PHYSICAL AND DURABILITY PROPERTIES OF STEEL SLAG PARTICLES FOR USE IN ROAD AND CONCRETE WORKS

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Abstract- This study aimed to assess the viability of steel slag as a substitute for natural coarse aggregates for road and concrete works. The slag aggregates underwent evaluation based on impact value, crushing strength, bulk density, abrasion value, and flakiness index. Concrete samples incorporating steel slag aggregates were then prepared and compared against those containing natural coarse aggregates in terms of physical and durability performance. For this investigation, a 1:2:4 (M15) concrete mix design was targeted. Results indicated that the slag aggregates exhibited an impact value of 29.5%, a bulk density of 1208 kg/m³, an elongation index of 10.8%, a crushing value of 31.3%, and a flakiness index of 10.95%. The prepared concrete samples demonstrated a water absorption rate of 4%, a Rebound number of 22, and a wet surface skid resistance of 56 on the British Pendulum scale. The findings suggest that steel slag aggregates hold promise as a viable alternative to natural aggregates in concrete production. This substitution offers several advantages, including the environmentally sound disposal of slag waste, the promotion of green concrete and road practices, and potential cost reductions in construction projects. These benefits align with the sustainable development goals outlined by the United Nations.

Keywords- Concrete, performance, road, slag aggregates.

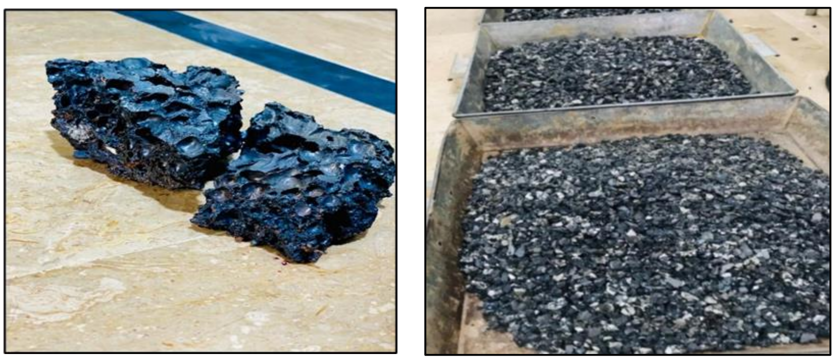
1 Introduction

About 12 million tons of concrete are being used world widely every year for construction purposes. Natural aggregates for concrete are acquired from rocks and mountains. Excessive use of natural rock in construction is disrupting the naturally balanced environment of the world by introducing air pollution, earthquakes, and landslides due to bombarding, volcanic eruptions, and non-recoverable resources loss. Using steel slag instead of traditional coarse aggregate for construction would reduce pollution, unbalanced environment, cost of construction and ensure safe disposal of steel slag. Several studies are available on the use of steel slag for use in cementitious materials. Some important and recent studies are mentioned here. Sezer et al. used steel slag as a partial replacement for natural fine, and coarse aggregates. The slag had a higher density than the natural aggregates. This not only enhanced the density of concrete, but also decreased the strength. The strength loss was more prominent where, fine aggregates were replaced with the slag particles [1]. Lai et al. used steel slag in percentages from 0-80% as a partial replacement of natural coarse aggregates. The authors revealed that the optimum value for strength enhancement of concrete is 50% [2]. Nguyen et al. investigated the effect of steel slag as a full replacement of natural coarse aggregates on the compressive strength of concrete. The main objective of the research was to examine the effect of age on compressive strength of slag concrete. Three types of concrete samples were prepared. The effect of higher cement content and lower sand and steel slag contents were studied. The results demonstrated an increase in strength of slag concrete up to an age of one year [3]. Jalil et al. used steel slag as a partial replacement of cement for making green concrete. The results showed that the slag has little pozzolanic value and the strength drastically reduced with the increasing slag content [4]. This work is an extension of our previous research. The previous study showed that slag has no cementing or pozzolanic value. Therefore, in this study the slag was used as a 100% replacement of coarse aggregates for making an eco-friendly concrete. The novelty of the work lies in the fact that a complete chemical, physical and mechanical analysis of the slag was performed before deciding its suitability for concrete work. The previous studies while address the physical and chemical analysis did not focus of the mechanical properties of the slag. The prepared samples were evaluated in terms of water absorption for durability, rebound number for strength and skid resistance for safety in concrete pavements.

2 Research Methodology

2.1 Materials

For this study, steel slag was sourced from a local steel factory and subsequently converted into aggregates through a crushing process. The waste slag and resulting aggregates are depicted in Figure 1. Specifically, aggregates passing through a 37.5 mm sieve and retained on a 9.5 mm sieve were selected for use as coarse aggregates in the experimentation. The concrete samples were prepared as per ASTM C31 specifications [5]. Two types of specimens were prepared for testing purposes, cylindrical and rectangular slabs. Rectangular slabs were specifically used for performing skid resistance test while the other tests were performed using concrete cylinders such as hardened density test, water absorption, acidic attack and Schmidt hammer test.



(a) (b)

Figure 1: Waste steel slag (a) raw form, (b) coarse aggregates.

2.2 Testing

The impact value of the aggregates was determined through D5874-16 method [6]. The elongation and flakiness indices were worked out through ASTM D4791-19 standards [7]. The crushing value was determined by ASTM D5821 standard method [8]. The abrasion value was determined by ASTM C131/C13M-14 [9]. The bulk density was determined by ASTM C29/C29-17 method [10]. Once the aggregate properties have been determined, the aggregates were mixed in a concrete mix 1:2:4 (M15). This is a common mix used for ordinary concrete works. Grade 53 OPC cement, Mangla reservoir sand, and tap water were used for making concrete. The hardened density, and water absorption were determined by ASTM C642-21 method [11]. The resistance to acid attack was measured through ASTM C1898-20 method [12], while the skid resistance and Schmidt rebound number were determined through ASTM E2340 2021[13] and ASTM C805/C805M-18 [14] respectively.

3 Results

3.1 Characterization of slag aggregates

The characteristics of the slag aggregates are compared with the natural limestone aggregates and the comparison is presented in Table 1.

Table 1 Comparison of characteristics of slag and natural aggregates

Sr. No.	Test on Aggregate	Natural Limestone Aggregate	Slag Aggregate
1	Impact value	13.20%	29.50%
2	Crushing strength	28.20%	31.35%
3	Bulk density	1601 kg/m^3	1369.8kg/m^3

4	Abrasion value	30%	34.28%
5	Flakiness Index	Less than 15%	10.95%
6	Elongation Index	Less than 15%	10.81%

The impact value of 10-20% designate the aggregates strong enough for all concrete works, whereas an impact value of 10-30% is designated as satisfactory for road works. This indicates that the impact value is a bit inferior to that of the natural aggregates. According to ASTM D5821, the crushing value of the aggregate shall not exceed 30% [8]. Here, the crushing value of steel slag material turns out to be 31.35%. Materials with lower crushing values are suitable for roads and pavements, as well for dense carpeting and bituminous dressing. According to ASTM C29 standard, the ideal Bulk Density range of aggregate is 1200-1750 kg/m^3[15]. However, the bulk density of steel slag aggregate comes out approximately 1370 kg/m^3. The obtained density value represents that the concrete mixture can provide good structural support and durability along with light weight structures. The abrasion value of steel slag turned out 34.28%; this value makes the aggregates suitable for a variety of works concrete and road works except the bituminous concrete surface coarse [9]. According to ASTM 4791-10 Standard, the flakiness index for road construction should remain in the limit of 15%, normally and should not exceed 25% [8]. The flakiness index of steel slag aggregate came out 10.95% which is quite within the limits for road construction. The elongation index is approximately 11%. According to ASTM D4791-19 standards, the elongation index should remain within the limit of 15% when it comes to aggregate and construction of roads. For pavements with bitumen included in the mixture, the value can go beyond 20 to 25 percent.

3.2 Concrete containing slag aggregates

The Fresh and Hardened Density value obtained by performing the test is approximately 2292kg/m^3 and 2333kg/m^3 respectively. The density of ordinary concrete ranges from 2200 to 2400 kg/m^3 [16]. The experimental density shows that the material can provide high performance where integrity of structure and protection is concerned. The skid resistance results are shown in Figure 2. According to ASTM E303, the obtained skid resistance value of 56 for wet surface represents an extremely low chances of slipping [17]. The dry surface skid resistance value represents that the concrete is appropriate for heavy duty [18].

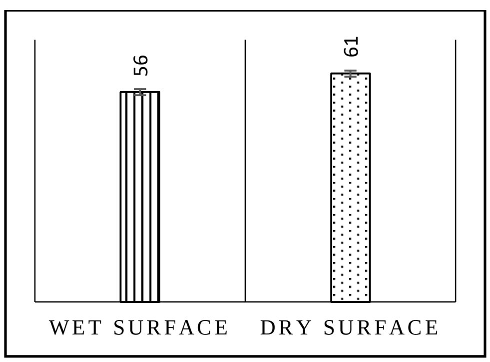


Figure 2: Skid resistance of slag concrete.

For acid attack test, the concrete cylinders containing natural and slag aggregates were dipped in 5% concentrated sulfuric acid. The compressive strength of the mixes cured for 28 days was measured before and after the test. The strength of concrete reduced by 18% and 22% respectively for natural and slag aggregates. The strength factor calculated before dipping into the acid, came out to be approximately 20% for the cylindrical steel slag concrete sample. On average, upon keeping the sample into the 5% H_2SO_4 mixed with water, the compressive strength value came out to be approximately 18%. The reduction in strength is an indication of lower resistance of slag against the acidic attack. The rebound number for concrete came out to be 30 and 22 for natural and slag aggregates respectively. Although Rebound number test is not considered to be a true measure of the quality, yet the lower number for slag is an indication of a lower strength for slag concrete.

4 Practical Implementation

The characteristics of the slag aggregates given in this work can guide the designers to adapt them in road and concrete structures. This will ensure a sustainable construction. The cost of the project will also reduce. The use of steel slag will result in lightweight structures, which are much beneficial in many practical situations like lightweight concrete, nonstructural concrete, subbase and base layers in roads, and more specifically in blended form, where these aggregates can be combined with the natural aggregates.

5 Conclusion

From this experimental work, the following conclusions are derived

1. The slag aggregates have an impact value of less than 30, which make them suitable for road works. The slag aggregates are light in weight (only 1370 kg/m^3) and thus shall reduce the dead weight of the structure. This makes them suitable for works, where lightweight members are required like subbase and base Layers in Road Construction, Precast concrete products, and pavement bedding etc.
2. The slag aggregates have adequate elongation (10.9%) and flakiness (10.8%) indices, whereas the crushing strength is 31%, which is a slightly lower than that of the natural aggregates.
3. The slag concrete offers suitable skid resistance in both dry (61 on British Pendulum scale) and wet conditions (56 on British Pendulum scale)however their resistance to chemical attack is lower than that of the concrete containing natural aggregates. The concrete containing slag concrete exhibits adequate water absorption characteristics and therefore can be considered as durable against moisture transport.

References

[1] G. İ. Sezer and M. Gülderen, "Usage of steel slag in concrete as fine and/or coarse aggregate," *Indian J. Eng. Mater. Sci.*, vol. 22, pp. 339–344, 2015.
[2] M. H. Lai, J. Zou, B. Yao, J. C. M. Ho, X. Zhuang, and Q. Wang, "Improving mechanical behavior and microstructure of concrete by using BOF steel slag aggregate," *Constr. Build. Mater.*, vol. 277, p. 122269, Mar. 2021, doi: 10.1016/j.conbuildmat.2021.122269.
[3] T.-T.-H. Nguyen, D.-H. Phan, H.-H. Mai, and D.-L. Nguyen, "Investigation on Compressive Characteristics of Steel-Slag Concrete," *Materials (Basel).*, vol. 13, no. 8, p. 1928, Apr. 2020, doi: 10.3390/ma13081928.
[4] A. Jalil, A. Khitab, H. Ishtiaq, S. H. Bukhari, M. T. Arshad, and W. Anwar, "Evaluation of Steel Industrial Slag as Partial Replacement of Cement in Concrete," *Civ. Eng. J.*, vol. 5, no. 1, p. 181, Jan. 2019, doi: 10.28991/cej-2019-03091236.
[5] ASTM C31, "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory," *ASTM Int.*, pp. 1–8, 2013, doi: 10.1520/C0192.
[6] ASTM D-5874-16, "Standard Test Methods for Determination of the Impact Value (IV) of a Soil," West Conshohocken, PA, 19428-2959 USA, 2016.
[7] ASTM D4791−19, "Standard Test Method for Flat Particles, Elongated Particles, or Flat and Elongated Particles in Coarse Aggregate," West Conshohocken, PA, 19428-2959 USA, 2019.
[8] ASTM D5821−13, "Determining the Percentage of Fractured Particles in Coarse Aggregate," West Conshohocken, PA, 19428-2959 USA, 2013.
[9] ASTM C131/C13M-14, "Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine," West Conshohocken, PA, 19428-2959 USA, 2014.
[10] ASTM C29 / C29M-17a, "Standard Test Method for Bulk Density ('Unit Weight') and Voids in Aggregate, ASTM International, West Conshohocken, PA," *Annu. B. ASTM Stand.*, no. C, pp. 1–7, 2017.
[11] ASTM C642-21, "Standard Test Method for Density, Absorption, and Voids in Hardened Concrete," West Conshohocken, PA, 19428-2959 USA, 2021. doi: 10.1520/C0642-21.
[12] ASTM C1898-20, "tandard Test Methods for Determining the Chemical Resistance of Concrete Products to Acid Attack," West Conshohocken, PA, 19428-2959 USA, 2020.
[13] ASTM E2340, "Standard Test Method for Measuring the Skid Resistance of Pavements and Other Trafficked Surfaces Using a Continuous Reading, Fixed-Slip Technique," West Conshohocken, PA, 19428-2959 USA, 2021.
[14] ASTM C805/C805M-18, "Standard Test Method for Rebound Number of Hardened Concrete," 2018, doi: 10.1520/C0805_C0805M-18.
[15] ASTM C29/C29M-17, "Standard Test Method for Bulk Density ('Unit Weight') and Voids in Aggregate," West Conshohocken, PA, 19428-2959 USA, 2017.
[16] A. Khitab, *Materials of Construction*. Allied Books, 2012.
[17] ASTM E303-22, "Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester," West Conshohocken, PA, 19428-2959 USA, 2022.
[18] M. R. Anwar, N. Ahmad, A. Khitab, and R. B. N. Khan, "Development of Pervious Concrete with Enhanced Skid Resistance using Waste Tires Particles," *Proc. Pakistan Acad. Sci. A. Phys. Comput. Sci.*, vol. 61, no. 1, Mar. 2024, doi: 10.53560/PPASA(60-1)830.