REVISTAMATĒRIA V.29 N.3
ISSN 1517-7076 articles e20240387, 2024

Strength properties of concrete using waste and industrial by products

Rajendran Selvapriya[1], Rajagopal Shanmugam[1], Murugesan Gopinath[1]

[1]Muthayammal Engineering College, Department of Civil Engineering. 637408, Rasipuram, Tamil Nadu, Índia.
e-mail: selvapriyarajendran96@gmail.com, shanmugamrgeo@gmail.com, prathee.gopi@gmail.com

ABSTRACT

Growing industrialization leads to a large amount of trash being disposed of, which puts the environment at risk. A significant issue for these sectors is the disposal of the Industrial By-Products/Waste produced by the industry, which results in ground water contamination and an average annual production of 3 million tons of caustic waste. In both developed and developing nations, the rate of urbanization and industrialization rises with the production of industrial waste. The recycling or use of industrial waste by-products has grown in popularity as a disposal option due to growing environmental awareness of potential harmful impacts. This study finds a chance to assess the results of using substitutes for both fine and coarse materials with copper slag, iron slag and recycled concrete aggregate with varying amounts of mix. The mechanical parameters of both the recommended mix and normal concrete were measured and compared during the 28-day curing period. Results were intended to show the proper mix proportion that would produce the highest mechanical strength. The above-mentioned proportions were the subject of an experimental investigation. The study found that adding recycled concrete aggregate to conventional concrete mix strengthened it by 40% RCA, 40% iron, and 25% iron slag.

Keywords: Recycled concrete aggregate; Iron slag; Copper slag; Performance of concrete.

1. INTRODUCTION

Civil engineers are under pressure to create new plans that should be both economically and environmentally feasible as awareness of the significance of considering natural resources in the building industry has grown recently. The countless articles that emphasized the need for sustainable growth and the loss of natural resources made this need abundantly evident. But achieving sustainable development in the construction sector requires a variety of innovative approaches, like picking the appropriate building materials, utilizing cutting-edge procedures and techniques for environmentally friendly operations, recycling and repurposing waste, and so forth. MITHUN and NARASIMHAN [1] state that the process of refining Almost 3 t of copper based slags were created by copper the majority of which was disposed of as land fill.

Copper-based slag can be obtained from the copper production process. While part of the copper slag was used to apply abrasives during the rust cleaning process, most of it was overlooked. However, even though India produces 17,000 tonnes of iron slag annually, similar industrial waste iron slag was disposed of in a landfill [2]. Even Nevertheless, the literature makes clear that numerous research have already attempted to use waste resources, particularly aggregates, in the construction industry.

Based on data from EUROSTAT [3], it has been mentioned that of the 2.5 billion tons of waste generated, demolition and construction waste account for about 860 million tonnes. Researchers are eager to organize these construction wastes and then advance the production of coarse aggregate because these Statistics in emerging nations like China and India are becoming worse. Bulk and water absorption, density distributions, graduation curves, and other attributes can actually be facilitated by a multitude; McNeil in addition to WAGIH *et al.* (2013) [4], KANG *et al.* (2013) [5], LEDESMA *et al.* [6], ARULRAJAH *et al.* [7]. RCA involves more than just keeping the waste-to-income ratio constant.With the exception of 60% replacement, the strength characteristics are unaffected by the addition of bottom ash and waste foundry sand as fine aggregate [8]. The observations were categorized into three sets according to the added mineral admixtures. To get the target compressive strength, the mix ingredients were provided as input parameters [9]. In the preparation of stabilized adobe blocks, as well as in the preparation of recycled masonry concrete blocks and stabilized mud concrete blocks, the experimental program suggests the suitability and potential of using demolished brick masonry waste, a

Corresponding Author: Rajendran Selvapriya Received on 27/06/2024 Accepted on 31/07/2024

DOI: https://doi.org/10.1590/1517-7076-RMAT-2024-0387

type of C&D waste, as a substitute for fine aggregate. One efficient method of managing the C&D wastes is through the procedure described in the preparation of masonry units [10]. When silica fume is properly added to concrete, the material's mechanical and durability properties are enhanced [11]. The flexural strength increases by 7.58% when comparing the composite Reactive powder concrete beam with stainless steel reinforcement to the composite concrete beam with stainless steel reinforcement. The composite Reactive powder concrete beam has a 5.6% higher flexural strength than composite concrete reinforced with PVC [12]. In UHPC mortar, the higher SCLT improved workability, compressive strength, and decreased porosity. 30 µm SCLT and 2.0 vol% steel fibers produced the best overall performance, with a compressive strength of 168.9 MPa and a workability of 230 mm [13]. The findings highlighted the significance of accurate design by proving that there are ideal particle spacing in the UHPC system at various scales [14]. Up to J25, compressive strength is still better than that of the control mix even if it declines with increasing jarosite replacement levels [15].

This study aimed to assess the feasibility of recommending a concrete mix that includes recycled coarse aggregate on fine aggregate and cop-per and iron slag as an alternative on coarse aggregate, to bridge the gap in the body of literature and satisfy the increasing demand. Other aggregate proportions were taken into consideration for a more thorough understanding, and they were as follows. Sand and gravel are replaced with copper slag, iron slag, and recycled concrete aggregate in that order. An experimental research was conducted as part of the study to test the compressive force, split tensile force, and flexibility of the mix% combinations.

2. MATERIAL INVESTIGATION

2.1. Materials

Cement, fine aggregate, coarse aggregate, iron and copper slag, recycled concrete aggregate, water from different designation, and materials for the preliminary inquiry were gathered. The physical characteristics of the materials that have been gathered are shown below.

2.2. Cement

53 Grade conventional Portland cement, which has a 3.15 average specific gravity, an acceptable consistency of 27%, and an ultimate fineness of 5%, was used in this investigation. It was claimed that 30 minutes and 10 hours, respectively, were recorded as the first and last setting times.

2.3. Fine aggregate

Fine aggregate is made from natural sand that, where applicable, has a specific gravity of 2.56 and a fineness modulus of 2.63, according to IS 2386 (Part III)-1963.

2.4. Coarse aggregate

In this experiment, 12 mm gravel with an average specific gravity of 2.67 and a particle size module of 6.89 was also applied as a coarse aggregate in addition to RCA.

2.5. Copper slag

Since Slag made of copper has been shown in earlier research to have superior quality and to have positive impacts on concrete, this study investigated the use of copper based slag as a partial fine aggregate replacement. Specific gravity is 3.31 and its fineness modulus is 3.44, as seen in Figure 1. The plain copper slag has been researched for this investigation without the use of any external inducements, such as NaOH.

Figure 1: Copper slag.

Figure 2: Iron slag.

Table 1: Physical characteristics of RCA.

S. NO	PROPERTY	VALUES
1.	Specific gravity	2.57
2.	Density	1220 kg/m^3
3.	Water absorption	5.2%

2.6. Iron slag

Several recent studies have unequivocally demonstrated that the mechanical along with other reactive properties of concrete have been enhanced by the substitution of iron slag for other materials in the concrete mix. Because of this, the study uses copper slag, a copper byproduct, in place of fine aggregate that is produced at rolling steel and has a an average specific gravity of 3.1. The comparable values for the fineness modulus are 2.49 and 2.72, as seen in Figure 2.

2.7. Recycled concrete aggregate

This was constructed with recycled concrete material taken from neighboring Trichy, Tamil Nadu, wrecked buildings. After the RCA were collected, the required size could be crushed with the help of crushing machinery. The crushed aggregate was also exposed to a 2-hour 2N-NaOH treatment to clear the area around the debris's surface of the collected dirt and mortar dust. The obtained RCA's bulk density, according to the preliminary analysis, was 1360 kg/m^3, more than 10% less than that of ordinary concrete. At 5.02%, the rate of water absorption is approximately 80 times more than the typical coarse aggregates. RCA absorbs more water than conventional aggregate because of the material's porosity. On the other hand, Table 1 presents the physical attributes of RCA ascertained by the laboratory examination.

2.8. Water

Toxic substances cannot be found in the water utilized for blending and healing. For concrete mix and curing processes, a portable water source with a pH of 6.9 is required.

3. EXPERIMENTAL INVESTIGATION

3.1. Mix design

To examine the effect of waste substitution on the strength of conventional concrete, concrete mixtures with different concentrations of copper slag, iron slag, and recycled concrete aggregate were employed as partial replacements for fine aggregates and coarse aggregates, respectively. The different percentages of replacement fine and coarse particles were considered when creating the concrete mixtures. According to IS: 516-1959, concrete samples were made and compacted. According to the specifications, each material—cement, water, coarse aggregate, and fine aggregate—was weighed individually in a container. Nevertheless, the components were combined in accordance with IS: 10262-2009 specifications.

3.2. Sample preparation

To achieve the aim, 27 cubes measuring 150 mm × 150 mm × 150 mm were cast using the previously defined mix design. Nevertheless, in order to carry out more research on strength, a range of specimen types other than

Table 2: Samples using various batch ratios that are used.

BATCH NO	QUANTITY OF RCA (%)	QUANTITY OF IRON SLAG (%)	QUANTITY OF COPPER SLAG (%)
1	20	30	30
2	25	30	30
3	30	30	30
4	20	40	30
5	25	40	30
6	30	40	30
7	20	50	30
8	25	50	30
9	30	50	30
10	20	30	40
11	25	30	40
12	30	30	40
13	20	40	40
14	25	40	40
15	30	40	40
16	20	50	40
17	25	50	40
18	30	50	40
19	20	30	50
20	25	30	50
21	30	30	50
22	20	40	50
23	25	40	50
24	30	40	50
25	20	50	50
26	25	50	50
27	30	50	50
28	0	0	0

cubes were produced. For example, 100 mm × 100 mm × 500 mm prisms were produced to evaluate the flexural strength and 150 mm diameter × 300 mm height cylinders were built to test the split tensile strength. All the specimens, however, are allowed to heal in ordinary water for 28 days while being monitored on a regular basis. Table 2 displays the different aggre-gate substitution ratios that were utilized in the concrete mix.

3.3. Testing procedure

The effectiveness of the suggested mix designs in expressions of compressive, tensile, and flexural strength was examined. Each strength feature provides a different viewpoint on the recommended blend because each testing has its own set of rules to go by, as explained below.

An electronic Universal Testing Machine (UTM) with a 100 T capacity was used to evaluate the compressive strength of the manufactured cube samples in accordance with IS:516 - 1959 specifications.

A 100 T capacity UTM was utilized for the experiment, and a cylinder specimen with all mix patterns was employed to assess the split tensile strength.

The prism specimen underwent a 28-day curing period prior to being put through the flexural test. Additionally, the test was designed to confirm that the IS:516-1959 requirements were being met, At two loading positions, a 100 T hydraulic jack was attached to support the specimen.

4. RESULTS AND DISCUSSION

4.1. Influence of iron, copper, and RCA slags on concrete's compressive strength

Figure 3 displays the calculated compressive strength values for various combination amounts. Test findings show that mix number 14, consisting of 25% RCA, 40% iron slag, and 40% copper slag, has the maximum compressive strength. It produces a maximum amount of compressive strength of 34.58 N/mm^2 in this mixture. The illustration indicates that strength first rises, eventually peaks, and then falls even further. Moreover, cement mortars' compressive strength rises with the proportion of copper slag in them until it reaches a point where cementitious material can be optimally substituted. Additionally, when the volume increased, the compressive strength decreased. Adding waste aggregate to ordinary concrete enhanced its compressive strength by nearly 6%.

4.2. Influence of iron, copper, and RCA slags on concrete's split tensile strength

Following a 28-day healing period, the split tensile strength of various concrete formulations is shown in Figure 4. The findings demonstrate that the average tensile strength satisfied design requirements and was within allowable bounds. It would be feasible to determine the tensile strength practically to be 0.45 pF_{cu} for design reasons. A 14-the variety mix, which consists of a blend of 25% RCA, 40% iron slag, and 40% copper slag, the maximum amount of split tensile strength was determined to be 7.87 N/mm^2. On the other hand, the ideal substitute for leftover cementitious material for fine aggregate and coarse aggregate that has been discovered is 6.45 N/mm^2 for conventional concrete.

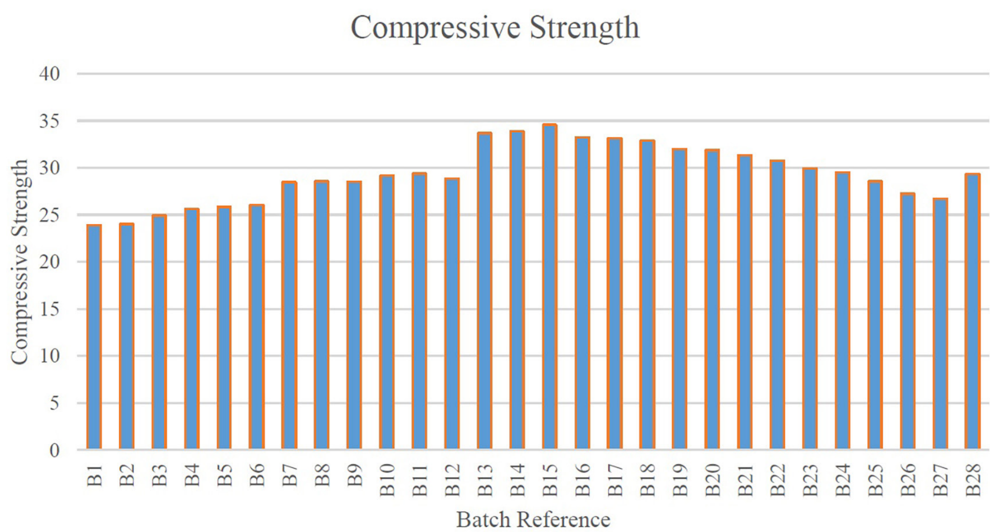

Figure 3: Compressive strength for various batch ratios.

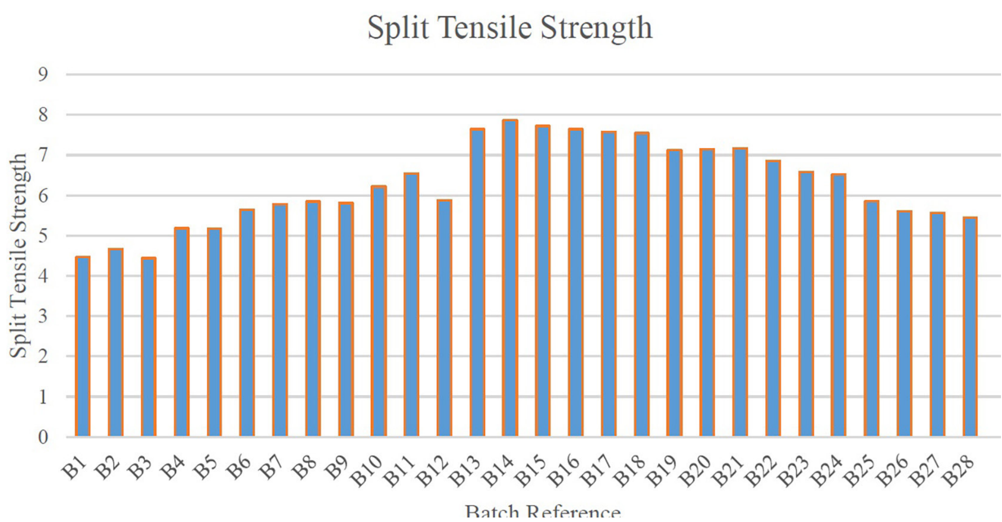

Figure 4: Split tensile strength for various batch ratios.

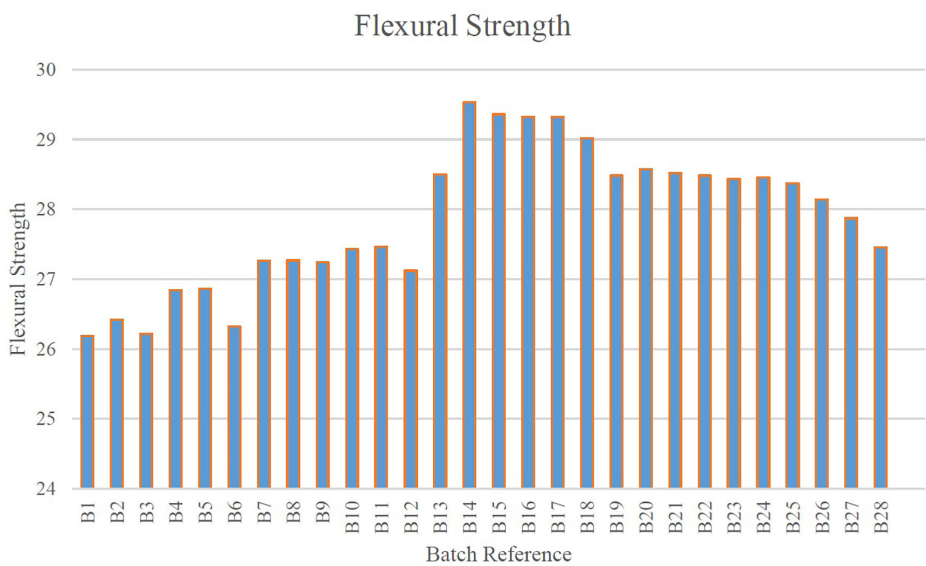

Figure 5: Flexural strength for various batch ratios.

Table 3: Comparing several mixes combination with respect to the strength qualities of concrete.

BATCH REFERENCE	COMPRESSIVE STRENGTH (N/mm²)	SPLIT TENSILE STRENGTH (N/mm²)	FLEXURAL STRENGTH (N/mm²)
B1	23.86	4.47	26.18
B2	24.02	4.66	26.42
B3	24.92	4.44	26.22
B4	25.62	5.18	26.84
B5	25.84	5.17	26.86
B6	26.02	5.64	26.32
B7	28.46	5.77	27.26
B8	28.54	5.84	27.27
B9	28.48	5.81	27.24
B10	29.14	6.22	27.43
B11	29.38	6.54	27.46
B12	28.85	5.88	27.12
B13	33.66	7.64	28.5
B14	33.87	7.87	29.53
B15	34.58	7.72	29.36
B16	33.22	7.64	29.32
B17	33.15	7.58	29.32
B18	32.86	7.54	29.02
B19	32.02	7.12	28.48
B20	31.85	7.15	28.57
B21	31.32	7.17	28.52
B22	30.76	6.85	28.48
B23	29.92	6.58	28.43
B24	29.52	6.52	28.46
B25	28.54	5.86	28.37
B26	27.25	5.6	28.14
B27	26.7	5.57	27.87
B28	29.32	5.45	27.45

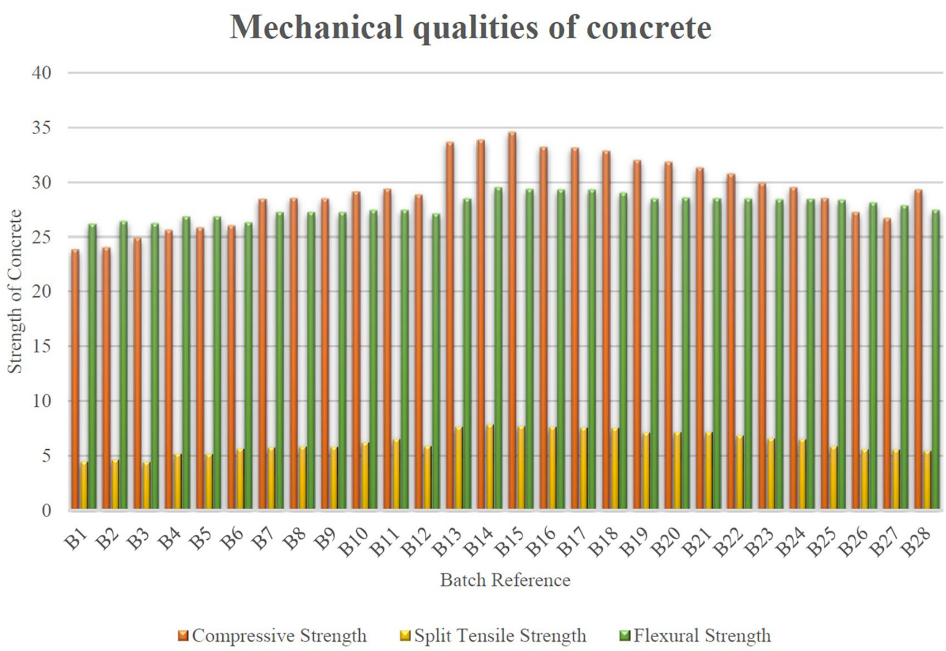

Figure 6: Comparing several mixes combination with respect to the mechanical qualities of concrete.

4.3. Influence of iron, copper, and RCA slags on concrete's flexural strength

The split tensile strength of several concrete formulations after a 28-day curing time is shown in Figure 4. The findings demonstrate that the average tensile strength was within permitted ranges and satisfied design specifications. It is possible to experimentally determine the tensile strength for design purposes to be 0.75 pF_{cu}. The maximum amount of split tensile strength on a 14 number mix a mixture of 25% RCA, 40% iron slag, and 40% copper slag was determined to be 29.36 N/mm^2. The found optimal substitution of leftover cement-like substance for fine and coarse aggregate is 6.45 N/mm^2, which is lower than conventional concrete (Figure 5).

4.4. Strength properties of concrete

Table 3 and Figure 6 illustrate the strength qualities of the different concrete mix concentrations in terms of flexural, split tensile, and compressive strength.

5. CONCLUSION

Number of environmentally friendly as well as economically beneficial environmentally conscious construction methods have been implemented by the building industry as an outcome of the need for long-term growth. With this project, construction and industrial waste was to be replaced with coarse and fine aggregate. This study examined substitute cementitious materials as a potential solution to this problem. Though most studies are limited to examining one of the elements' effects on concrete, none of the three combinations have been examined previously. Tests were conducted on the flexural, tensile, and compressive properties of 27 sample compositions that were cast. This study indicates that of 25% RCA, 40% iron slag, and 40% copper slag make up the ideal replacement mix of fine and coarse material. When compared to regular concrete, this mixture significantly improves the concrete's mechanical characteristics. Further research on other attributes, such durability, could be beneficial because the presence of iron slag raises the risk of corrosion.

6. BIBLIOGRAPHY

[1] MITHUN, B.M., NARASIMHAN, M.C., "Performance of alkali activated slag concrete mixes incorporating copper slag as fine aggregate", *Journal of Cleaner Production*, v. 112, pp. 837–844, 2016. doi: http://doi.org/10.1016/j.jclepro.2015.06.026.

[2] SINGH, M., SIDDIQUE, R., "Effect of coal bottom ash as partial replacement of sand on workability and strength properties of concrete", *Journal of Cleaner Production*, v. 112, pp. 620–630, 2016. doi: http://doi.org/10.1016/j.jclepro.2015.08.001.

[3] EUROSTAT, *Eurostat Report* 2012, https://ec.europa.eu/eurostat/publications/statistical-reports, accessed in October, 2016.

[4] WAGIH, A.M., EL-KARMOTY, H.Z., EBID, M., *et al.*, "Recycled construction and demolition concrete waste as aggregate for structural concrete", *HBRC J.*, v. 9, n. 3, pp. 193–200, 2013. doi: http://doi.org/10.1016/j.hbrcj.2013.08.007.

[5] MCNEIL, K., KANG, T.H.K., "Recycled concrete aggregates: a review", *International Journal of Concrete Structures and Materials*, v. 7, n. 1, pp. 61–69, 2013. http://doi.org/10.1007/s40069-013-0032-5.

[6] LEDESMA, E.F., JIMÉNEZ, J.R., FERNÁNDEZ, J.M., *et al.*, "Properties of masonry mortars manufactured with fine recycled concrete aggregates", *Construction & Building Materials*, v. 71, pp. 289–298, 2014. doi: http://doi.org/10.1016/j.conbuildmat.2014.08.080.

[7] ARULRAJAH, A., MOHAMMADINIA, A., PHUMMIPHAN, I., *et al.*, "Stabilization of recycled demolition aggregates by geopolymers comprising calcium carbide residue, fly ash and slag precursors", *Construction & Building Materials*, v. 114, pp. 864–873, 2016. doi: http://doi.org/10.1016/j.conbuildmat.2016.03.150.

[8] AGGARWAL, Y., SIDDIQUE, R., "Microstructure and properties of concrete using bottom ash and waste foundry sand as partial replacement of fine aggregates", *Construction & Building Materials*, v. 54, pp. 210–223, 2014. doi: http://doi.org/10.1016/j.conbuildmat.2013.12.051.

[9] CHITHRA, S., KUMAR, S.R.R.S., CHINNARAJU, K., *et al.*, "A comparative study on the compressive strength prediction models for High Performance Concrete containing nano silica and copper slag using regression analysis and Artificial Neural Networks", *Construction & Building Materials*, v. 114, pp. 528–535, 2016. doi: http://doi.org/10.1016/j.conbuildmat.2016.03.214.

[10] AL-JABRI, K.S., HAGO, A.W., TAHA, R., *et al.*, "Strength and insulating properties of building blocks made from waste materials", *Journal of Materials in Civil Engineering*, v. 21, n. 5, pp. 191–197, 2009. doi: http://doi.org/10.1061/(ASCE)0899-1561(2009)21:5(191).

[11] ANASTASIOU, E.K., LIAPIS, A., PAPAYIANNI, I., "Comparative life cycle assessment of concrete road pavements using industrial by-products as alternative materials", *Resources, Conservation and Recycling*, v. 101, pp. 1–8, 2015. doi: http://doi.org/10.1016/j.resconrec.2015.05.009.

[12] SELVAPRIYA, R., "Silica fume as partial replacement of cement in concrete", *International Research Journal of Multidisciplinary Technovation*, v. 1, n. 6, pp. 325–333, 2019.

[13] SELVAPRIYA, R., TAMILCHELVAN, P., GOPINATH, M., *et al.*, "Experimental investigation on flexural strength behaviour of reactive powder concrete", *Materials Today: Proceedings*, 2023. doi: http://doi.org/10.1016/j.matpr.2023.04.394.

[14] FAN, D.Q., ZHANG, C., LU, J.-X., *et al.*, "Recycling of steel slag powder in green ultra-high strength concrete (UHSC) mortar at various curing conditions", *Journal of Building Engineering*, v. 70, pp. 106361, 2023. doi: http://doi.org/10.1016/j.jobe.2023.106361.

[15] SAINI, S.K., RANSINCHUNG, G.D., KUMAR, P., "Effect of different mineral admixtures on the performance of pavement quality concrete containing the optimum amount of jarosite as partial replacement of cement. arabian journal for science and engineering", *Springer Berlin Heidelberg*, v. 47, n. 10, pp. 13523–13535, 2022. doi: http://doi.org/10.1007/s13369-022-06892-5.