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# A Review on the Applicability of Iron Slag in Different Forms for Concrete Production

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## Abstract

Concrete is one of the most demanding building materials, consisting of cement, coarse aggregate, fine aggregate, and water. Extraction and production of these primary ingredients (cement, coarse aggregate, and fine aggregate) consume a significant amount of natural resources and have a detrimental effect on the environment. Due to the threat of global warming and rising temperatures, civil engineers are looking for environmentally friendly alternatives to traditional building materials. Emphasizing industrial by-products is an innovative way to promote sustainable development. One such replacement is iron slag, a by-product of the steel industry. According to research, filler iron slag can replace up to 50% of the coarse aggregates in concrete production. In contrast, steel slag powder acts as a binding material and can replace approximately 20% of cement. In both cases, the final concrete mixture exhibits mechanical and compressive strengths comparable to conventional concrete. By using this by-product, the construction industry will be able to adhere to Sustainable Development Goal 12 while being more cost-effective and environmentally responsible. This paper explores the use of iron slag in concrete production through a literature review and promotes the idea of a circular economy.

***Keywords:*** *Iron Slag; Concrete; Green Building; Circular Economy*

## 1 Introduction

Concrete is a unique advanced material consisting of cement, coarse aggregate, and fine aggregate, primarily used in civil engineering projects. It is an appealing construction material due to its workability and wide range of uses (Ansari and Bandewar, 2022). Studies conducted by Lehne and Preston (2018) and Jain et al. (2022a) revealed that the concrete industry is responsible for approximately 4% to 8% of the world's $CO_2$ emissions. In addition, according to the U. S. National Ready Mixed Concrete Association (NRMCA), one pound of concrete releases 0.93 pounds of $CO_2$ (Psci, 2020). Furthermore, annually, approximately 200 million metric tonnes of cement are combined with various types of admixtures, such as fly ash, silica fume, etc., to produce high-strength concrete (Alizadeh et al., 2003; Samad and Shah, 2017). The production of clinker, the most energy-intensive stage of the cement-making process, results in around half of the emissions associated with concrete (Rubenstein, 2012).

Ferrous slag however, is a high-performance supplementary cementitious material (SCM), a by-product of the steel industry, which can be used in concrete production to enhance its strength and durability (Amran et al., 2020; Dai et al., 2019; Lothenbach et al., 2011; Piatak et al., 2015). In addition, using iron slag will allow the construction industry to adhere to Sustainable Development Goal 12, responsible consumption and production of resources. This will, in turn, allow us to preserve our natural resources for future generations (Goal 12, 2022). The main objective of this study is to explore the potential of iron slag as a constituent in concrete production while promoting a circular economy (Jain et al., 2022b).

Research shows that the concrete industry is consuming almost a 10th of the world's industrial water, often straining the drinking and irrigation water supplies since almost 75% of the consumption occurs in drought-prone, water-stressed areas (Miller et al., 2018). It also significantly contributes to the urban heat island effect in cities due to its ability to absorb heat and gases from the sun as well as cars and air-conditioning units (Watts, 2019). In addition, Damtoft et al., (2008) concluded that a typical modern rotary cement kiln with a specific heat consumption of 3.1 GJ/tonne clinker that burns traditional carbon-based fuels like coal, oil, or petroleum coke produces about 0.31kg $CO_2$/kg clinker.

Steel production on the other hand, is predicted to grow by approximately 25% to 30% by 2050. This sector accounts for about 7% of all anthropogenic $CO_2$ emissions as a result of its energy-intensive iron making process using the blast furnace (Holappa, 2020). In order to reduce greenhouse gas (GHGs) emissions in the building sector, the construction industry must implement the concept of a circular economy by encouraging the utilization of industrial waste (Gokul et al., 2012). Recycling or reusing industrial by-products from the steel industry is ecologically sustainable as well as economically beneficial (Ouda and Abdel-Gawwad, 2017). One such recycling technique is the partial substitution of the major concrete constituents with iron slag (Parron-Rubio et al., 2019). This will allow us to reduce the amount of waste and GHGs produced in cement and concrete production while increasing the national material recycling rate following SDG target 12.5 (Goal 12, 2022).

## 2 Methodology

This literature review-based study summarizes the existing literature on the potential of slag in the concrete industry following the steps as shown in Figure 1. The compiled data as represented in the pie chart in Figure 2 indicates 41% of the reviewed literature explored the use of powdered iron slag as a replacement for cement, 31% analyzed the possibilities of replacing coarse aggregates, and 28% looked at fine aggregate substitutes.

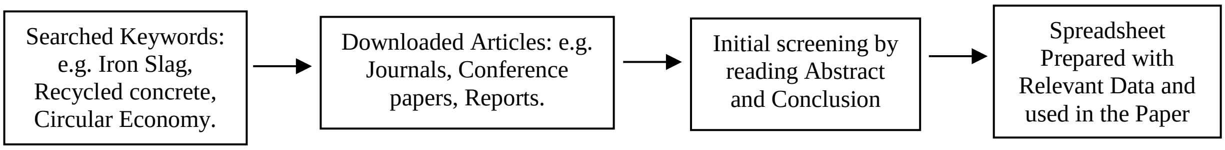


Figure 1. Research methodology for collecting data.

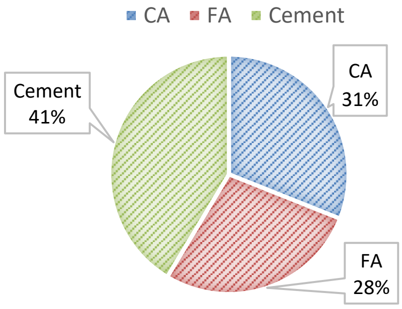


Figure 2. Percentage of total reviewed work recommending to replace each concrete component.

## 3 Chemical Composition of Slag

Slag is mainly categorized into two types, blast furnace slag, and steelmaking slag. These can be further characterized into four categories: granulated blast furnace slag, air-cooled blast furnace slag, converter slag, and electric arc furnace slag (U.S. Geological Survey, 2013). The key component of blast furnace slag is non-ferrous materials from the iron ore combined with lime and ash, while steel slag mainly consists of scrap steel as the raw material (NIPPON SLAG ASSOCIATION, 2023). The primary components of iron and steel slag are silica ($SiO_2$) and limestone (CaO). Secondary components include $Fe_2O_3$, $Al_2O_3$, MgO, MnO, FeO, and $P_2O_5$ (Bing et al., 2019). Iron slag's physical characteristics and shape resemble traditional crushed stone and sand. However, due to variations in chemical composition and cooling techniques, various types of slag exist with a wide range of properties (NIPPON SLAG ASSOCIATION, 2023). A general composition range of blast furnace iron slag is provided in Table 1.

Table 1. General composition range of blast furnace iron slag (Liang et al., 2012; NIPPON SLAG ASSOCIATION, 2023).

| **Component** | **$SiO_2$** | **Al2O3** | **CaO** | **MgO** | **MnO** | **FeO, Fe2O3** | **S** | **P2O5** | **TiO2** |
|---|---|---|---|---|---|---|---|---|---|
| Value (%) | 8-40 | 1-22 | 30-42 | 5-15 | 0.1-8 | 0.1-35 | 0.2-2 | 0.1-1.7 | 0.4-2 |

## 4 Properties of Slag

### 4.1 Physical Properties

Slag can be of different shapes (i.e., angular, roughly rounded, smoothly rounded) and sizes (coarse grain > 4.75 mm, fine grain < 4.75 mm) depending on the cooling methods used and its chemical composition. The unit weight of slag varies within a range of 1600 $kg/m^3$ to 1920 $kg/m^3$ with a specific gravity between as high as 3.6 (Hainin et al., 2014). Research shows that it has water absorption rates of up to 3%, and its porosity ranges between 2.5 to 31.2% (Hainin et al., 2014). Depending on the moisture content, efficiency of granulation, and chemical composition, the color of slag ranges from beige to dark to off-white (fine ground slag is usually white in color).

### 4.2 Mechanical Properties

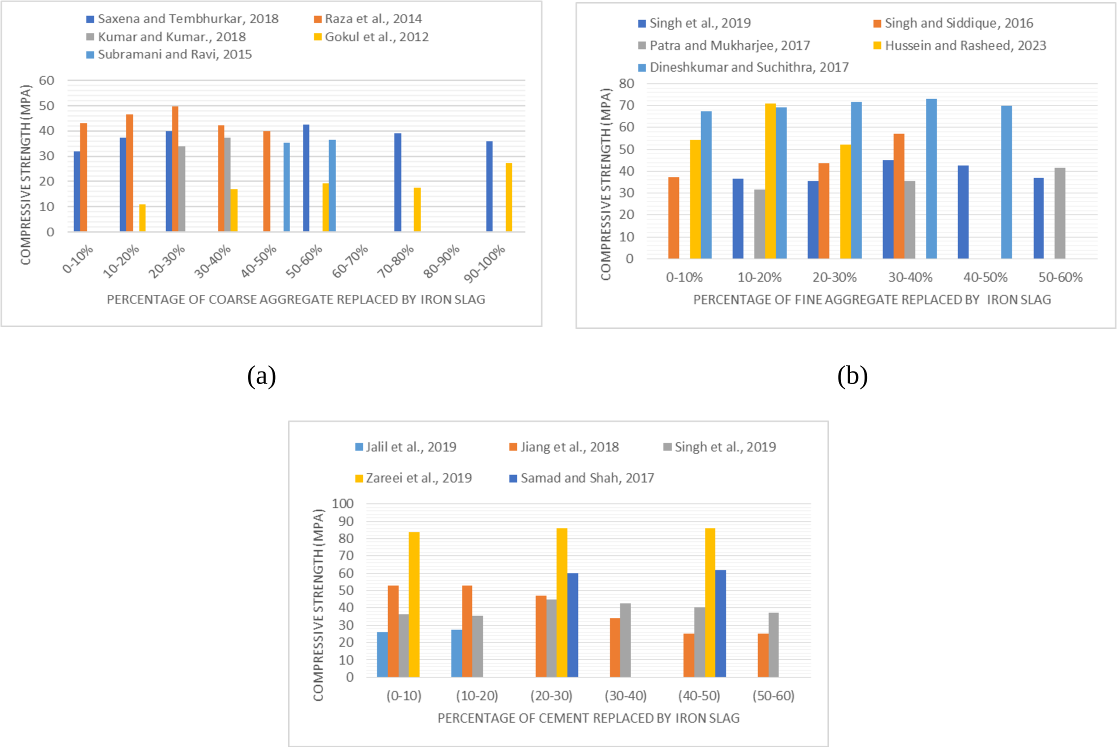
The U. S. Department of Transportation's Federal Highway Administration suggests that processed iron slag has appropriate mechanical properties for construction (FHWA-RD-97-148, 2016). LA abrasion test, sodium sulfate soundness test, angle of internal friction, hardness and California bearing ratios of steel slag were tested and presented by Noureldin and McDaniel (1990) at the 69th Annual Meeting of the Transportation Research Board. The experiments showed that slag has a good abrasion resistance at 20% to 25%, and its sodium sulfate soundness loss is lower than 12%. It has an angle of internal friction between 40° and 50° with its hardness ranging from 6% to 7%. Lastly, slag with a maximum size of 19 mm (3/4 in) possess a California bearing ratio of up to 300 (Noureldin and McDaniel, 1990; FHWA-RD-97-148, 2016).

## 5 Slag in Concrete Production

Iron slag has the potential to replace coarse aggregate, fine aggregate as well as cement due to it versatile physical and mechanical properties. This potential has been further explored in the following subsection 5.1 to 5.3. Figure 3 demonstrates the attainable 28 days compressive strength of concrete after substituting its major constituents with various forms of iron slag, i.e. as cement, coarse aggregate and fine aggregate.

### 5.1 Slag as a Replacement for Coarse Aggregate

Coarse iron slag can be used as a coarse aggregate (stone chips and brick chips) replacement in the concrete matrix. Research conducted by Raza et al., (2014) used a mixed proportion of 1:1.65:2.92 and a w/c ratio of 0.45. Stone chips were replaced with coarse iron slag at 10%, 20%, 30%, 40%, and 50%. Tests conducted at 7, 14, and 28 days show that up to 40% of the coarse aggregates can be replaced with iron slag, as it has a higher compressive strength than traditional concrete. Karim et al. (2022) reported similar findings. Concrete specimens with 50% to 70% coarse slag replacement have higher flexural strength (7.36 MPa to 7.88 MPa) than the control batch comprising of stone chips (7.5 MPa) after 28 days (Subramani and Ravi, 2015). Furthermore, partially replaced test specimens have a higher split tensile strength than regular concrete (Kumar and Kumar, 2016). Similarly, Gokul et al., (2012) replaced stone chips with mild steel iron slag from 20% to 100% at 20% intervals. The highest 28 days compressive strength was achieved at 100% replacement which was 25.79 MPa. Experiments conducted by Karim et al., (2023) concluded that concrete with iron slag has a higher compressive strength than traditional concrete using brick chips. However, Saxena and Tembhurkar (2018) modified their mix design by using wastewater instead of regular water along with basalt aggregate replacement. Following these modifications and the addition of superplasticizer, a higher compressive strength of approximately 40 MPa was observed at 28 days compared to the 30 MPa of regular cement concrete. The compressive strengths achieved due to various percentages of coarse iron slag replacement has been demonstrated in Figure 3(a).



(a)

(b)

(c)

Figure 3. 28 days compressive strength for various percentage of iron slag replacement

### 5.2 Slag as a Replacement for Fine Aggregate

Singh et al., (2019) replaced natural sand with 10% to 50% fine grained slag and achieved a 28 days compressive strength of 45.1 MPa for 30% replacement which is comparable to that of conventional concrete. Singh and Siddique (2016) on the other hand produced concrete specimens with 10%, 25% and 40% fine slag replacement. They concluded that the 40% iron slag specimen had a 41% increase in compressive strength at 28 days compared to that of the control batch. A 60% partial replacement of granulated blast furnace slag with 0.5 w/c ratio, obtained a compressive strength of 40.61 MPa, which is 23.69% higher than regular concrete (Patra and Mukharjee, 2017). Hussein and Rasheed (2023) conducted experiments replacing 0% to 30% fine aggregate with slag, their findings show that the best replacement percentage for fine aggregate is at 20%. When river sand was replaced with 0% to 50% steel slag, the 28 days compressive strength results showed that sand can be replaced by slag up to 40% (Dineshkumar and Suchithra, 2017). These results has been summarized in Figure 3(b).

### 5.3 Slag as a Replacement for Cement

Among the greenhouse gases, $CO_2$ contributes to about 65% of global warming. The global cement industry contributes about 7% of GHG emissions to the Earth's atmosphere (Subramani and Ravi, 2015). Cement is partially substituted with slag, a pozzolanic material (Zareei et al., 2019), to produce blended cement (Miller et al., 2015; Barabanshchikov et al., 2020). In terms of concrete production, the addition of iron slag notably reduces the required hydration heat of cement, enhances long-term compressive strength, and improves durability (Liu and Li, 2014; Mengxiao et al., 2015). Fine steel slag powder, with a surface area of $400m^2/kg$–$600\ m^2/kg$ and a bulk density of $1200\ kg/m^3$, can be mixed with lime to replace 40% to 60% of the total cement content. The 28 days compressive strengths achieved by the partial replacement of cement in concrete has been illustrated in Figure 3(c). Research shows that on average, 10% to 20% cement substitution gives similar results to that of conventional concrete. Parron-Rubio et al., (2019) replaced cement with ladle furnace slag (LFS) and blast furnace slag (BFS) at varying proportions and concluded that BFS is more suitable for concrete production due to its 10% increase in compressive strength at the 90 days mark compared to traditional concrete.

## 6 Concluding Remark

This study has explored the potential of iron slag as a replacement for major constituents in the concrete due to its physical and mechanical properties through previous literature. From the above sections, it can be concluded that it is possible to gradually replace traditional concrete materials with more sustainable elements with a lower energy consumption rate. Iron slag can be used as coarse and fine aggregate when proper mix design ratios are maintained. Moreover, as shown by the compressive strength test results above, due to its pozzolanic nature, it can also be used as a binding agent in conjunction with cement. One of the main sources of GHG emission in the construction industry are the cement and concrete production phases. This is mainly due to the energy-intensive material extraction and processing. Partial replacement of the raw materials, even though in small amounts, if implemented on a large scale will allow us to maintain the balance of nature. In addition, the above reviewed literatures ensure that iron slag has potential to be a major concrete constituent. The implementation of recycling waste materials within the construction industry will promote a circular economy and increase our nation's recycling rate while fulfilling SDG target 12.5 and reduce our carbon footprint.

## References

Alizadeh, R., Chini, M., Ghods, P., Hoseini, M., Montazer, S., and Shekarchi, M. (2003). Utilization of electric arc furnace slag as aggregate in concrete. Environmental Issue, 6th International Conference on Recent Advances in Concrete Technology, June. 451-464.

Amran, Y.H.M., Alyousef, R., Alabduljabbar, H. and El-Zeadani, M. (2020). Clean production and properties of geopolymer concrete; A review. Journal of Cleaner Production, 251, p.119679.

Ansari, N., and Bandewar, D. K. (2022). Experimental Study of the Physical Properties of Concrete Prepared by Partial Replacement of Cement with Alccofine, Metakaolite and GGBS. International Journal for Research in Applied Science and Engineering and Technology, 10(8), 1344–1362.

Barabanshchikov, Y., Usanova, K., Akimov, S. and Bílý, P. (2020). Low-heat concrete with ground granulated blast furnace slag. IOP Conference Series: Materials Science and Engineering, 896(1), p.012098.

Bing, L., Biao, T., Zhen, M., Cheng H., and Hongbo, L. (2019). Physical and Chemical Properties of Steel Slag Utilization Technology of Steel Slag at Home and Abroad. 242, 032012–032012.

Chemical characteristics of iron and steel slag: NIPPON SLAG ASSOCIATION. (2023). [Accessed 16 May 2023].

Dai, J., Wang, Q., Xie, C., Xue, Y., Duan, Y. and Cui, X. (2019). The Effect of Fineness on the Hydration Activity Index of Ground Granulated Blast Furnace Slag. Materials, 12(18), p.2984.

Damtoft, J. S., Lukasik, J., Herfort, D., Sorrentino, D., and Gartner, E. (2008). Sustainable development and climate change initiatives. 38(2), 115–127.

Dineshkumar, R., and Suchithra, S. (2017). Properties of concrete with partial replacement of steel slag with fine aggregate, International Conference on Energy, Communication, Data Analytics and Soft Computing. (pp. 3850-3852).

Goal 12 | Department of Economic and Social Affairs. (2022). Un.org. [Accessed 3 June 2023].

Gokul, J., Suganthan, S., Venkatram, R., and Karthikeyan, K. (2012). MILD STEEL SLAG AS A POTENTIAL REPLACEMENT FOR CONCRETE AGGREGATE. International Journal of Current Research, Vol. 4, Issue, 11, pp.106-109

Hainin, M. R., Aziz, A., Shokri, M., Jaya, R. P., Hassan, N. A. and Ahsan, A. (2014). Performance of Steel Slag in Highway Surface Course. Jurnal Teknologi, 71(3).

Holappa, L. (2020). A General Vision for Reduction of Energy Consumption and CO2 Emissions from the Steel Industry. 10(9), 1117–1117.

Hussein, M. I. M., and Rasheed, M. M. (2023). Effect of Replacement of Fine and Coarse Aggregate by Iron Slag and Steel Slag on Concrete Properties. Eurasian Journal of Engineering and Technology, 15, 90–103.

Iron and Steel Slag Statistics and Information | U.S. Geological Survey. (2013). Usgs.gov. [Accessed 16 May 2023].

Jain, K. L., Sancheti, G. (2022a). Effect of granite fines on mechanical and microstructure properties of concrete. Advances in Concrete Construction, 13(6), 461.

Jain, K. L., Sharma, D. K., and Bhargava, S. (2022b). Impact of Waste Iron Slag on Mechanical and Durability Properties of Concrete, Jordan Journal of Civil Engineering, Volume 17, No. 1 (pp. 45-57)

Karim, M., Rahman, J., Barua, P., Ahmed, K. S., and Hoq, S. M. A. (2022). Iron Slag as a Potential Replacement of Conventional Coarse Aggregate in Concrete Production, In Proceedings of the 6th International Conference on Advances in Civil Engineering, CUET, Chittagong, Bangladesh, (pp. 553-558).

Karim, M., Rahman, J., Sikder, S., Nath, A., Rashid, H., Ahmed, K. S., and Hoq, S. M. A. (2023). Applicability of Iron Slag as Coarse Aggregate in Concrete Production. In Proceedings of the 2nd International Conference on Advances in Civil Infrastructure and Construction Materials, Military Institute of Science and Technology (MIST), Mirpur Cantonment, Dhaka, Bangladesh, (pp. 964-971)

Kumar, P. V., and Kumar, R. R. (2018). An Experimental Study on Partial Replacement of Coarse Aggregate by Iron Slag with Polypropylyne Fiber. In International Journal of Science and Research. IJSR. ISSN (Online): 2319-7064 Volume 5, Issue 3, (pp. 212-216).

Lehne, J., and Preston, F. (2018). Chatham House Report Making Concrete Change Innovation in Low-carbon Cement and Concrete. https://www.chathamhouse.org/2018/06/making-concrete-change-innovation-low-carbon-cement-and-concrete [Accessed 16 May 2023].

Liang, Y., Li, W., and Wang, X. (2012). Influence of Water Content on Mechanical Properties of Improved Clayey Soil Using Steel Slag. 31(1), 83–91.

Liu, S., and Li, L. (2014). Influence of fineness on the cementitious properties of steel slag. Journal of Thermal Analysis and Calorimetry, 117(2), 629–634.

Lothenbach, B., Scrivener, K. and Hooton, R.D. (2011). Supplementary cementitious materials. Cement and Concrete Research, 41(12), 1244–1256.

Mengxiao, S., Qiang, W., and Zhikai, Z. (2015). Comparison of the properties between high-volume fly ash concrete and high-volume steel slag concrete under temperature matching curing condition. Construction and Building Materials, 98, 649–655.

Miller, S. A., Horvath, A., Monteiro, P. J. M. and Ostertag, C. P. (2015). Greenhouse gas emissions from concrete can be reduced by using mix proportions, geometric aspects, and age as design factors. Environmental Research Letters, 10(11), p.114017.

Miller, S. A., Horvath, A., and Monteiro, P. J. M. (2018). Impacts of booming concrete production on water resources worldwide. 1(1), 69–76.

Noureldin, A. S., and McDaniel, R. S. (1990). Evaluation of Steel Slag Asphalt Surface Mixtures. Presented at Transportation Research Board 69th Annual Meeting, Washington, DC.

Ouda, A.S. and Abdel-Gawwad, H.A. (2017). The effect of replacing sand by iron slag on physical, mechanical and radiological properties of cement mortar. HBRC Journal, 13(3), pp.255–261.

Parron-Rubio, M. E., Perez-Garcia, F., Gonzalez-Herrera, A., Oliveira, M., and Rubio-Cintas, M. D. (2019). Slag Substitution as a Cementing Material in Concrete: Mechanical, Physical and Environmental Properties. 12(18), 2845–2845.

Patra, R. K., and Mukharjee, B. B. (2017). Influence of incorporation of granulated blast furnace slag as replacement of fine aggregate on properties of concrete. 165, 468–476.

Piatak, N.M., Parsons, M.B. and Seal, R.R. (2015). Characteristics and environmental aspects of slag: A review. Applied Geochemistry, 57, pp.236–266.

Psci. (2020). Cement and Concrete: The Environmental Impact — PSCI. PSCI. https://psci.princeton.edu/tips/2020/11/3/cement-and-concrete-the-environmental-impact [Accessed 3 June 2023].

Raza, K., Singh, A., Patel, R., and Scholar, P. (2014). Strength Analysis of Concrete by Using Iron Slag as a Partial Replacement of Normal Aggregate (Coarse) in Concrete. In International Journal of Science and Research. IJSR. ISSN (Online): 2319-7064, Volume 3, Issue 10, (pp. 190-193)

Rubenstein, M. (2012, May 9). Emissions from the Cement Industry. State of the Planet. https://news.climate.columbia.edu/2012/05/09/emissions-from-the-cement-industry/ [Accessed 3 June 2023].

Samad, S. and Shah, A. (2017). Role of binary cement including Supplementary Cementitious Material (SCM), in production of environmentally sustainable concrete: A critical review. International Journal of Sustainable Built Environment, 6(2), pp.663–674.

Saxena, S., and A.R. Tembhurkar. (2018). Impact of use of steel slag as coarse aggregate and wastewater on fresh and hardened properties of concrete. 165, 126–137.

Singh, A., Bhadauria, S. S., Kushwah, S. S., and Tare, K. (2019). The study on optimization of cement and fine aggregate by blast furnace slag in concrete. AIP Conference Proceedings 2158, 020031, Volume 2158, Issue 1.

Singh, G., and Siddique, R. (2016). Effect of iron slag as partial replacement of fine aggregates on the durability characteristics of self-compacting concrete. 128, 88–95.

Steel Slag - Material Description - User Guidelines for Waste and By-product Materials in Pavement Construction - FHWA-RD-97-148. (2016). Dot.gov. [Accessed 30 May 2023].

Subramani, T., and Ravi, G. (2015). Experimental Investigation Of Coarse Aggregate With Steel Slag In Concrete. IOSR Journal of Engineering (IOSRJEN). ISSN (e): 2250-3021, ISSN (p): 2278-8719, Vol. 05, Issue 05, pp. 64-73

Watts, J. (2019, February 25). Concrete: the most destructive material on Earth. The Guardian; The Guardian. [Accessed 16 May 2023].

Zareei, S. A., Ameri, F., Bahrami, N., Shoaei, P., Moosaei, H. R. and Salemi, N. (2019). Performance of sustainable high strength concrete with basic oxygen steelmaking (BOS) slag and nano-silica, J. Build. Eng. 25 (2019) 100791.