

Effect of Incorporation of Nano- SiO₂ and Plastic in Cement Mortar

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ABSTRACT: The world observed rapid growth in the consumption of plastic in recent decades, which created huge quantities of plastic related wastes. The opportunity was popped up to recycle the plastic waste to produce the new materials like concrete or mortar. Which perhaps is the best solution for the decomposition of plastic waste, having copious economic and ecologic advantages.

This paper states the review on the incorporation of nano- SiO₂ in cement mortar,, incorporation of Plastic in cement mortar and incorporation of both nano- SiO₂ and Plastic in cement mortar, This paper mainly discuss the results when nano- SiO₂ and plastic were added separately in cement mortar and results of addition of both plastic and nano- SiO₂ added in cement mortar simultaneously. As by the separated addition of plastic increases the physical properties like porosity, water absorption and drying shrinkage of cement mortar. To counteract the increase in the physical properties, the addition of nano- SiO₂ in the plastic mortar helps.

KEYWORDS: Nano- SiO₂, Recycled Plastic, Cement, Aggregate, Properties, Concrete, Mortar,etc.

I. INTRODUCTION

The consumption of plastic is merely increasing day-by-day. Due to the properties of plastics like flexibility, durability, high strength-weight ratio, reasonable cost it is very hard to replace it with some other materials [1]. Different use of plastics like packing films, wrapping materials, food packaging, fluid containers, toys, shopping and garbage bags, etc. consumes large percent of plastic production. As every coin has two sides the plastic comes with very hazardous impact on environment [2]. Approximately 56 hundred thousand tons plastic waste is generated annually in India, the method to dispose plastics are re-extrusion, mechanical and chemical energy recovery schemes and technologies, incineration[3]. The sudden increase in the consumption of plastic is observed all over the world in recent years which ultimately lead to the production of plastic related waste. However, plastic contain several toxic chemicals, which pollutes soil, air, and water. As plastic is hard to degrade naturally, land filling using plastic means preserving the harmful material forever. This may lead to the problem of blocking the drainage system, blockage of rain-water percolation, it may hinder the ground water flow and can also block root movements.

Recycling the plastic could be the possible option to get rid of plastic. However, to recycle the plastic cannot be very economical as plastic degrades in its qualities and necessitates new plastic to make a new product. For the disposal of plastic one of the best solution is cement composites, due to its emotional and ecological benefits. There is great work already done and in progress on the use of plastic waste such as polythelenterephthalate (PET) bottle.[4]; [5]; [6]; [7]; [8]; [9]; [10]; [11]; [12]. High density polyethylene (HDPE)[13], Thermosetting plastics [14], Shredded and recycled plastic waste [15]; [16]; [17], expanded polystyrene foam (EPS) [18]; [19], glass reinforced plastic (GPR) [20], Polycarbonate [21], Polyurethane Foam [22]; [23], Polypropylene Fibre [24].

As concrete or mortar shows decrease in compressive strength compared to normal concrete when incorporated with plastics, ultimately limits the use of plastic waste in concrete or mortar. The most effective emerging technology i.e. Nanotechnology is widely used in many industries, in construction industries also. Many research studies have shown that the unique size effect of nano-materials can improve the microstructure of the interfacial transition zone (ITZ) between hardened cement paste and aggregates and the strength of concrete is increased [25]; [26]; [27]; [28]; [29]. Hence, the properties like mechanical properties of plastic-filled concrete can be enhanced by adding nano-materials. Hasan- Nattaj and Nematzadeh[30]stated that the introduction of Nano- SiO₂ in the fiber reinforced concrete improved the elastic modulus due to an increase in the compactness of cement paste bond with aggregates.

The experimental study of Nazari and Riahi[31]found that by adding SiO₂ nano-particles up to 4.0 wt. % improved the strength and water permeability of the specimen. Zhau and Liu [32]showed that due to the introduction of



Nano-SiO₂ in the rubber-recycle concrete and the mechanical properties of rubber-recycled concrete are improved significantly. Joet *et al.*, [33] concluded that nano-SiO₂ acted not only as filler to improve microstructure of cement mortar but also as a promoter of pozzolanic reaction.

II. MATERIALS

1. Cement paste with Nano-material.
2. Cement paste with Plastic waste or Recycled Plastic.
3. Cement paste with Nano-material and Plastic waste or Recycled Plastic.

1. Cement paste with Nano-material:

Ghafari. E, *et al.*, 2014[34] used Portland cement, type I 52.5R. An addition of silica fume (SF) presenting a specific area of 18.41 m²/g and also the addition of nS with an average particle size 15nm were adopted. Table 1 shows some physical and chemical properties of cement and silica fumes and Table 2 summarises the properties of nS. The siliceous sand with 0.6 mm of max aggregate size was used. The adopted admixture was polycarboxylic acid based super-plasticizer (SP) with solids content between 28.5wt. % -31.5 wt. % and density between 1.067 - 1.107 g/cm³. Now, five series of UPHC mixtures containing different percentage of nS were prepared for the study. The references for the mixtures proportion of UHPC was obtained through previous studies [35]; [36]; [37] and the nS was incorporated as cement replacement by 1, 2, 3 and 4 by wt. % of cement. To mix the materials, it requires several steps. Firstly, to prevent agglomeration and also to promote uniform distribution of very fine particles, all powders and siliceous sand were mixed for 5 min at low speed. Due to very low density of dry nS, to incorporate it would not have been possible, causing particles to disperse in the air. To overcome this problem, nS was first dissolved in water, already containing super-plasticizer and then gradually added to the mixture. The mixture becomes fluid after 5 minutes. The concrete poured in the moulds after mixing and 24 hours later, it was demoulded. Then the specimen were cured in the water immersion at 20°C until the day of test.

Chemical composition and physical properties of cement and silica fume.

| Chemical analysis in percentages. | Cement | Silica fume |
|------------------------------------|--------|-------------|
| SiO ₂ | 20.9 | 93.6 |
| Al ₂ O ₃ | 4.60 | 1.3 |
| Fe ₂ O ₃ | 3.15 | 0.90 |
| CaO | 62.0 | 0.4 |
| MgO | 2.00 | 1 |
| SO ₂ | 3.60 | 0.4 |
| K ₂ O Na ₂ O | <1 | 1.52 |
| Specific gravity | <1 | <1 |

Table 1[34]

Properties of nano-SiO₂:

| Formula | Specific surface area (m ² /g) | Purity | Crystal phase | Diameter (nm) | Density (g/cm ³) | Morphology |
|-----------------------|---|-----------|---------------|---------------|------------------------------|------------|
| SiO ₂ (nS) | 160±20 | >99.9 (%) | Amorphous | 15 ± 5 | <0.15 | Spherical |

Table 2[34]

➤ Production method of nS:

In the recent years, there are many methods to produce nS products. One of the production method is based on sol-gel process (Organic or water route) at room temperature. This process involves starting materials (mainly Na_2SO_4 and organometallics like TMOS/ TEOS) are added in a solvent and then the pH of the soil is changed, reaching the precipitation of silica gel. The produced gel is aged and filtered to become Verogel. [38]. This verogel is dried and burned or dispersed again with the stabilized agent (Na, K, NH_3 etc.) which produces a concentrated dispersion (20% - 40% solid content) suitable for the use in concrete industries [27]; [39].

Also, nano-silica (nS) is being developed via an alternative production route. Primarily, olivine and sulphuric acid are contrived whereby precipitated silica with extreme fineness but agglomerate form is synthesized (nano-size with particles between 6-30nm) and even cheaper than contemporary micro-silica [40]. Two preceding PhD thesis and published data [41]; [40]; [42] proved the feasibility of the process. Now, the parallel PhD project [43] focuses on the process to produce nS on industrial scale in large quantities for concrete productions. Furthermore, the combination of raw materials and process parameters on production will be examined.

2. Cement paste with Plastic waste or Recycled Plastic:

The majority of the reported studies generally evaluated the properties of plastic wastes to be used as an aggregate in concrete preparations such as size distribution, bulk density, specific gravity and water absorption. The standard sieving method is used for the evaluation of size distribution of plastic aggregates [9]; [12]; [14]; [16]; [44]; [45]; [46]. The author's experiment finds the standard procedure used to evaluate properties like bulk density, specific gravity, and water absorption of coarse and fine natural aggregates can be used to evaluate these parameters in plastic aggregate with slight modification. [46]

However, on the flip side, some other properties such as hardness (tensile and compressive strength, elastic modulus) of plastic aggregate, decomposition temperature, melting and initial degradation temperature and melt flow index (MFI), heat capacity and thermal conductivity were also reported.

➤ Preparation and curing of cement mortar/ concrete using plastic aggregates:

Mostly, the design, preparation and casting of concrete mix containing plastic aggregate are similar to normal concrete/ mortar mix design and done according to various standards specification. However, designing and/or curing of some concrete mixes containing plastic aggregates were done by slightly different approaches than for the normal concrete mix design [47]; [9]; [16]; [18]; [23]; [48]. Some types of plastic aggregate such as plastic foam can consume water that is necessary for hardening and therefore, concrete specimens containing these types of plastic aggregates at certain replacement amount cannot be completely hardened after 24 hours of normal curing before demoulding the specimen [22].

3. Cement paste with Nano-material and Plastic waste or Recycled Plastic:

For this work, [59] Portland cement, sand, poly carboxylate based super-plasticiser, nano- SiO_2 and recycled PP plastic particles were used. The chemical composition of cement is as shown in table given below. From the local sources the sand was obtained with the fineness modulus of 2.6 and apparent density of 2650 Kg/m^3 . ShaxxiQuifen building materials Co. Ltd. (China) produced super-plasticizer, whose water reduction rate was 30%. The nano- SiO_2 (content $\geq 99.5\%$, powder particle size $\approx 30 \pm 5 \text{ nm}$ and specific area is $200 \text{ m}^2/\text{g}$) was produced by Shanghai Keyan Industries Co. Ltd. The recycled PP plastic particles were purchased from ZhujiyangYuyuoFengli plastic Co. Ltd. (China), which were short columns with lengths from 2mm – 3.5mm, elastic modulus of 0.97GPa water capacity of less than 0.4% and relative density of $0.89\text{-}0.92 \text{ g/cm}^3$.

➤ Mix design and Processing of mortar:

The table shows the mix proportion of mortar. The super-plasticizer's content was taken as the percentage of the weight of cementitious materials. To avoid the floating phenomenon of recycled PP plastic particles due to its light density, the dosage of super-plasticizer was controlled. Replacing sand by 0%, 20%, 40% and 60% by volume of the plastic particles were added. The nano- SiO_2 content was 5% by wt. of cement.

The step-by-step procedure for mortar was as follows:

- 1) Put the nano-particles, cement and sand in the mixing pot and mix it for 2 minutes.
- 2) Add water and super-plasticizer into mixing pot slowly and mix for additional 3 minutes.
- 3) Add the recycled PP plastic particles into the mixing pot and mix it for additional 3 minutes. During the mixing process, the flowability and workability of the mortar mixtures were kept consistent by adjusting the dosages of super-plasticizer.

When this mixing process was finished, the recycled PP plastic particles and nano-SiO₂ were homogeneously distributed throughout the mortar.

III. RESULT AND DISCUSSION

1. Nano-SiO₂ in UHPC:

a. Pozzolanic reactivity of nS and SF in Cement paste:

Due to incorporation of nS and SF in the water, suspension conductivity increases as ions transferred from nS and SF into water. As the water soluble-ions were higher in nS- water suspension, its conductivity value is higher than SF- water suspension. Results indicated that after 30 minutes only the value of relative loss in conductivity reached 51 % and 20 % by incorporation of nS and SF respectively. Madani. H, *et al.*, [49] experimental studies found that nS showed a considerably higher reactivity than silica fume at early ages (32%) which can be attributed to relatively higher specific surface areas of nS.

b. Fresh and Hardened state properties:

From the experiment, upto 3 wt. % replacement of nS particles there is increase in compressive strength, but with 4 wt. % replacement of nS particles, it has been observed that there is slight decrease in the compressive strength. Hence, the higher replacement of nS did not lead to an improvement in compressive strength, which can be due to improper dispersion of nS particles in the mixture. The key factor governing the performance of these products is the dispersion of nano-particles within the cement paste. While experimenting, when the addition of nano-particles are in excess quantity with the mixture, they are not uniformly dispersed in the cement paste, and as a consequence weak areas appear in cement mortar due to agglomeration. To achieve the composite materials with improved properties, thus the disagglomeration of nano-particles is crucial [50].

c. Microstructure and Pore structure:

By the experiments, it can be observed that by increasing nS content, the volume of capillary pores in specimens always decreases, which shows that the density of concrete is increased and the pore structure is refined. The decrease in total porosity up to 25.3%, 26.7%, 32.1%, and 24.5% has been observed when nS is incorporated for respective specimens [51]. Due to incorporation of nS further densification in the microstructure and to a concurrent reduction in the capillary porosity of concrete mixture is observed. It is universally known that the portlandite a mineral oxide has a detrimental effect on bond strength of aggregate-to-paste which causes a significant reduction in the durability and in mechanical properties [52]. According to results, the nS can effectively reduce the amount of portlandite making a denser microstructure of interfacial transition zone (ITZ) between the aggregates and paste.

d. Transport properties:

After the addition of nS it was found to be effective in reducing the water absorption. From the result, it can be seen that the amount of absorbed water in the sample decreased by increasing the nS content [34]. Teichmann. T, Schmidst. M, [53] found that porosity of cement paste, the aggregates and the proportion of these two components in the mixture mainly affects the penetration of gas and gas will penetrate more where the porosity is higher [54]. From the results in this study calculated a relation between porosity of concrete specimens and gas permeability. This relation is stated for self-compacting concrete and high-volume fly ash concrete [54][55].

2. Plastic in concrete:

Nabajyoti. Saiki, and Jorge. De Brito, [56] found that the incorporation of plastic waste as aggregate in concrete can improve various properties, which can solve a part of the problem of plastic disposal. Some of the results are stated below:

- a. The density of concrete becomes less when plastic is incorporated. The standards for light-weight concrete has been satisfied when concrete contains various types of plastic aggregates.
- b. By using waste plastic in concrete leads to improvement of toughness behaviour and therefore this kind of concrete can absorb high amounts of energy, which has several practical implications.
- c. As the plastic waste aggregates has significantly lower thermal conductivity than the natural aggregates when they are used in the concrete preparations. Hence, the plastic concrete having plastic aggregates tends to have better thermal insulation properties than conventional concrete which can be used to control heat loss from building during winter and heat gain during summer.

3. Cement paste with Nano-material and Plastic waste or Recycled Plastic:

- a. Physical Properties: By increasing the content of recycled PP plastic particles there is considerable increase in the porosity and water absorption. On the contrary to that, increase in the ratio of PP plastic particles, caused decrease in the specific gravity and bulk density. From the decrease in the density, conclusion could be made that the density of recycled plastic is lower than that of sand [57]. With the introduction of nano- SiO_2 there is improvement in the pore structure of plastic mortar, which ultimately reduces the porosity and water absorption, making them more compact and hence improves the bulk density of plastic mortar.
- b. Mechanical Properties:

Compressive strength: Increasing content of plastic material decreases the compressive strength of PP plastic particles filled mortars. As the plastic has smaller elastic modulus [58], which plays key role for porosity and also the plastic's ability to transfer the stresses is poor too. Just to make the interface between the aggregates and cement pastes more compact, nano- SiO_2 can be used as physical filler. The nano- SiO_2 particle size is very small, it has high activity. C-S-H gel, which can enhance the structure of interfacial transition zone, could be formed as nano- SiO_2 can reach with $\text{Ca}(\text{OH})_2$ in the interfacial transition zone between the aggregates and cement paste, thus increases the compressive strength of plastic mortar.

IV. CONCLUSION

1. Nano- SiO_2 in Cement mortar/ concrete:

Significant work has been done to evaluate the pozzolanic behaviour of nS and its effect on the micro-structure of UHPC, from the results obtained following conclusion can be drawn:

- a. As the percentages of nS increases, the water demand in the mixture also increases remarkably. By considering acceptable range of slump flow i.e. 3 wt. %.
- b. In the early ages of UHPC mixtures the compressive strength increased with the increase of nS percentages. The highest compressive strength was noted at replacement of nS at 3 wt. % of cement in cement paste, which is an optimum amount of cement replacement by nS. To get the proper results, dispersion of nS is key factor for the incorporation of highest percentages into the cement pastes.
- c. Addition of nS makes UHPC denser and more homogenous by reducing capillary pores. By the SEM results, it can be concluded that with the addition of nS, the extreme fine particles of nS acts as filler as well as an effective pozzolanic materials. As the fine particles of nS reacts with $\text{Ca}(\text{OH})_2$ crystals, which develops improved pore structures. The micro-structural interfacial transition zone (ITZ) between the aggregates and binding pastes experiences improvement by the incorporation of nS.
- d. The water absorption and sorptivity experiences reduction due to addition of nS in cement pastes mixtures, which also indicates that due to pozzolanic reactivity of nS, when there are additional hydration products the numbers of capillary pores connections are reduced. Porosity is the critical parameter which is responsible to tackle the transport properties of UHPC.

2. Plastic in cement mortar/ concrete:

Using different sizes of plastic waste as aggregate in the concrete significant work has been done. The studies showed that plastic wastes are susceptible for the use as partial replacement of natural aggregates. From the results obtained from various studies following conclusions can be drawn:

- a. Due to size and shape of plastic aggregate there exists 2 parallel views on the workability performance of concrete containing plastic aggregate. The slump of fresh concrete mix is decreased due to flaky and porous plastic aggregates and on the flip side of that the spherical shaped plastic aggregate increases the slump. To prepare lightweight concrete different studies were undertaken by using several types of plastic aggregates, because as the incorporation of plastic aggregate leads to the reduction in the density of resulting concrete and cement mortar.
- b. Because of very low binding strength between the surface of plastic particles and cement pastes, the incorporation of plastic aggregates lowers the various properties of resulting concrete mortar specimens, irrespective of the type of plastics and amount of substitution.
- c. Due to incorporation of plastic aggregate, the reduction in tensile strength and flexural strength were relatively less notable than the reduction in compressive strength of concrete. Failure behaviour changes by the incorporation of plastic.
- d. With reference of existing data, the incorporation of various plastic aggregates can improve permeability behaviour of concrete and hence in the aggressive chemical attack the concrete with plastic stands out durable in comparison to other. On the contrary, the shrinkage of the concrete considerably increased due to incorporation of various types of plastic aggregates.

3. Cement mortar with nano-particles and Plastic:

The various studies presented the results of the influence of nano- SiO_2 and recycled PP plastic particles on different properties of mortar like physical, mechanical and shrinkage properties. From the result obtained from this study, the following conclusions can be drawn:

- a. By addition of recycled PP plastic particles in the cement mortar, the apparent porosity, water absorption and drying shrinkage increases. However, to counteract this, the addition of nS helps. Adding nS reduces the porosity, water absorption and drying shrinkage also enhances density and flexural- compressive strength of plastic mortar.
- b. On the contrary, the addition of nano- SiO_2 adds up to autogenous shrinkage of plastic mortar. Hence, the adverse effect of addition of nano- SiO_2 on autogenous shrinkage strain of plastic mortar should be considered.
- c. As with a lot of results stating about the poor adhesion between plastic particles and cement paste, the addition of nano- SiO_2 helps. Thenano- SiO_2 enhances contact between the surface of plastics and cement particles leading to the improvement in the mechanical properties of plastic mortar.

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