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Sustainable Use of Nano Silica, Silica Fume and Copper Slag in Concrete

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Abstract - *Concrete is the world's second most consumed material after water. Cement, fine aggregate, coarse aggregate, and water are the traditional components of concrete. Natural resources are disappearing at a faster rate as a result of excessive concrete usage, causing environmental problems. As a result, the use of stable and solid waste materials in concrete is becoming increasingly important in order to reduce overuse of natural resources, associated environmental impacts, and waste management issues. The current study focuses on using waste materials to partially replace traditional concrete components. The trials compared the distinctive qualities of M sand and copper slag in a 3:2 ratio as fine aggregate to a control mix. Nano silica and Silica Fume were used to replace cement by 1 to 3% by weight. Silica fume addition increased the compressive strength of concrete more than nano silica. The concrete mix with 2% cement replacement with silica fumes and 40% fine aggregate replacement with copper slag had a maximum 28-day cube compressive strength of 38.4 N/mm² compared to control mix (26.1 N/mm²).*

Key Words: **Copper Slag, Nano Silica, Silica Fume, Concrete, Compressive Strength, Workability, Split Tensile Strength.**

1. INTRODUCTION

Cement plays a significant role in concrete due to adhesive property, even though the larger volume of concrete is constituted by aggregate. Thus the mechanism of cement hydration decide the quality and properties of concrete. Different cementitious materials known as supplementary materials are added to concrete so that the improvement of properties can be done. Some of the materials are fly ash, blast furnace slag, rice husk, silica fumes, and even bacteria. The latest researches are oriented in Nano-technology as a promising approach in improving the properties of concrete. In concrete, cement acts the binder material and it binds the other material together. But one disadvantage of application of cement is it emits the large amount of CO2 in the environment and pollute them. Nano silica is effectively high pozzolanic material. The size of nano silica is 1000 times smaller than the average size of cement particle [1].

The America Concrete Institute (ACI) defines silica fume as 'Very fine non-crystalline silica produced in electric arc furnaces as a by-product of the production of elemental silicon or alloys containing silicon. It is a grey coloured, ultrafine powder consists of spherical particles with an average particle size (diameter) of 150 nm. The application of these materials expected to improve the performance of concrete similar to addition of other pozzolanic material [2]. The cementitious characteristics of silica fume (SF) and nano silica (NS) have been established in latest concrete researches. If their usage in concrete improves the strength properties, it will gain more acceptability as a result of more cost-effective constructions, as well as contributing to energy conservation and providing a substantial solution for the disposal of industrial by-products.

Many countries are witnessing rapid growth in the construction industry in which the use of natural resources for the development of the infrastructure. Natural resources are depleting worldwide, at the same time the generated wastes from the industry are increasing. The sustainable development for construction involves the using of non-conventional and innovative materials, and recycling of waste materials in order to reduce the use of natural resources for conserving the environment and future generation. Due to the depletion of non-renewable resources, a wide range of research projects are underway around the world to find effective ways to use waste products in the building sector as alternative materials to cement and fine aggregate. The following are a few of them:

Al-Jabri (2009) et al., investigated the use of copper slag as a sand substitute in high-performance concrete, finding that using up to 50% copper slag as a sand replacement yielded comparable strength to the control mix. As the percentage of copper slag in the mix increased, the mix's workability improved [3]. Selvi et al. (2014) conducted an experiment on concrete utilizing copper slag as a fine aggregate replacement material. For the same water-cement ratio, workability and unit weight of concrete improved as the copper slag concentration of fine aggregate replacements rose. The concrete showed the best strength characteristics when copper slag was used to replace 40% of the fine aggregate [4]. Patil and Patil (2016) also investigated the impacts of copper slag as sand replacement in concrete. At 40% fine aggregate replacement of copper slag, the modulus of elasticity and compressive strength of concrete improved by 15.22%, and 32 % respectively. At 60% fine aggregate replacement, the concrete gained highest modulus of elasticity than normal concrete [5].

The effects of nano silica on concrete compressive strength and durability were investigated experimentally by Isfaani et al. (2016), who observed that adding nano silica to concrete improves compressive strength. By increasing nano silica dosage, the durability properties of concrete with diverse w/c ratios showed a highly variable tendency, but the apparent chloride diffusion coefficient dropped [6].The effects of colloidal nano silica (CNS) on cement hydration and gel characteristics were investigated by Hou et al. (2012). Results revealed that the accelerating effect of CNS on hydration in the early age is achieved by the acceleration of cement dissolution and hydrate nucleation on reacted nano-SiO2 particles. Cement hydration was hampered as it time passed [7].

Chithra et al. (2016) investigated at how colloidal nano silica affected the workability, mechanical properties, and durability of cement mortar and concrete utilising copper slag as a partial fine aggregate. The findings show that when the percentage of micro silica increases, the water demand increases due to its large specific surface area. With the addition of a little amount of nano silica to the concrete mix, the strength, penetration properties, and abrasion resistance of high performance slag concrete (HPSC) were all improved [8].

Flores (2017) examined the influence of nano-silica with three different silica-based materials (quartz, ultrafine quartz, and silica fume) in cement pastes with 2.5% cement replacement. When nano-silica and silica fume are used, the porous structure is refined, resulting in an increase in compressive strength [9].

Mostafa Jalal et al. (2015) investigated the impacts of various admixtures on the qualities of high performance self-compacting concrete, including nano silica, silica fume, and Class F fly ash (HPSCC). The investigation showed that in combinations comprising admixtures, mechanical and transport qualities increased, particularly in a blend of silica nanoparticles and silica fume [10].

In their study, Bingliu Zhang et al. (2018) attempted to use nano silica and silica fume to modify cement mortar as a surface protection material (SPM) in order to improve the overall penetration resistance. The results demonstrate that the surface has strong integrity, with great interfacial bond strength between matrix and SPM with negligible shrinkage. The chloride diffusion coefficient has decreased significantly when SPM was coated on the surface of the matrix [11].

This study examines the feasibility of using industrial waste materials to replace cement as well as natural aggregates, thus leading sustainable development in the field of construction. Hence the objectives of this research is to investigate the suitability of using nano silica and silica fume as partial replacement of cement in concrete and to find an economical solution for its disposal. The paper compare the compressive strength and split tensile strength of concrete made of partially replaced nano silica and silica fume for cement with the control sample. The optimum percentage replacement of nano silica and silica fume for cement to get maximum strength in concrete was also investigated. Throughout the investigation, a 3:2 mixture of M sand and copper slag was used as fine aggregate.

2. MATERIALS AND METHODOLOGY

2.1 Material Properties

2.1.1 Cement

Cement is the most important constituent in a concrete mix, which act as a binder between the fine and the coarse aggregate and to fill the voids in between aggregate particles to form a compact mass. For the experiments, ordinary Portland Cement (OPC) conforming to 53 Grade was used, with a high Tri Calcium Silicate content ensuring long-term durability of concrete. The physical properties of cement used in the study are showed in the table 1.

Table -1: Properties of Cement

Sl. No	Properties	Value
1	Specific Gravity	3.1
2	Consistency	29.35%
3	Initial setting time	90 minutes
4	Final setting time	>600 minute

2.1.2 Aggregate

Locally available good quality M-Sand and coarse aggregate were used for the study. The physical qualities of aggregate were assessed using IS standards, and the results are shown in table 2.

2.1.3 Copper Slag

Copper slag is a byproduct of the copper extraction. Copper slag was purchased from a local industry for this project.

2.1.4 Nano Silica

Nano-silica is a fine material with pozolanic reactivity. The nano silica used in this research was purchased from Chennai-based suppliers.

2.1.5 Silica Fume

Silica fume is a byproduct of silicon metal production. Silica fume used in this project was bought from a local industry.

Table -2: Properties of Aggregate

Sl. No	Properties	Fine Aggregate	Coarse Aggregate
1	Specific Gravity	2.83	2.67
2	Bulk Density (non-compacted)	1580 kg/m^3	1660 kg/m^3
3	Effective size	0.16 mm	3.9 mm
4	Uniformity Coefficient	3.625	3.33
5	Coefficient of curvature	1.39	1.109

2.2 Methodology

The main focus of this study was to determine the effect of partial replacement of cement with nano silica and silica fume. According to the literature, fine aggregate in concrete can be replaced with copper slag, which is an industrial waste, and the optimum percentage of replacement in terms of strength was found to be 40%. The workability, compressive strength, and split tensile strength of cement concrete were studied by substituting fine aggregate with 40% copper slag and partially replacing the cement with nano silica and silica fume (1%, 2% and 3%). The properties were compared to control samples of M20 nominal mix and concrete with fine aggregate replaced with 40% copper slag without replacement for cement.

The concrete used in the experiment was of the M20 nominal mix (1:1.5:3:0.5). The amount of coarse aggregate, water content, and water to binder ratio were all kept constant in all of the mixes. The required quantity of materials for each mix was calculated. The table 3 shows the abbreviations and proportions of mix used in this work for various mixtures.

Table -3: Various mixes used in this study

Mix designation	Cement (%)	Nano silica or Silica Fume (%)	Fine Aggregate (%)		Coarse Aggregate (%)
			Sand	Copper Slag	
Pc	100	0	100	0	100
P_0	100	0	60	40	100
P_1	99	1	60	40	100
P_2	98	2	60	40	100
P_3	97	3	60	40	100

Mixer machine was used for mixing the ingredients of each mix of concrete to get consistent uniform mix. The workability of the different mixes were done immediately after the mixing by slump test as per IS standards. Then sufficient number of concrete cubes (150 mm X 150 mm X 150 mm) and concrete cylinders (150 mm X 300 mm) were casted for all mixes mentioned in the table 3 to conduct tests on hardened concrete. Concrete specimens were molded with standard compaction in three layers. Specimens were removed from the mold after 24 hours and cured it in water for both 7 and 28 days. The compressive strength and split tensile strength of cured concrete specimens were done as per IS standards.

3. RESULT AND DISCUSSION

3.1 Workability

The slump test is one of the simplest ways to determine if concrete is workable in the field. As per Chart - 1, the workability has improved with the addition of 40% copper slag substituting fine aggregate (P0), compared to control mix (P_c). Copper slag's glass surface prevents water from penetrating it. It absorbs less water than river sand, which could be the cause of the behaviour. As a result, adding copper slag to concrete reduces the need for admixture. Also, as shown in Chart 1, partial replacement of nano silica boosted concrete workability due to its fine nature, but partial replacement of silica fume decreased concrete workability due to its coarser nature.

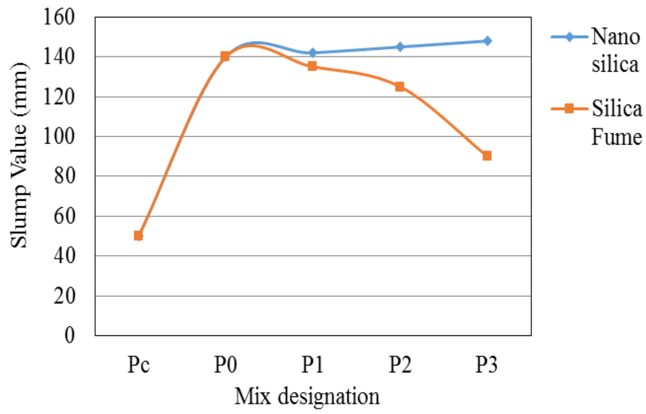

Chart -1: Variation of slump values for different replacement of Nano Silica and Silica Fume

3.2 Compressive strength of concrete cube

The compressive strength of concrete is a crucial parameter while designing the concrete structures. The quality of concrete prepared usually measured by the compressive strength of concrete. Partial replacement of nano silica and silica fume improved the compressive strength of concrete cube as shown in Chart - 2. When comparing the compressive strength of concrete with 40% copper slag replaced with fine aggregate (P_0), and other mixes after 7 days of curing it was observed that, as nano silica partially replaced cement from 0% to 2% the strength increased from 14.07 MPa (P_0) to 18 MPa and the corresponding percentage increase is 27% and a decreased when the addition of nano silica was from 2% to 3% (compressive strength decreased from18 MPa to 11.48 MPa). Similiarly, when 3% silica fume partially replaced with cement, the strength increased from 14.07 MPa (P_0) to 18.9 MPa and corresponding percentage increase is 34%. Also when comparing with the compressive strength of control mix (P_c), the nano silica showed an increase from 12.5 MPa (P_c) to 18 MPa (P_2) and corresponding percentage increase is 44%. Similarly, with partial replacement with silica fume the value raised from 12.5 MPa (P_c) to 18.9 MPa (P_2) which is an increase of 51%.

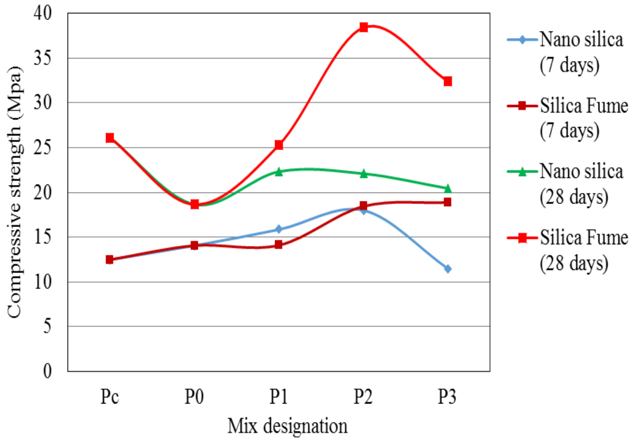

Chart -2: Variation of compressive strength of concrete cubes for different percentage of nano silica and silica fume

When comparing the strength after 28 days, as nano silica replaced the cement partially by 1%, the compressive strength increased from 18.66 MPa (P_0) to 22.33 MPa and the corresponding percentage increase is 19% and the strength decreased from 22.33 MPa to 20.45 MPa when the the percentage of nano silica increased from 1% to 3% as shown in the Fig. 2. When the Silica Fume is partially replaced with cement from 0% to 2%, the compressive strength increased from 18.66 MPa (P_0) to 38.4 MPa and the corresponding percentage increase is 105%. But when comparing the compressive strength of control mix and concrete with nano silica and silica fume, the former showed a decreased in strength (26.1 MPa to 22.33 MPa) whereas later shows improvement (26.1MPa to 38.4 MPa).

3.3 Compressive Strength of Concrete Cylinders

Compressive strength of cylinders also showed similar behavior as that of compressive strength of concrete. The partial replacement of fine aggregate with 40% of copper slag showed decrease in compressive strength of cylinders. But the partial replacement of nano silica and silica fume with cement showed improvement in the compressive strength of concrete cylinder as shown in Chart - 3. When nano silica partially replaced cement from 0% to 1% the compressive strength of cylinder strength increased from 6.5 MPa (mix P_0) to 7.75 MPa and the corresponding percentage increase is 19% and the strength decreased from 7.75 MPa to 4.5 MPa when the percentage of replacement increased from 1% to 3%. When the silica fume partially replaced cement from 0% to 3% the strength increased from 6.5 MPa (mix P_0) to 9.69MPa and the corresponding percentage increase is 49%.

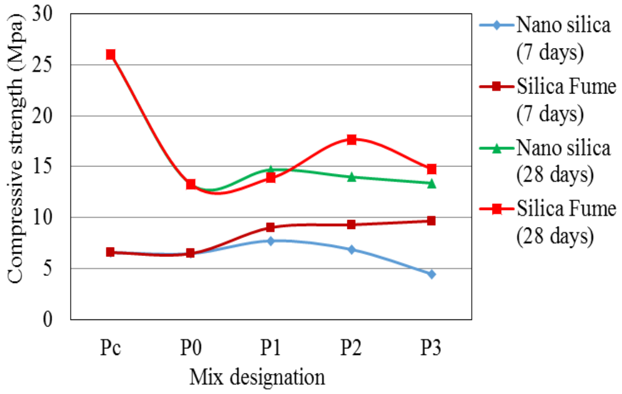

Chart -3: Variation of compressive strength of concrete cubes for different percentage of nano silica and silica fume

The addition of both nano silica and silica fume showed improvement in compressive strength of cylinder after 28 days of curing also. When comparing the 28 days strength as nano silica partially replaced 1% cement the strength increased from 13.29 MPa (mix P_0) to 14.71 MPa and the corresponding percentage increase is 10% and a decreased the compressive strength of cylinder from 14.71 MPa to 13.4 MPa when the replacement of nano silica was from 1% to 3%. Also when the silica fume partially replaced cement the strength increased from 13.29 MPa (mix P_0) to 17.68 MPa when 2% cement replaced with silica fume and the corresponding percentage increase is 33% and then decreases.

When comparing the compressive strength of cylinders it can be seen that partial replacement of silica fume and nano silica showed maximum strength in compression of cylinder at 2% and 1% respectively for both 7 and 28 days of curing. After 7 days of curing the compressive strength values of cylinders were nearly same for 1% (7.75 MPa) and 2% (6.9 MPa) replacement of nano silica. Similarly, for 28days also compressive strength of cylinders were nearly same for 1% and 2% partial replacement of cement with nano silica. Hence comparing the compressive strength of concrete cylinders when 2% cement is replaced with silica fume and nano silica it can be seen that on 7th day of testing the value of 2% partially replaced silica fume is 9.32 MPa which is greater than that of the 2% partially replaced nano silica concrete which was 6.9 MPa. On 28th day of testing the compressive strength of cylinders with 2% nano silica and 2% silica fume were 14 MPa and 17.68 MPa respectively. Hence the replacement of silica fume is more beneficial than nano silica in terms of compressive strength of concrete cylinders.

3.3 Split tensile strength of concrete

Tensile strength is an important property of concrete because concrete structures are highly vulnerable to tensile cracking due to various kinds of effects and applied loading itself. However, the tensile strength of concrete is very low due to its brittle character when compared to its compressive strength. Split tensile test on concrete cylinders is an indirect method for determining tensile strength for concrete.

Partial replacement of nano silica and silica fume improved the split tensile strength of concrete cylinders as shown in Chart - 4. After 7 days of curing when the nano silica partially replaced with 1% cement, the strength increased from 1.31 MPa (mix P_0) to 1.735 MPa and the percentage increase is 32% and the split tensile strength decreases thereafter as in the case of compressive strength of cubes and cylinders. In silica fume partially replaced cement concrete the strength increased from 1.31 MPa to 1.94 MPa when the percentage of silica fume increases from 0% to 3% and the corresponding percentage increase is 48%. Similar variations were observed for the split tensile strength of concrete after 28 days of curing also.

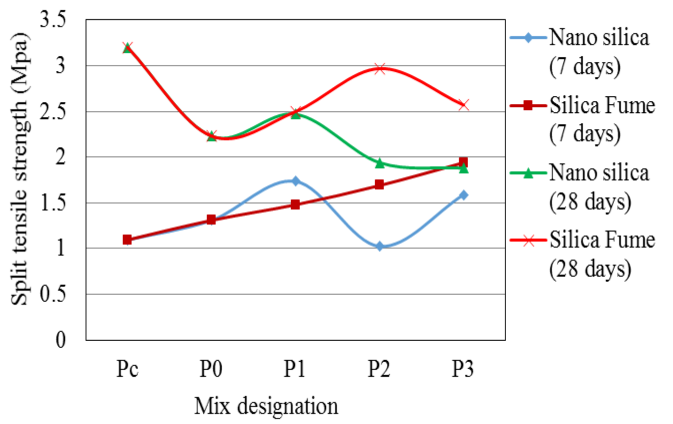

Chart -4: Variation of split tensile strength of cylinder for different percentage of nano silica and silica fume

Partial replacement of silica fume and nano silica showed maximum strength in split tensile of cylinder at 2% and 1% respectively for both 7 and 28 days similar to compressive strength of concrete cubes and cylinders. But the difference in split strength of cylinder with 1% and 2% nano silica replacement with cement is less. Hence, comparing the strength corresponding to 2% replacement of cement with silica fume and nano silica, the silica fume replaced concrete showed better results similar to compressive strength of cubes and cylinders.

Nano-silica and silica fume is a material having pozolonic reactivity and also its fineness helps pore-filling effect in concrete. Due to its fineness and high amorphous silicon dioxide content, silica fume is a very reactive pozzolanic material. Silica fume influences the thickness of transition phase in mortars and the degree of the orientation of the CH crystals. Addition of silica fume accelerates the hydration of cement at all stages of hydration. The pozzolanic action of silica fume seems to be very active at early hours of hydration [12, 13].

4. CONCLUSIONS

Natural resources are depleting at a faster pace as a result of excessive concrete usage in the present world, causing environmental problems. Hence the use of stable and solid waste materials in concrete is becoming increasingly important in order to minimize both environmental impacts and waste management issues. Here in this study it was found that the waste materials nano silica and silica fume can be effectively used in the concrete production. The following were the conclusions obtained from the study.

- The addition of copper slag increased the workability of concrete. Further the addition of nano silica increases the workability whereas the addition of silica fume reduces the workability of concrete.
- The compressive strength of concrete cubes and cylinders and split tensile strength of concrete has increased by the addition of nano silica and silica fume and optimum percentage was found to be 2% to obtain maximum strength.
- Comparing the strength gained by the addition of nano silica and silica fume, higher strength was obtained for silica fume replaced concrete.

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