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ORIGINAL ARTICLE

Effective utilization of waste textile sludge composite with Al_2O_3 nanoparticles as a value-added application

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Abstract

Waste materials utilization as value-added materials and micro, nanoparticles inclusion is gaining huge attention. The sludge generated from the textile industry constitutes a high toxic compound and hazardous in nature. Currently, large quantities of solid sludge remain unattended and undisposed in various effluent plants, waiting to be disposed of at the landfills. In this study, the waste sludge generated from the textile industry was processed and reused as a substitute for cement material. The specimens prepared from the textile waste sludge along with nanoparticles were tested for durability and mechanical properties. The usage of textile sludge decreases the strength properties marginally until a replacement level of 10%. Beyond the addition of 10% textile sludge waste reduces the strength and durability properties significantly. Textile waste sludges were replaced for cement of varying proportions, i.e., 2.5%, 5%, 7.5%, 10%, 15% and 20%. The addition of alumina nanoparticles has dual effects, enhances the hydration properties and also acts as a filler material. The formation of calcium silicate hydrate gel was improved significantly due to the utilization of nano alumina. The optimum amount of alumina nanoparticles observed from the previous studies was found to be 3% by weight of cement due to high durability and mechanical properties. The combination of 10% textile waste sludge along with 3% nano alumina blended cement concrete leads to enhanced strength and durability characteristics as compared to all other concrete specimens and it was found to better eco-friendly construction material.

Keywords Textile waste sludge · Alumina nanoparticles · Acid attack · Hazardous material · Landfills

Introduction

Due to the consequences of overpopulation, urbanization and industrialization, the infrastructure sector has been seeing a significant rise in the consumption of the resources, which poses a threat environmentally and well as leads to depletion of the same. Due to this problem, various methodologies and experimentations are being carried out to test out alternatives of these construction materials, especially by recycling the waste effluents from the industries which are more sustainable. In this way, there can be a balance in the system, where there will not be depletion of resources, as well as management of the waste effluents, which is a major problem faced as well.

As far as the industrial sector is concerned, the textile sector proves to be one of the oldest and the largest sector in India as it comprises about 14% of the total production (Balasubramanian et al. 2006). As being one of the important foreign exchange earning industries, it is also responsible for the consumption of water in large quantities, which is necessary for production, thus polluting the environment with its waste effluents (Man et al. 2018). Usually, the textile mills generate mixed wastewater in large quantities of upto 600 m^3/kg fabric, which constitutes about 100 mg/L of high organic load (Palanivelu

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and Rajkumar 2001). These waste effluents are collected from various textile mills and treated in a common effluent treatment plant. Here, the waste effluents are treated using various chemical processes. In the treatment process the textile wastewater, the effluent treatment plants (ETP) produce large quantities of biological, inorganic and organic mixed sludge, which eventually turns into solid sludge. This solid sludge is released which does not have any commercial returns (Rahman et al. 2017) and is said to be considered hazardous as per Indian Hazardous Waste Management Rules, 2008 (Vellingiri et al. 2015). In the present scenario, large quantities of this solid sludge remain unattended and undisposed of in various Effluent Treatment Plants, waiting to be disposed of at the landfills (Idachaba et al. 2001).

Various disposal methods and technologies have been and are being introduced to treat the different types of wastes. The conventional techniques involve landfilling, Open dumping, and agricultural uses. These techniques cannot be used and are not preferred for the sludge from the ETP because of the potential toxicity of the constituents of the effluents. Open dumping causes degrading of the soil, which affects the fertility of the land, which can in turn cause contamination of the surface and underground water (Goyal et al. 2019). These contribute to another type of pollution, which is not environmentally good. The solid wastes from the industries are usually treated using the process of Stabilization/Solidification, which prevents the toxic effluents to dissolve in the environment. Moreover, in this process the toxic potential of the effluent is reduced by Stabilization, by turning the organic matter into the least soluble form. This technology is used to prevent the hazard caused by radioactive elements as well. The process of Solidification involves encapsulating the waste into a hardened solid, which has significant structural integrity. The migration of the contaminants is reduced to a higher level by the chemical process of leaching (Patel and Pandey 2012; Malviya and Chaudhary 2006; Batchelor 2006). Generally, in the stabilization process, an alkaline material is used. Pozzolanic binders, Ordinary Portland Cement (OPC) and Lime are the most common absorbents which are used in the process of stabilization (Vellingiri et al. 2015; Lynn et al. 2015).

This technique is mostly preferred, due to its simplicity, in terms of its execution, cost effectiveness and the result which is comparatively environment friendly (Soundararajan 1990; Baker and Bishop 1997). Using this technology, the solidified sludge can be used as an alternate solution as a building material. Using sludge as a potential building material has many benefits. First, being that the toxicity of the contaminants is reduced to a very high level, which also leads to proper disposal of the same. Second, being a proper alternative to the conventional building material, which also prevents the soluble migration of the contaminants. Moreover, this also leads to the prevention of unwanted exploitation of the existing natural resources (Goyal et al. 2019).

From a very long time, many experiments and explorations have been done to see the potential of textile sludge as a building material. There were many ways proposed, for the usage of the textile sludge as a building material. One, the sludge being in the production of bricks, by the clay-sludge binder system. It was seen that while mixing up to 45% of the dried sludge with clay, which is used to produce bricks, the performance can be improved by having the clay ignited at about 600 °C before mixing the combination (Ansari and Thakur 2001). In the study conducted by Baskar, the various factors in the process of the brick-making, such as the firing temperature and firing time were explored, which can eventually determine the quality of the clay bricks produced with the partial usage of the CETP sludge. In this venture, the sludge was categorized to be added from 3 to 30%. The quality of the bricks was found to increase when the amount of sludge increased and vice versa (Baskar et al. 2006). In the study conducted by Rahman, The bricks produced from the partial substitute of sludge were also found to be very preferable for the load-bearing capacity, when the percentage of sludge is about 10%. When the percentage of the sludge increased to 30%, the bricks behaved as non-structural building material (Rahman et al. 2015).

Many researchers have tried to experiment with the usage of Textile sludge in cement. The sludge is used as cement-sludge binder systems. It was observed that cement–concrete flooring tiles as per BIS 1237-1980, can be produced when 20% of the sludge is added with cement. These are non-bearing units (Balasubramanian et al. 2006). Zhan and Phoon concluded that it is feasible to use sludge as a minimal substitute in concrete, and when more amounts are added, the load-bearing capacity decreases. This was due to the presence of Lead and Zinc in the sludge (Zhan and Poon 2015). The compressive strength of the sludge was also experimented by Joseph and Kumar, where it was concluded that the mixes of the sludge and concrete can be used as non-structural components of the building (Joseph and Kumar 2017).

The usage of sludge in the production of bricks has been explored quite frequently. The studies about incorporating sludge in cement concrete are very limited. The main intent of this research focuses on using sludge as a potential alternative in the concrete and exploring the performance of the same using various factors.

Materials and methods

The waste sludge generated from the textile industry obtained from the Tiruppur, India was used. The common effluent treatment plant receives waste sludge coming from the textile industry. The sludge samples were collected from the treatment plants using polypropylene jars and refrigerated at a temperature of 4 °C. After refrigeration, the samples were taken out and allowed to dry in a hot oven at a temperature of 100 °C for about 24 h. The samples taken out from the hot oven were grounded into fine powder using a ball mill. The textile sludge powder was dark green in colour. The chemical properties of sludge obtained from the textile industry are shown in Table 1.

The concrete specimens were prepared confirming to the ASTM C150-19a standards. The nano alumina used in the study was 3% by weight of cement. Textile waste sludge was utilized in this study at varying compositions, i.e., 2.5%, 5%, 7.5%, 10%, 15% and 20%. Fine and coarse aggregates with a maximum size of 4.75 mm and 20 mm were used in this study. TS-0%, TS-2.5%, TS-5%, TS-7.5%, TS-10%, TS-15% and TS-20% stands for 2.5%, 5%, 7.5%, 10%, 15% and 20% replaced textile waste sludge by weight of cement, respectively. TSN-0%, %, TSN-2.5%, TSN-5%, TSN-7.5%, TSN-10%, TSN-15% and TSN-20% stands for 2.5%, 5%, 7.5%, 10%, 15% and 20% replaced textile waste sludge by weight of cement along with 3% nano alumina, respectively (Olmo et al. 2001; Jalal et al. 2013). The mix proportion of textile waste sludge and nanoparticles incorporated concrete specimens were shown in Table 2.

Table 1 Physio-chemical properties textile waste sludge

Parameters	Values
Total solids	90.11%
Total fixed solids (% of dry solids)	37.2%
Total volatile solids (% of dry solids)	62.8%
pH	7.90
Moisture content (%)	12.45%
Electrical Conductivity (mS/m)	6.87
Specific gravity	0.93
Total Organic Carbon (%)	11.17
Density (Kg/m^3)	901.32
Calorific value (Kcal/kg)	932.3
Cr (III) (mg/kg)	243.1
Cd (mg/kg)	6.4
Zn (mg/kg)	192.4
Cu (mg/kg)	221.1
Ni (mg/kg)	92.5
Pb (mg/kg)	48.4

Compressive strength test

As per BS EN 12390–3:2009 and IS 4926: 2003 (R2017) concrete specimens of 100mmx100mmx100mm cube were cast and subjected to wet curing. The concrete specimens were tested for compressive strength at 7th, 28th and 90th days at a sustained load of 2.5 kN/s using a compressive testing machine until the specimen breaks and no further load can be resisted by the concrete specimen. Three samples were cast for each mix and the average of three values was considered as compressive strength of concrete.

$$\text{Compressive strength } (\text{N/mm}^2) = \text{F/A} \quad (1)$$

where, *F* maximum load of the concrete specimen until to fail; *A* cross-sectional area of the concrete specimen.

Split tensile strength test

As per IS 5816:1999, the concrete specimens of size 150 mm diameter and 300 mm length were cast in metal moulds and

Table 2 Mix design of textile waste sludge incorporated concrete specimens

Sample designation (%)	Cement	Textile sludge	Fine aggregate	Coarse aggregate	Nano alumina	Water
TS-0	410	0	565	1030	0	180
TS-2.5	399.75	10.25	565	1030	0	180
TS- 5.0	389.5	20.5	565	1030	0	180
TS-7.5	379.25	30.75	565	1030	0	180
TS-10	369	41	565	1030	0	180
TS-15	348.5	61.5	565	1030	0	180
TS-20	328	82	565	1030	0	180
TSN-0	410	0	565	1030	12.3	180
TSN-2.5	399.75	10.25	565	1030	12.3	180
TSN- 5.0	389.5	20.5	565	1030	12.3	180
TSN-7.5	379.25	30.75	565	1030	12.3	180
TSN-10	369	41	565	1030	12.3	180
TSN-15	348.5	61.5	565	1030	12.3	180
TSN-20	328	82	565	1030	12.3	180

subjected to wet curing. The concrete specimens were tested for split tensile strength at the 7th, 28th and 90th days of wet curing. (Meddah et al. 2020; Bautista-Gutierrez et al. 2019) The concrete specimens were tested at a sustained load of 3 kN/s using a universal testing machine until the specimen breaks and no further load can be resisted by the concrete specimen. Three samples were cast for each mix and the average of three values was considered as a split tensile strength of concrete.

Rapid chloride penetration test

Concrete specimens subjected to water curing as per ASTM C1202 and AASHTO T277 for 28 days of sizes 50 mm × 100 mm diameter cylinder were monitored by passing electric current during 6-h period after coated with epoxy in the concrete sides. A potential difference of 60 V direct current is maintained across two uncoated sides of the concrete samples. One end of the sample was immersed in 3% (by wt) of sodium chloride solution used as anode; other sample was immersed in a 0.3 N sodium hydroxide solution used as cathode. During 6 h, the electric charge passed, in coulombs is taken during 30-min time interval and the electric charge passed through concrete sample denotes the amount of chloride ion penetration in the sample.

Resistance to acid attack

As per ASTM C267-12, the disintegration of supplementary cementitious materials and nanoparticles incorporated concrete samples against Hydrochloric acid (HCl) attack were performed. Concrete specimens of size 100 mm × 100mm × 100mm were cast in a metal mould and subjected to wet curing for 28 days. After the curing period, the initial weight of surface dried concrete specimens was noted. The surface dried specimens were immersed in a 3.5% concentration of Hydrochloric acid for a period of 14 and 28 days (Silva et al. 2018; Chandanshive et al. 2018). The weight of concrete specimens after immersed in HCl was noted. The difference in weight of concrete specimens was noted at 14 and 28 days and the values have been compared with the initial weight of surface dried concrete specimens.

Carbonation Test

One of the causes of the deterioration of concrete is carbonation. It is a process by which a reaction takes place in between cement hydration of concrete and carbon dioxide of atmosphere products to form calcium carbonate. The carbonation resistance of concrete cubes can be evaluated by the carbonation depth of the cube specimen under the action of CO_2 pressure. A series of cube specimens with the size of 150 mm × 150 mm × 150 mm were used to determine the carbonation resistance of concrete cubes. Before going to the carbonation test near about 42 cubes were cast for 14 different mixes of concrete as per the designed mix. After 24 h, all the cubes were demolded and immersed in a curing tank for 28 days. After completion of 28 days of curing, they were taken out and allowed to dry the surface at normal temperature and kept inside the carbonation chamber for another 28-day curing. The dose of carbon dioxide inside the carbonation chamber was kept at 5%, temperature 35 °C and 70% humidity. After completion of carbonation curing all the specimens were broken in to two halves and 1% phenolphthalein solution was applied on the broken surfaces of specimen. After some time, it was seen the portion which was carbonated looking colorless and which was not carbonated became a pink surface. The carbonation depth was measured through slide calipers and noted as shown Fig. 5.

Results and discussion

Compressive strength

Figure 1 shows the compressive strength of varying percentages of textile sludge waste ranging from 0 to 20% and 3% nano alumina blended concrete specimens. The compressive strength of textile sludge waste incorporated concrete specimens showed a decrease in strength for all the concrete mixes. The strength of 2.5%, 5%, 7.5%, 10%,15% and 20% incorporated sludge waste showed 2.83%, 6.5%, 14.2%, 16.5%, 22.3% and 31.4% decrease in compressive strength respectively as compared to conventional concrete mix at 7-day curing period. The addition of textile sludge in concrete reduced the compressive strength proportionally. The reduction in strength of textile sludge waste incorporated concrete is due to the presence of compounds including lead, zinc and chromium in the sludge, which retards the hydration process of concrete responsible for the development of strength. The presence of zinc and other compounds may forma layer around the cement particles due to calcium hydroxyl-zincate precipitation ($CaZn_2(OH)_6{\cdot}2H_2O$). The precipitation of calcium hydroxyl-zincate prevents the ion and water transportation necessary for the hydration reaction (Silva et al. 2018; Chandanshive et al. 2018). The formation of the Pb layer on the cement particles retards the hydration reaction. The other constituents present in the textile waste sludge may also lead to a decrease in compressive strength. The concrete specimens prepared with textile sludge waste, water to cement ratio increases marginally which also leads to reduced compressive strength. The characteristic of organic waste significantly affects the compressive strength of concrete specimens. The absorption of water by the other constituents in the textile waste sludge during the mixing process, releases water during the compaction process

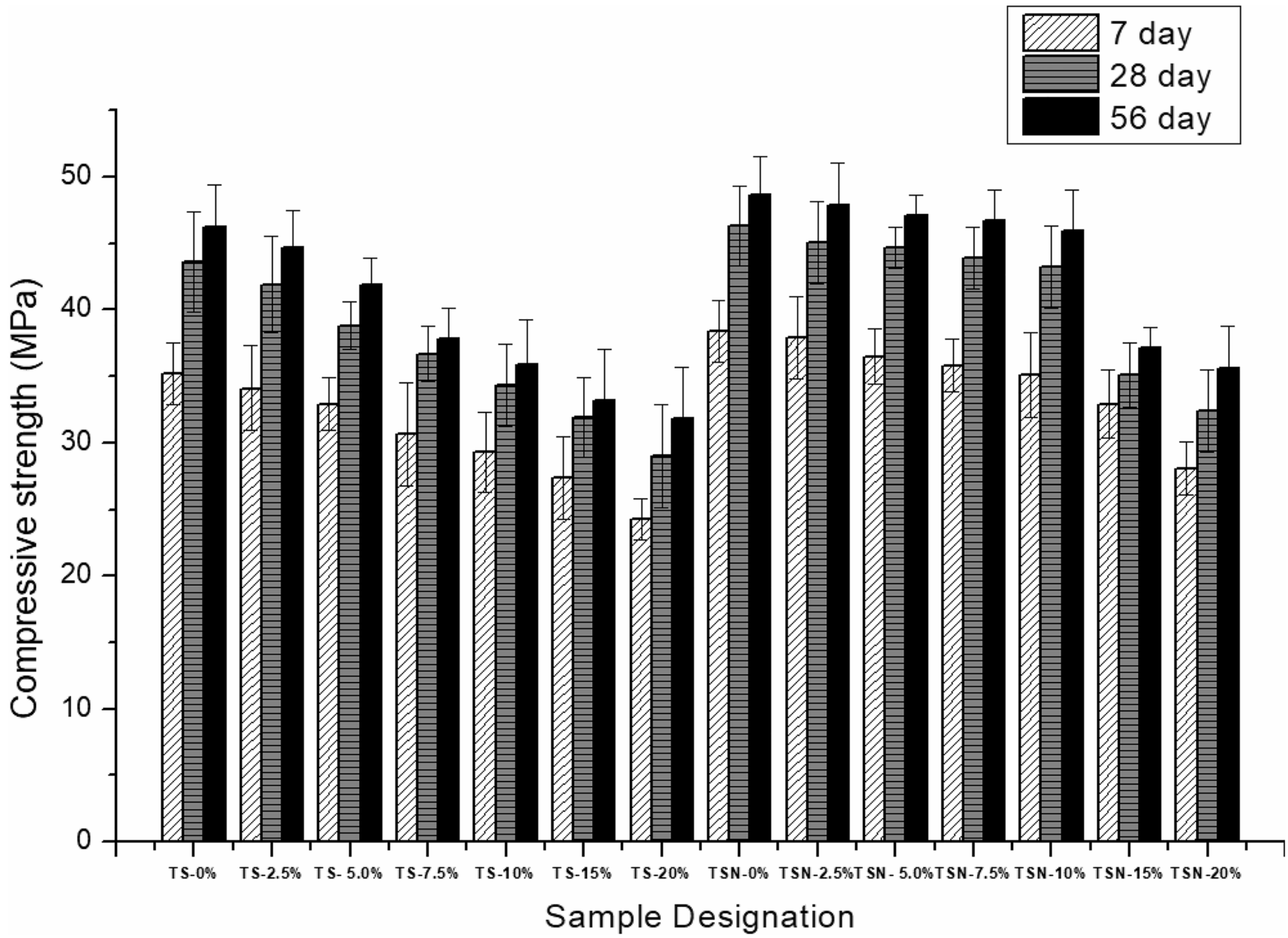

Fig. 1 Compressive strength of textile sludge waste and nanoparticles incorporated concrete specimens

increases the water-cement ratio. This tends to be a major reason for the decrease in compressive strength. In addition, the decrease in strength may also due to excess sulphates and organic compounds present in textile sludge.

The addition of nanoparticles in textile sludge waste incorporated concrete enhances the compressive strength of specimens significantly. The strength of TSN-2.5%, TSN-5% and TSN-7.5%, showed increase in strength of around 5.1%, 2.7% and 1.7% as compared to conventional concrete mix. TSN-10% mix showed similar strength as that of the conventional mix. TSN-15% and TSN-20% showed a 6.52% and 17.1% decrease in strength as compared to conventional mix cured at 7 days. The inclusion of nano-alumina enhances the strength of specimens at all curing ages. The optimum amount of nano-alumina was found from the previous studies. Nanoparticles enhance the microstructure of the cement concrete matrix. The addition of nanoparticles improves the compressive strength of 10% replaced textile sludge incorporated concrete, whereas 15% and 20% textile sludge incorporated concrete specimens increment in strength as compared to textile sludge waste incorporated specimens without nanoparticles but lesser than conventional concrete specimens (Zhan et al. 2020). The presence of bicarbonates and fluorides in textile waste sludge reacts with nano-alumina and forms calcium fluoro aluminate and thus leads to higher compressive strength. In addition, the minerals present in the textile sludge were highly reactive and thus enhances the hydration process of cement which ultimately enhances the strength properties.

Split tensile strength

Figure 2 depicts split tensile values of textile sludge waste ranging from 0 to 20% and 3% nanoparticles incorporated concrete specimens. Similar to compressive strength, an increase in the percentage of textile waste sludge incorporation reduces the splitting tensile strength of concrete. The split tensile strength of TS-2.5%, TS-5%, TS-7.5%, TS-10%, TS-15% and TS-20% were 4.07 MPa, 3.97 MPa, 3.89 MPa, 3.78 MPa, 3.57 MPa and 3.47 MPa respectively. The tensile strength of nanoparticles incorporated concrete increases the tensile strength values of concrete specimens significantly

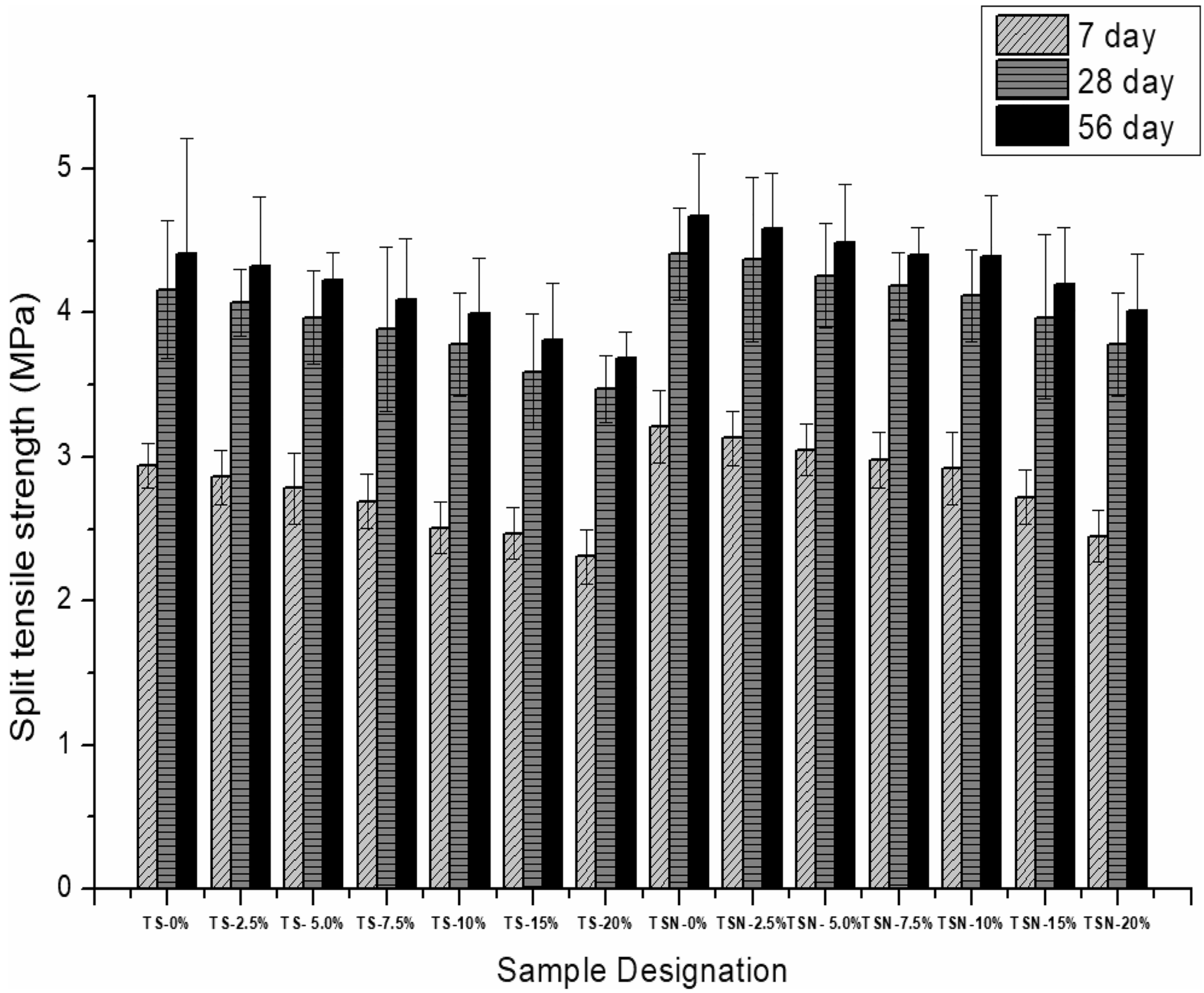

Fig. 2 Split tensile strength of textile sludge waste and nanoparticles incorporated concrete specimens

as compared to textile sludge concrete specimens without nanoparticles. The strength of TSN-2.5%, TSN-5% and TSN-7.5% were increased by 4.3%, 2.9% and 0.81% respectively as compared to conventional concrete cured at 28 days. TSN-10%, TSN-15% and TSN-20% showed 0.23%, 4.6% and 6.23% decrease in strength values as compared to conventional mix. The strength of TSN-10% showed 9% increase in strength as compared to TS-10% concrete specimens. The reduction in split tensile strength of textile sludge concrete specimens may be due to the presence of excess organic compounds. The presence of excess organic compounds stores water and it releases during the compaction and placing of concrete which increases the water to cement ratio which ultimately reduces the split tensile strength of concrete (Zhan et al. 2020; Haque 2020). The variation in split tensile strength values of various mixes may be due to the micro cracks bridging effect during loading and after loading due to utilization of textile waste sludge in concrete specimens. Further, the addition of textile waste sludge alone does not contribute any improvement in strength without nanoparticles and keeping the tensile strength marginally lower than conventional concrete mix.

Rapid chloride penetration test

Figure 3 depicts the chloride ion penetration level for the textile sludge waste and nanoparticles incorporated concrete specimens. The serviceability and durability of concrete specimens were affected due to de-icing salts and chlorides present in sea water, penetrates into concrete structures which leads to reinforced concrete structure deterioration. Hence chloride ion penetration is considered to be a major parameter in terms of durability characteristics of concrete. The increase in chloride ion penetration on the surface of the steel bars

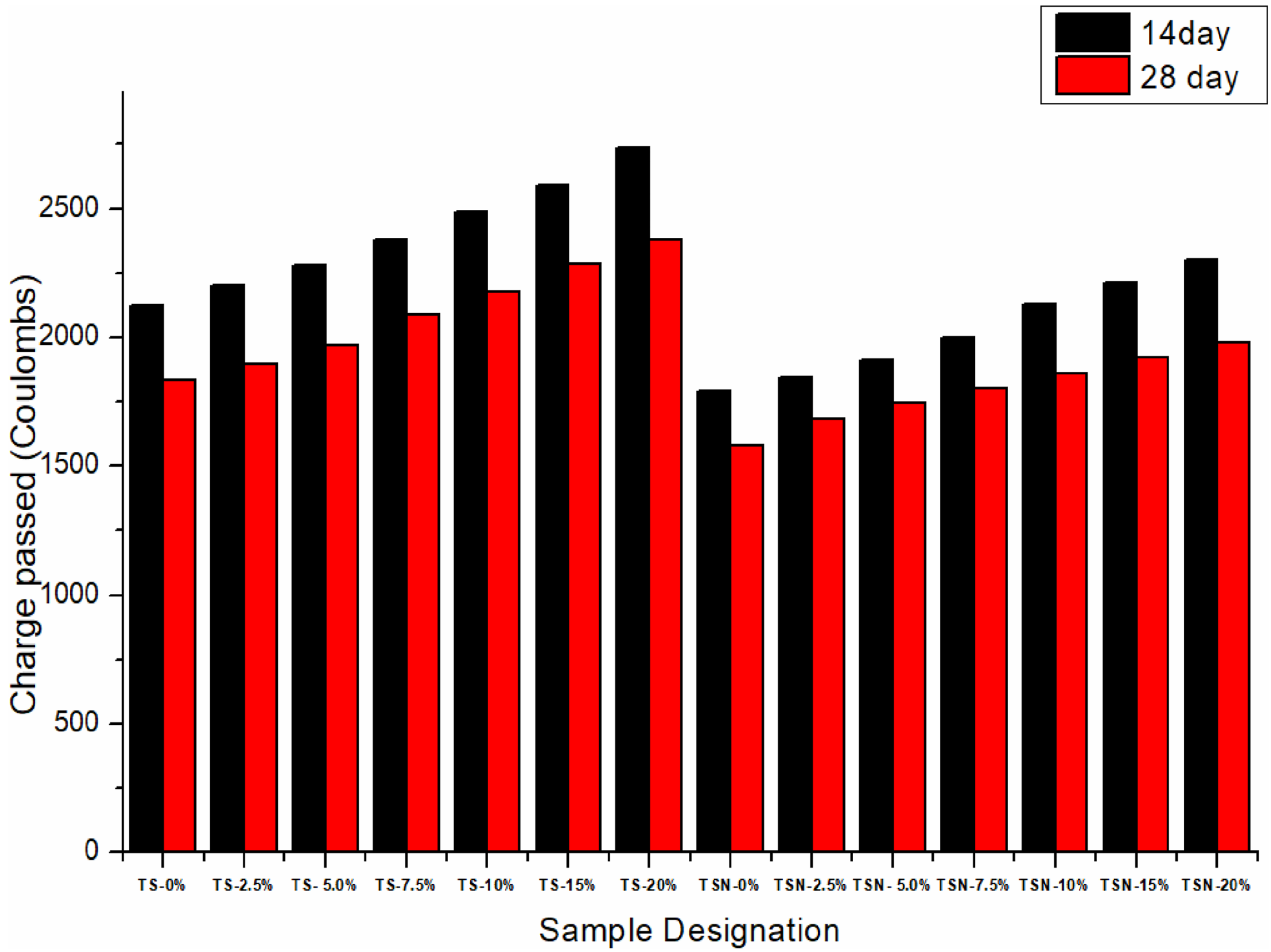

Fig. 3 Chloride ion penetration strength of textile sludge waste and nanoparticles incorporated concrete specimens

onsets the corrosion process along with oxide formation which leads to spalling of concrete and changes in the volume of the structures. During the oxidation process, the presence of chloride ions can act as a catalyst and form $FeCl^{3-}$complex. $FeCl^{3-}$complex was unstable and reacts with the hydroxide ions present in the cement matrix forming iron hydroxide. The pH value of concrete specimens reduced significantly due to the formation of iron hydroxide (Wang et al. 2019), (Zhao and Wei 2020; Paz et al. 2017). In addition, presence of iron hydroxide reduces the oxide film formation and thus chloride ions can penetrate easier. The corrosion mechanism due to chloride penetration reaction in reinforced concrete specimens may occur by means of following reactions.

$$Fe \rightarrow Fe^{2+} + 2e^{-} \quad (2)$$

$$2H_2O + O_2 + 4e^{-} \rightarrow 4OH^{-} \quad (3)$$

$$2Fe + 6Cl^{-} \rightarrow 2FeCl^{3-} + 4e^{-} \quad (4)$$

$$FeCl^{3-} + 2OH^{-} \rightarrow Fe(OH)^{2} + 3Cl^{-}. \quad (5)$$

The current study utilizes 4% sodium chloride solution to investigate the chloride penetration of concrete specimens. Similar to compressive and split tensile strength results, the penetration of chloride ions was more in textile sludge waste incorporated concrete specimens. The increase in replacement percentage of textile waste increases the chloride penetration level of concrete specimens. The inclusion of 3% nanoalumina along with textile sludge waste concrete specimens improves the chloride ion penetration significantly. The presence of mineral constituents present in sludge reacts with chloride and sulphate ions form complex compounds and it deteriorates the concrete structures by increasing the permeability of chloride ions (Tony 2020). Increased chloride ion penetration may also due to the low pH of concrete due to the formation of complex compounds.

Acid attack resistance on concrete specimens

The alkaline characteristic of cement mortar makes the concrete structures more vulnerable against acid attack. When the concrete structures were exposed to acid attacks particularly towards the sewerage systems, the structures may deteriorate. Thus, resistance to acid attack is considered to be significant durability characteristics to be identified. Sulphuric acid usually has a low pH range and it is considered to most destructive among other acids. The sulphuric acid usually reacts with excess portlandite present in concrete during the hydration process and produces calcium sulphate and causes quick deterioration (Meng et al. 2018). The loss in weight of textile sludge and nanoparticles incorporated concrete after immersed in acid for 14 and 28 days were tested. The textile sludge waste and nanoparticles incorporated concrete specimens were cured about 28 days and then submerged in acid to determine the mass loss due to acid attack. Figure 4 shows the mass loss of textile sludge and nanoparticles incorporated concrete specimens submerged in acid for 14 and 28 days. The deterioration of textile sludge waste incorporated concrete was more as compared to conventional concrete specimens. The mass loss of TS-2.5%, TS-5%, TS-7.5%, TS-10%, TS-15% and TS-20% showed 8.6%, 12.1%, 16.5%, 25.5%, 34.4% and 41.7% reduction in mass loss respectively as compared to conventional concrete specimens. The concrete deterioration was high in textile sludge waste incorporated concrete due to low pH of concrete specimens. In general, the pH value of acid influences the concrete deterioration significantly and also due to the presence of excess chemicals constituents present in textile sludge waste (Xie et al. 2018). The presence of cadmium, zinc, lead and other compounds form a film on cement particles retards the formation of calcium silicate hydrate gel. Similar to strength and chloride ion penetration test, nanoparticles incorporation enhances the microstructure thereby provides better resistance to acid attack.

Carbonation test

From a durability point of view, the testing for carbonation is an important laboratory activity. When carbon dioxide

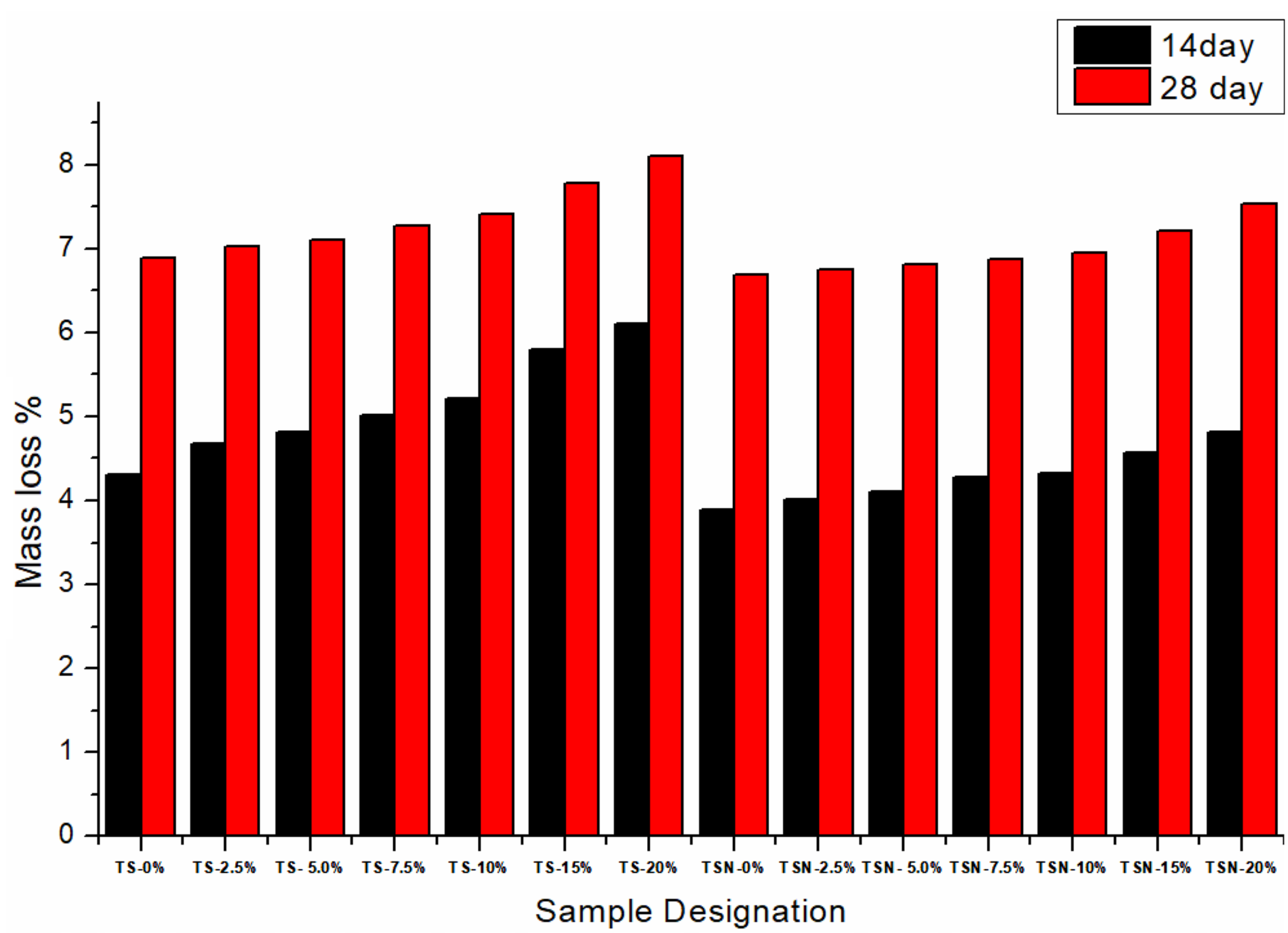

Fig. 4 Resistance to acid attack strength of textile sludge waste and nanoparticles incorporated concrete specimens

gas from the atmosphere penetrates to the concrete surface, it reacts with the calcium hydroxide and forms calcium carbonate by reducing the pH value of concrete. In this research, the concentration of carbon dioxide was kept as 5% and the time of exposure of concrete specimen in carbon dioxide chamber was for 28 days. The relative humidity and relative temperature were kept at 70% and 35-degree centigrade. According to Limbachiya et al. (2012) that, "one week-time exposure of concrete specimen in the carbonation chamber is somewhat equivalent to 12 months exposition under a natural environment of CO_2 concentration is 3.5%" (Limbachiya et al. 2012). The carbonation depth was based on the average results of two opposite sides of the concrete cube and graphs are plotted between different mixes versus carbonation depth in Fig. 5. The diffusion of carbon dioxide on the surface of the concrete depends upon the type of cement, water-cement ratio and degree of hydration (Rath et al. 2022). All these factors also influence the strength of concrete. Hence the rate of carbonation is a function of the strength of control concrete. But this is not always true for blended concrete with supplementary cementitious materials. From Fig. 5, it can be noticed that as the percentage of textile sludge increased, the carbonation depth gradually decreased. The carbonation depth of concrete in which 20% cement was replaced by textile sludge found one-sixth of the carbonation depth of traditional concrete. Also, it can be seen that the highest carbonation depth has control concrete without the addition of nanoparticles and lowest carbonation depth has mix having 20% cement replacement with textile sludge along with 3% nanoparticles. The finer particles of textile sludges were spherical in nature with smooth texture. Hence it required less amount of water demand and provided more lubrication. Hence the extra amount of water came to the concrete surface and filled all the voids and improved the ITZ layer. Also, the textile sludges were alkali in nature and helped to improve the alkalinity of concrete. Hence a strong passivation layer was formed on the top surface which resisted entering both carbon dioxide and water inside the concrete. In this study, both nanoparticle and textile sludge play main role to resist the carbonation reaction. When 3% nano alumina is added to traditional concrete the carbonation depth decreased 25%. This happened due to increasing of the packing density of concrete. The nanoparticles were finer than cement and they filled the voids between the cement particles and increased the packing density of concrete. Due to the high activity and filling effect of nanoscale size of alumina particles, the concrete matrix was highly compacted and resisted migrating both carbon dioxide and water through the concrete surface. It was found that nanoparticles have a better filling effect and higher activity than other types of additives. Due to the increasing the packing density of concrete, the microstructure of concrete has refined to a different extent and the ITZ layer of concrete improved significantly. Hence it was difficult to enter the carbon dioxide gas through the concrete surface. The nano alumina possessed pozzolanic property. $Ca(OH)_2$ crystals were consumed by those nanoparticles and converted those $Ca(OH)_2$ into C–S–H gel. These extra C–S–H gel filled the micropores inside the concrete by decreasing the porosity. Hence the density of the concrete composite increased significantly and more amount of Ca^{2+} ions can exist in the stable hydration products. It was found that there was a lower amount of Ca/Si in C–S–H gel when nano alumina particles were added. That type of C–S–H gel has a capacity to bind more alkali ions increasing the content of OH^- ions. Due to increasing of OH^- ion, the pH value of concrete increased and the carbonation process went slow down.

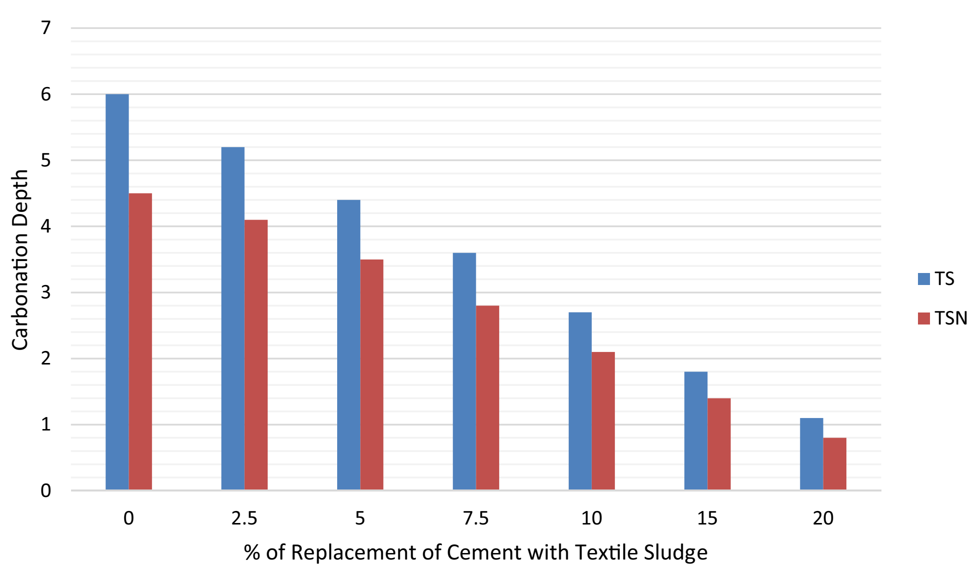

Fig. 5 Carbonation depth of textile sludge waste and nanoparticles incorporated concrete specimens

Conclusion

Based on the investigation, the following conclusions were made:

The results revealed that the concrete strength and durability reduce marginally when 10% textile waste sludge was used as a replacement material for cement. Beyond the replacement of 10% textile waste sludge, there is a significant reduction in strength and durability properties. Combining 3% nanoparticles with textile waste sludge up to a replacement level of 10% enhances the strength and durability properties of concrete specimens. The split tensile and compressive strength of concrete specimens decreases as the percentage of textile waste sludge increases. The textile sludge improved the ITZ layer as well as increased the alkalinity of the concrete matrix whereas alumina nanoparticles increased the packing density of concrete. The inclusion of alumina nanoparticles densifies the concrete microstructure, thereby enhances the compressive, tensile strength and better resistance towards carbon dioxide, chloride and acid attack.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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