International Journal of Innovative Research in Engineering & Management (IJIREM)
ISSN: 2350-0557, Volume-9, Issue-4, August 2022
https://doi.org/10.55524/ijirem.2022.9.4.7
Article ID IJIRD-1188, Pages 41-46
www.ijirem.org

Mechanical Strength Analysis of Concrete with Partial Replacement of Fine Aggregates by Iron Slag and Cement by Silica Fume

Amir Sohil

Assistant Professor, Department of Civil Engineering, RIMT University, Mandi Gobindgarh, Punjab, India

ABSTRACT- The world's population is becoming more environmentally conscious, and as a result, regulations governing the management of industrial waste are becoming more stringent. As a result, the world's attention is increasingly being directed toward researching the properties of industrial waste and finding solutions on how to make use of the waste's valuable component parts. This is done in the expectation that these priceless component components can be repurposed for use as secondary raw material in one or more other types of industrial applications. This report demonstrates that it is possible to use iron slag as a partial replacement for sand and silica fume as a partial replacement of cement in concrete. This is accomplished by taking into account the specificity of the physical and chemical properties of these products. In addition, the report also takes into account the optimized content of these two materials. An investigation into the mechanical properties is provided. According to the findings, the strength attributes of concrete significantly improve when iron slag and silica fume are used to partially substitute for sand and cement in the optimized combination.

KEYWORDS- Iron Slag, Silica Fume, Concrete, Strength, Environment.

I. INTRODUCTION

The limestone quarries and other raw carbonate mineral sources are the primary raw materials used in the cement production process [1]. Thus, cement is made in huge production plants that need a significant investment in capital. These plants are typically situated in close proximity to other raw carbonate mineral sources [2]. In spite of the widespread adoption and high profitability of cement production, the cement industry continues to struggle with a number of obstacles brought on by environmental concerns and questions of long-term viability [3]. During the manufacturing of one tonne of clinker, approximately 850 kilogrammes of carbon dioxide and 850 kilogrammes of environmental particulate matter are released into the atmosphere [4]. It is believed that the manufacturing of cement is responsible for between 5 and 8 % of all of the carbon dioxide and other greenhouse gases that are produced as a result of human activities [5]. The calcination process is responsible for approximately sixty % of the total CO2 emissions, while fuel combustion is responsible for the remaining forty % of the total CO2 emissions [6]. Extremely significant is the requirement for innovative approaches to energy management in the cement manufacturing process [7].

Iron and steel slag have been put to use for a variety of purposes for a significant amount of time [8]. Extensive research and development has enabled the transformation of slag into a contemporary industrial product that is both functional and useful [9]. Slag is a waste material that is formed whenever pig iron and steel are manufactured in a factory [10]. The industry, which previously disposed of it as waste, is now investing in research connected to the manufacturing of vast quantities of goods at the lowest possible cost [11,12]. The emission of carbon dioxide, which is responsible for the greenhouse effect, is the most significant effect of the formation of slag [13]. There has been an uptick in demand for granulated slag, which has resulted in improved profits for Portland cement manufacturers [14]. The use of slag can be beneficial both commercially and in a variety of ways to the infrastructure [15]. The slag can be used as a I base and top course for roads that are made by using asphalt, (ii) used as anti-skid or rough surfacing for paths on accident prone intersections, (iii) unimportant ways where low-strength concrete is required, (iv) where soil is poor in nature or required stabilisation, and (v) concrete sub-base in the rigid pavements [16].

Silica fume is an extremely fine, non-crystalline form of silica that is a by-product of the manufacturing of alloys containing silicon or elemental silicon in electric arc furnaces [17]. Both cementitious and pozzolanic qualities can be observed in silica fume as a result of its extremely tiny particle size and extremely high proportion of amorphous silicon dioxide [7]. It has been discovered that it can significantly improve both the cement mortar's physical and mechanical qualities [18]. The addition of silica fume to cement mortar causes a reduction in its permeability and the amount of calcium hydroxide it contains. This, in turn, leads to the cement's refined pore structure and enhanced durability [19]. It also leads to a reduction in the diffusion of toxic ions and a rise in the resistance to sulphate attack, both of which are outcomes of this process [20].

Environmental scientists and toxicologists study the behaviour of waste materials from the chemical point of view, and the results show the improper disposal and dumping of waste has an impact on human health or the environment if it is applied to materials that are used in a variety of residential, agricultural, industrial, and construction works [21,22]. This conclusion was reached based on the findings of the researchers. It may also be seen that other animals or plants do not enter the food chain and that they do not participate in the formation of plant tissue. The aquatic ecosystem, including rivers, lakes, and streams, is negatively impacted by waste materials and get contaminated [23]. On the other hand, it demonstrates benefits for the environment in every respect. When cement is made, a very high %age of carbon dioxide (CO_2) is emitted into the atmosphere [24]. When used as aggregate and cement replacement, slag and silica fume respectively reduces the amount of raw material that is required, which in turn saves both the energy that is required to obtain the natural material and the amount of harmful gases that are emitted when transporting the natural material from its point of origin to the location where it is utilized [25].

The production process as well as the end application can result in a wide variety of industrial pollutants [26]. Granulated blast furnace slag is added during the production of Portland slag cement because of the pozzolonic behaviour it possesses. Slag and silica fume are utilised for soil conditioning and the production of mineral wool, both of which are utilised for insulating purposes at a reduced cost [27]. In addition to this, the addition of slag and silica fume to cement production results in a lower overall emission of carbon dioxide into the atmosphere [28]. The primary purpose of this investigation is to investigate the effects of partially substituting sand for iron slag and silica fume for cement in the concrete. It has been suggested that replacing some of the fine particles with iron slag, and determining the effect that this has on the properties of cement concrete, particularly the strength qualities of concrete, will be the next step.

II. MATERIALS AND METHODS

The materials were procured from local waste material vendor and have the properties listed ahead. Cement, coarse aggregates, and fine aggregates that have been mixed with iron slag are the components that are utilised for the experimental programme [29]. The standard ennore sand was used as fineaggregates [30]. All of the material satisfies the requirements of the IS Code, and the qualities of the material are determined in the laboratory in accordance with Indian standards in an atmosphere that is conducive to such determinations [31]. The physical properties of fine aggregate are examined in accordance with the recommendations of IS: 383-1970 [32]. Coarse aggregate is defined as the aggregate that does not pass through the IS Sieve 4.75 mm [33]. The cement's conformance to Indian Standard IS: 8112:1989 was determined by the results of a series of experiments carried out in the lab [34]. With the assistance of the appropriate gear and equipment, some key tests, including initial and final setting time, specific gravity, fineness, and compressive strength, are carried out on the cement [35]. These tests include: initial and final setting time [36].

Making and casting were both done in accordance with IS 516: 19595, which was reaffirmed in 1999, hence the technique in its entirety was used. To an accuracy of 0.1 kilogramme, the quantities of cement, coarse aggregate (20mm and 10mm size), fine aggregate, and water were weighed individually for each batch [37].

Table 1: Mix proportion for per m3 concrete

Signation	Cement (kg)	Sand	Coarse Aggregate (kg)	Iron slag (%)	Iron slag (kg)	Silica fume (%)	Silica fume (kg)	Water (L)
CM0	350	851	1442	0	0	0	0	175
SM1	350	808	1442	5	43	0	0	175
SM2	350	765	1442	10	85	0	0	175
SM3	350	723	1442	15	128	0	0	175
SM4	350	680	1442	20	170	0	0	175
SM5	305	723	1442	15	128	15	45	175
SM6	305	723	1442	15	128	15	45	175
SM7	305	723	1442	15	128	15	45	175
SM8	305	723	1442	15	128	15	45	175

The required amounts of each component, including cement, coarse aggregate, fine aggregate, iron slag, silica fume and water, are added in the appropriate proportions before being fully combined [38]. After that, the remaining quantity of water was also added in order to complete the process of meeting the desired value of the water-to-cement ratio [39].

The concrete was withdrawn from the mixer once it had been mixed with all of the necessary ingredients, and it was then placed into the cube moulds. After the concrete had had time to firm, it was removed from the moulds and placed in the water tank to cure [40]. For each of the tests conducted with normal cement concrete and mix concrete, specimens were cast using casting equipment [41]. The Universal Testing Machine was used to carry out this evaluation (UTM).

III. RESULT AND DISCUSSIONS

In this study, the cement and fine aggregate were first combined in a dry state until a uniform colour was achieved. After that, coarse aggregate was added to the cement and fine aggregate mixture, and the whole thing was combined once more [42]. After that, water was added, and the entire mixture was stirred together. The interior surface of the moulds as well as the base plate were oiled just prior to the placement of the concrete. After a period of twenty-four hours, the specimens were taken out of the moulds and placed in clean, fresh water that was heated to 270 degrees Celsius [43]. After seven, twenty-eight and fifty sixdays of curing, as measured from the time water is added to the dry mix, the samples were put through their paces for testing [44]. During the compression testing, no cushioning materials of any kind were placed between the specimen being evaluated and the plates of the machine. A force was applied in an axial direction without causing any shock to the specimens until they were crushed [45].

A. Compressive strength

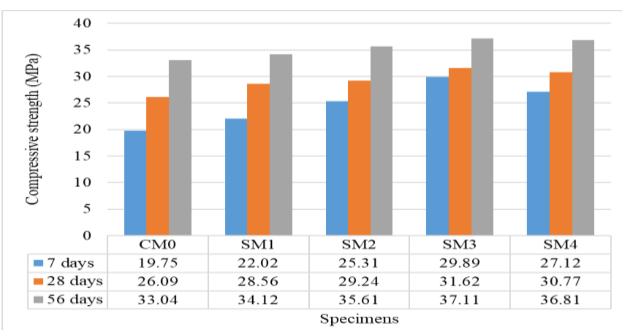

Figure 1: Variation of compressive strength with addition of iron slag

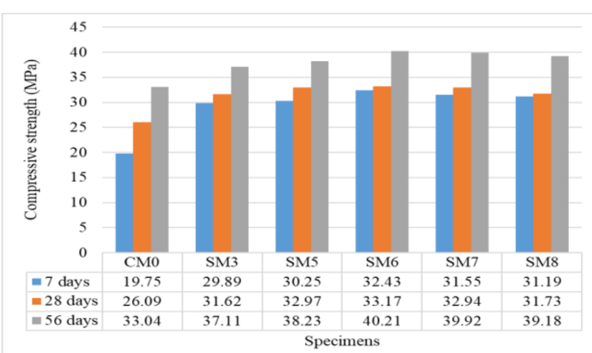

Figure 2: Variation of compressive strength with addition of silica fume

The results of the tests comparison of them in terms of their compressive strength can be found in Figure 4.1. The only w/c ratios that have been taken into consideration in this study are 0.5. The possibility of replacing as much as 20 % of the sand used in these processes with iron slag is being investigated here followed by substitution of cement by upto 20 % of silica fume in presence of optimized content of iron slag. When iron slag is added to the mix at a rate of 5 %, the mix can develop compressive strength of up to 11.49 % after 7 days, 9.47 % after 28 days and up to 3.47 % after 56 days. This is more than the compressive strength of the control mix.

After seven days, respectively, there is a considerable amount of improvement in the compressive strength that may be attributed to the inclusion of 5, 10, 15 and 20 % of silica fume in the mix. Specifically, these %ages correspond to 53.16 %, 64.20 %, 59.75 %, and 57.92 %. Compressive strength of the mixture improves in proportion to the growing amount of silica fume content in the mixture. Thus 10 % is the optimum content of silica fume in presence of 15 % of iron slag. This accounts for the pozzolanic effect of silica fume that is beneficial upto 10 % followed by slight decrease in compressive strength. This is because the higher content of silica fume may result in friction among the particles that may impact the microstructure and mechanical properties of the cement matrix [46].

B. Split Tensile Strength

It was found that the split tensile strength of the samples was significantly higher than the control mix. After seven days, respectively, there is a considerable amount of improvement in the split tensile strength that may be attributed to the inclusion of 5, 10, 15, and 20 % of iron slag in the mix. The reason for this may be attributed to the fact that the seven days have passed since the beginning of the process [47]. To be more specific, these numbers equal 10.27 %, 29.59 %, 37.35 %, and 35.81 % respectively. The amount of iron slag content in the mixture has a direct correlation to the amount of improvement in the mixture's split tensile strength that can be expected as the amount of iron slag increases. The rise in split tensile strength at an early age is much greater than the gain in split tensile strength at a later age when 15 % of the fine aggregate is switched out for iron slag [48]. This level of iron slag content is considered to be ideal. We can see that the mix can develop split tensile strength of up to 37.35 % after seven days when 5 to 20 % of the cement is replaced by silica fume. After 28 days, the mix can develop split tensile strength of up to 14.18 %, and after 56 days, it can develop split tensile strength of up to 5.97 %. This is greater than the split tensile strength of the mix that was used as the control.

After seven days, respectively, there is a large degree of improvement in the split tensile strength that may be attributed to the presence of 5, 10, 15, and 20 % of silica fume in the mix. This can be due to the fact that the mixture was allowed to cure for seven days to gain early strength [49]. To be more specific, these %ages equal 55.06 %, 60.24 %, 59.27 %, and 58.41 % respectively. The quantity of silica fume content in the mixture has a direct correlation to the amount of improvement in the split tensile strength of the mixture as the amount of silica fume content increases [50]. Therefore, a silica fume content of 10 % is the optimal level in the presence of an iron slag level of 15 %.

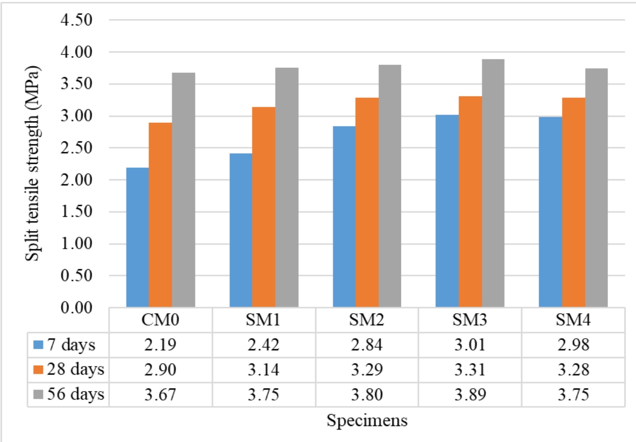

Figure 3: Variation of split tensile strength with addition of iron slag

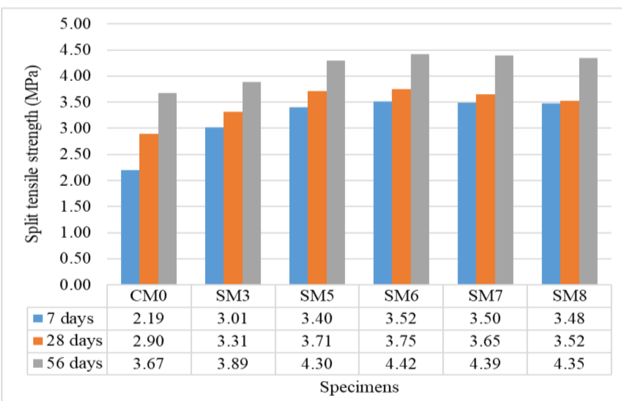

Figure 4: Variation of split tensile strength with addition of silica fume

IV. CONCLUSION

The following observations and inferences can be made based on the findings of the research that was carried out on the strength properties of concrete mixtures by substituting varying %ages of iron slag for the sand (ranging from 5 to 20 %) and varying %ages of silica fume for the cement (ranging from 5 to 20 %) at optimized %age of iron slag:

- It was found that adding 15 % of iron slag to the mix increased the compressive strength of the mixture significantly at all the studied ages. These results are superior to those obtained with the control mix.
- The compressive strength of the mixture improves as the amount of iron slag used in the mixture grows to be a greater proportion.
- When compared to later ages, the gain in compressive strength that occurs in the early ages is greater when 15 % of the fine aggregate is substituted with iron slag.
- Following 7 days, the mix resulted in a significant increase in compressive strength after the addition of the iron slag.
- The proportion of iron slag in the mixture has a direct correlation to the split tensile strength of the final product.
- When silica fume is added to the mix at a rate of 5 %, the mix gains strength quite higher than those achieved with the control mix.
- There is a considerable degree of increase in the split tensile strength with the inclusion of 5 % and 10 % silica fume in the mix followed by a slight decrease.
- The inclusion of an optimized quantity of iron slag as a sand replacement and silica fume as a cement repalcement in concrete at an early age is advantageous for improving the concrete's strength qualities.

REFRENCES

[1] P.R. de Matos, J.C.P. Oliveira, T.M. Medina, D.C. Magalhães, P.J.P. Gleize, R.A. Schankoski, R. Pilar, Use of air-cooled blast furnace slag as supplementary cementitious material for self-compacting concrete production, Constr. Build. Mater. 262 (2020). https://doi.org/10.1016/j.conbuildmat.2020.120102.

[2] A.M. Rashad, H.E.-D.H. Seleem, A.F. Shaheen, Effect of Silica Fume and Slag on Compressive Strength and Abrasion Resistance of HVFA Concrete, Int. J. Concr. Struct. Mater. 8 (2014) 69–81. https://doi.org/10.1007/s40069-013-0051-2.

[3] J. Lee, T. Lee, Durability and engineering performance evaluation of CaO content and ratio of binary blended concrete containing ground granulated blast-furnace slag, Appl. Sci. 10 (2020). https://doi.org/10.3390/app10072504.

[4] R. Garg, M. Bansal, Y. Aggarwal, Strength, rapid chloride penetration and microstructure study of cement mortar incorporating micro and nano silica, Int. J. Electrochem. Sci. 11 (2016) 3697–3713. https://doi.org/10.20964/110455.

[5] Rishav Garg, Manjeet Bansal, Yogesh Aggarwal, Split Tensile Strength of Cement Mortar Incorporating Micro and Nano Silica at Early Ages, Int. J. Eng. Res. Technol. 5 (2016) 16–19. https://doi.org/10.17577/ijertv5is040078.

[6] A. Nazari, S. Riahi, Splitting tensile strength of concrete using ground granulated blast furnace slag and SiO2 nanoparticles as binder, Energy Build. 43 (2011) 864–872. https://doi.org/10.1016/j.enbuild.2010.12.006.

[7] H. Sharma, R. Garg, D. Sharma, M. umar Beg, R. Sharma, Investigation on Mechanical Properties of Concrete Using Microsilica and Optimised dose of Nanosilica as a Partial Replacement of Cement, Int. J. Recent Reasearch Asp. 3 (2016) 23–29.

[8] S.C. Pal, A. Mukherjee, S.R. Pathak, Investigation of hydraulic activity of ground granulated blast furnace slag in concrete, Cem. Concr. Res. 33 (2003) 1481–1486. https://doi.org/10.1016/S0008-8846(03)00062-0.

[9] R. Sharma, D. Sharma, R. Garg, Development of Self Compacted High Strength Concrete using Steel Slag as Partial Replacement of Coarse Aggregate, Int. J. New. Inn. 5 (2016) 556–562.

[10] R. Garg, R. Garg, N.O. Eddy, Influence of pozzolans on properties of cementitious materials: A review, Adv. Nano Res. 11 (2021) 423–436. https://doi.org/10.12989/anr.2021.11.4.423.

[11] N.O. Eddy, R. Garg, R. Garg, A.O. Aikoye, B.I. Ita, Waste to resource recovery: mesoporous adsorbent from orange peel for the removal of trypan blue dye from aqueous solution, Biomass Convers. Biorefinery. (2022). https://doi.org/10.1007/s13399-

022-02571-5.

[12] R. Garg, R. Garg, N. Okon Eddy, A. Ibrahim Almohana, S. Fahad Almojil, M. Amir Khan, S. Ho Hong, Biosynthesized silica-based zinc oxide nanocomposites for the sequestration of heavy metal ions from aqueous solutions, J. King Saud Univ. - Sci. 34 (2022) 101996. https://doi.org/10.1016/j.jksus.2022.101996.

[13] R. Sharma, D. Sharma, R. Garg, H. Sharma, Development of Self Compacted Concrete Using Steel Slag as Partial Replacement of Coarse Aggregate vibrators to realize consolidation by the access is stuck by slender gaps between it ' s difficult or not possible to use mechanical term ultra-high compres, in: Proc. ICAST-2017 McGraw Hill Publ., 2017: pp. 88–89.

[14] R. Garg, R. Garg, N. Okon Eddy, Handbook of Research on Green Synthesis and Applications of Nanomaterials Edited by, IGI Global, 2022. https://doi.org/10.4018/978-1-7998-8936-6.

[15] R. Garg, T. Biswas, M.D.D. Alam, A. Kumar, A. Siddharth, D.R. Singh, Stabilization of expansive soil by using industrial waste, J. Phys. Conf. Ser. 2070 (2021). https://doi.org/10.1088/1742-6596/2070/1/012238.

[16] C.M. Kansal, S. Singla, R. Garg, Effect of Silica Fume & Steel Slag on Nano-silica based High-Performance Concrete, IOP Conf. Ser. Mater. Sci. Eng. 961 (2020). https://doi.org/10.1088/1757-899X/961/1/012012.

[17] H. Sharma, R. Garg, R. Sharma, Investigation on Microstructure of Concrete Using Microsilica and Optimized Dose of Nanosilica as Partial Replacement of Cement, in: Proc. ICAST-2017 McGraw Hill Publ., 2017: pp. 3–4.

[18] S. Mondal, A. (Dey) Ghosh, Review on microbial induced calcite precipitation mechanisms leading to bacterial selection for microbial concrete, Constr. Build. Mater. 225 (2019) 67–75. https://doi.org/10.1016/j.conbuildmat.2019.07.122.

[19] R. Garg, R. Garg, S. Singla, Experimental Investigation of Electrochemical Corrosion and Chloride Penetration of Concrete Incorporating Colloidal Nanosilica and Silica fume, J. Electrochem. Sci. Technol. 12 (2021) 440–452. https://doi.org/10.33961/jecst.2020.01788.

[20] M.U. Beg, R. Garg, C. Khajuria, Experimental study on strength of concrete using composite replacement of coarse aggregate, Int. J. New. Inn. 5 (2016) 563–567. https://doi.org/10.22214/ijraset.2018.1451.

[21] R. Garg, P. Rani, R. Garg, N.O. Eddy, Study on potential applications and toxicity analysis of green synthesized nanoparticles, Turkish J. Chem. 45 (2021) 1690–1706. https://doi.org/10.3906/kim-2106-59.

[22] N.O. Eddy, U.J. Ibok, R. Garg, R. Garg, A. Iqbal, M. Amin, A Brief Review on Fruit and Vegetable Extracts as Corrosion Inhibitors in Acidic Environments, Molecules. 27 (2022) 1–19. https://doi.org/10.3390/molecules27092991.

[23] R. Garg, R. Garg, M.A. Khan, M. Bansal, V. Garg, Utilization of biosynthesized silica-supported iron oxide nanocomposites for the adsorptive removal of heavy metal ions from aqueous solutions, Environ. Sci. Pollut. Res. Accepted f (2022) 1–10. https://doi.org/https://doi.org/10.21203/rs.3.rs-1394501/v1.

[24] A. Garg, A. SIngh, R. Garg, Effect of Rice Husk Ash & Cement on CBR values of Clayey soil, in: Int. Conf. Adv. Constr. Mater. Struct., 2018: pp. 1–7. http://lejpt.academicdirect.org/A11/047_058.pdf?origin=publication_detail.

[25] IS: 6042, Indian standard code of practice for construction of lightweight concrete block masonry, Indian Stand. Institution, New Delhi, India. (1969).

[26] M. Bansal, R. Garg, V.K. Garg, R. Garg, D. Singh, Sequestration of heavy metal ions from multi-metal simulated wastewater systems using processed agricultural biomass, Chemosphere. 296 (2022) 133966. https://doi.org/10.1016/j.chemosphere.2022.133966.

[27] A. Singh, A. Garg, R. Garg, Influence of Nano-Silica and Ground Granulated Blast Furnace Slag on Cement Using Statistical Design of Experiment, in: Int. Conf. Adv. Constr. Mater. Struct., 2018.

[28] K. Kumar, M. Bansal, R. Garg, R. Garg, Mechanical strength analysis of fly-ash based concrete in presence of red mud, Mater. Today Proc. 52 (2022) 472–476. https://doi.org/10.1016/j.matpr.2021.09.233.

[29] K. Kumar, M. Bansal, R. Garg, R. Garg, Penetration and Strength Analysis of Pervious Concrete, J. Phys. Conf. Ser. 2070 (2021) 012244. https://doi.org/10.1088/1742-6596/2070/1/012244.

[30] D. Prasad Bhatta, S. Singla, R. Garg, Microstructural and strength parameters of Nano-SiO2based cement composites, Mater. Today Proc. 46 (2020) 6743–6747. https://doi.org/10.1016/j.matpr.2021.04.276.

[31] IS 2250 (1981): Code of Practice for Preparation and Use of Masonry Mortars [CED 13: Building Construction Practices including Painting, Varnishing and Allied Finishing], Bur. Indian Stand. New Delhi New Delhi. Reaffirmed (1981).

[32] R. Garg, M. Kumari, M. Kumar, S. Dhiman, R. Garg, Green synthesis of calcium carbonate nanoparticles using waste fruit peel extract, Mater. Today Proc. 46 (2021) 6665–6668. https://doi.org/10.1016/j.matpr.2021.04.124.

[33] A. Singh, S. Singla, R. Garg, R. Garg, Performance analysis of Papercrete in presence of Rice husk ash and Fly ash, IOP Conf. Ser. Mater. Sci. Eng. 961 (2020). https://doi.org/10.1088/1757-899X/961/1/012010.

[34] M. Kumar, M. Bansal, R. Garg, An overview of beneficiary aspects of zinc oxide nanoparticles on performance of cement composites, Mater. Today Proc. 43 (2021) 892–898. https://doi.org/10.1016/j.matpr.2020.07.215.

[35] S. Dhiman, R. Garg, R. Garg, S. Singla, Experimental investigation on the strength of chipped rubber-based concrete, IOP Conf. Ser. Mater. Sci. Eng. 961 (2020). https://doi.org/10.1088/1757-899X/961/1/012002.

[36] D. Prasad Bhatta, S. Singla, R. Garg, Experimental investigation on the effect of Nano-silica on the silica fume-based cement composites, Mater. Today Proc. 57 (2022) 2338–2343. https://doi.org/10.1016/j.matpr.2022.01.190.

[37] IS 15917-2010, Building Design and Erection using Mixed/ Composite Construction - Code of Practice, (2011).

[38] R. Garg, R. Garg, A. Thakur, S.M. Arif, Water remediation using biosorbent obtained from agricultural and fruit waste, Mater. Today Proc. 46 (2021) 6669–6672. https://doi.org/10.1016/j.matpr.2021.04.132.

[39] R. Garg, R. Garg, Effect of zinc oxide nanoparticles on mechanical properties of silica fume-based cement composites, Mater. Today Proc. 43 (2021) 778–783. https://doi.org/10.1016/j.matpr.2020.06.168.

[40] R. Garg, R. Garg, M. Bansal, Y. Aggarwal, Experimental study on strength and microstructure of mortar in presence of micro and nano-silica, Mater. Today Proc. 43 (2020) 769–777. https://doi.org/10.1016/j.matpr.2020.06.167.

[41] G.M. Fani, S. Singla, R. Garg, R. Garg, Investigation on Mechanical Strength of Cellular Concrete in Presence of Silica Fume, IOP Conf. Ser. Mater. Sci. Eng. 961 (2020) 012008. https://doi.org/10.1088/1757-899X/961/1/012008.

[42] T. Biswas, R. Garg, H. Ranjan, A. Kumar, G. Pandey, K. Yadav, Study of expansive soil stabilized with agricultural waste, J. Phys. Conf. Ser. 2070 (2021). https://doi.org/10.1088/1742-6596/2070/1/012237.

[43] V. Kumar, S. Singla, R. Garg, Strength and microstructure correlation of binary cement blends in presence of waste marble

powder, Mater. Today Proc. 43 (2020) 857–862. https://doi.org/10.1016/j.matpr.2020.07.073.

[44] G. Singh, M. Bansal, R. Garg, Influence of the Incorporation of Polypropylene Fiber in High Performance Concrete, in: Natl. Conf. “Recent Trends Environ. Sci. Technol., 2016: pp. 140–143.

[45] IS 456-2000: Plain and Reinforced Concrete - Code of Practice [CED 2: Cement and Concrete], Bur. Indian Stand. New Delhi. Reafflrmed (2000).

[46] R. Garg, R. Garg, B. Chaudhary, S. Mohd. Arif, Strength and microstructural analysis of nano-silica based cement composites in presence of silica fume, Mater. Today Proc. 46 (2020) 6753–6756. https://doi.org/10.1016/j.matpr.2021.04.291.

[47] R. Garg, R. Garg, Performance evaluation of polypropylene fiber waste reinforced concrete in presence of silica fume, Mater. Today Proc. 43 (2021) 809–816. https://doi.org/10.1016/j.matpr.2020.06.482.

[48] R. Sharma, D. Sharma, R. Garg, Development of Self Compacted High Strength Concrete using Steel Slag as Partial Replacement of Natural Fine Aggregate, (2016) 96–99.

[49] M.U. Beg, A. Goyal, C. Khajuria, R. Garg, Study of Mechanical Properties of Concrete by Partial Replacement of Cement with Rice Husk Ash and Alccofine as Mineral Admixture, (2016) 72–77.

[50] M. Sahmaran, G. Yildirim, T.K. Erdem, Self-healing capability of cementitious composites incorporating different supplementary cementitious materials, Cem. Concr. Compos. 35 (2013) 89–101. https://doi.org/10.1016/j.cemconcomp.2012.08.013.