the structure.

## CONCLUSION

i. The partial replacement of fine aggregate with weld slag should be encouraged as it offers a significant benefit in improving the strength performance, most especially the compressive strength of the concrete than the control mix.

ii. Incorporation of weld slag into concrete will give a high potential of waste minimization and at the same time prevent the environment from the negative impact of the improper disposal of the weld slag.

iii. The methodology provides a general framework for conducting a research on utilizing weld slag as a partial replacement of aggregate in concrete, be that as it may, the test flows may depend on the objectives and target of the review as well as the applicable principles and rules in the area where the review is to be performed.


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