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Review Article

Effect of Quality of Fine Aggregate in Strength of Concrete: A Review

Khub Chand Sahu[1#], Alok Krishnan[2], Barkha Gupta[1]

[1,3]M. Tech. Scholar [2]Assistant Professor

Department of Structural Engineering, University Teaching Department, Chhattisgarh Swami Vivekanand Technical University, Bhilai – 491107, Chhattisgarh, India.

Email id: [1#] 998kcs@gmail.com; [2]alokkrishanan@gmail.com; [3]barkhaguptag1997@gmail.com

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Abstract

Background: It is known that concrete is composed of water, cement, and aggregates, out of which the aggregates cover more than 3/4th part alone. The quality of aggregates affects the parameters such as strength, durability, and various characteristics of concrete. In the current scenario, good-quality aggregates are barely available due to their high demand. Aggregates are broadly classified into two categories i.e., Fine and Coarse aggregate. Coarse aggregate majorly obtained from crushed stone by crusher the probability of getting impurities from coarse aggregate to concrete reduces. Fine aggregate may have various impurities such as fines of clay and silt.

Scope and approach: This review paper describes the various impurities and several effects of those impurities in fine aggregate on the strength of concrete. Several experiments are already performed by the researcher main aim is to combine those results output and summarise it.

Key finding and conclusion: There are several standards suggested by Indian Standards if they are within the limits then need not take any action, but the limit exceeds then activities such as the washing of aggregate need to be taken. Impurities like clay and silt (fine particle) affects the strength of concrete and the collapse of the structure.

Keywords- Silt Content, Fine Aggregate, Quality of Aggregate, Strength of Concrete.

1. Introduction

Silt: Particles are smaller than 150µm in aggregate become impurities in concrete because of the high surface area of the particles as well as the majority of them are amorphous [1]. Fine Aggregate (FA) are the aggregates used in concrete whose sizes are smaller than 4.75mm or can be passed through 4.75mm sieve called fine aggregate [2]. Quality of Aggregate suggest in terms of Strong, hard, durable, dense and should be free from impurities is the sign of good quality aggregate [3] & [4].

Strength of Concrete is analysed in terms of compressive, flexural& tensile strength by which we can define properties but in the case of concrete usually considered 28 days compressive strength [1] & [5]. As we all know concrete is the most widely used structural material. The strength of concrete depends on its constituents out of which the aggregates contribute maximum strength and cement only acts as a binder [1], [6] & [7]. Two categories of aggregates are Fine and Coarse [8] & [9]. The fine aggregate fills the voids in concrete and provides a homogeneous mix [10]. The quality of fine aggregate should be of major concern because the compressive strength of concrete is affected by it.

As the majority of rivers in Chhattisgarh for the excavation or mining of sand are controlled by the state government and National Green Tribunal (NGT), Government also restricts the extraction of river sand from the rivers due to environmental factors. Last year Chief Minister of Chhattisgarh restricts the excavation of sand from 10 June 2020 to 15 October 2020 [11]. As a result of the above order by higher authority, the supplier increases the stock of sand by lips and bound beyond the royalty limits [12]. Price of sand soot up from 2200Rs. To 10,000Rs. For each 600sqft quality of sand was also compromised, rock dust and poor-quality sand is used as fine aggregate by the contractors [13].

Suppliers are unable to fulfil the demand of the customer and to get more profit they supply poor quality fine aggregate to the buyer. most construction sites in Chhattisgarh have a deficiency of quality management due to which severe reduction in durability and strength may occur and also can be life-threatening in some situations [14]. The most common impurity in the sand as fine aggregate is silt or clay [15]. The source of impurity can be anything such as poor handling of material at the site or at the origin from where the sand was obtained etc [16]. These both reason is most common all-around Chhattisgarh. While hand mixing smaller sites commonly has a deficiency of inspection by the engineer or supervisor [17] & [18], the ground's impurity at the site can be mixed with concrete while hand mixing by the layman. However, at the site, it seems common to have some amount of impurity in material but the distribution of impurities sometimes may be uneven. Important joints with bad aggregate concrete may lead to drastically drop in the strength of a particular joint but it is a topic that needs deep study and experiments. The Indian standard suggested that the amount of silt content in aggregate should not exceed certain limits because it may cause a bad effect on the concrete [19]. US code also suggested the same but the allowable limits are different in both the codes [20].

A smaller site usually fine aggregate imported one and after over the stock because of the shortage of the storage of material, in such situation testing the aggregate, again and again, becomes a laborious process and as already mentioned due to lack of quality management the contractor uses as it available to them. Silt in concrete aggregate acts as impurity [21]. Hence the strength of concrete reduces [22], not only in normal temperature but also in freezing [23], the durability of concrete also reduces as an increase in impurities [24].

1.1 Sources of Impurities in Fine Aggregate

In a smaller site, the major cause of impurity can be from two sources

- From Source
- At site

From Source: while the extraction of sand from the river at silt deposited location or at over scoured section in the river is the major cause of silt in the sand.

At Site: When Fine aggregate is placed at the location where the water stagnates from various sources deposit silt to the site and that silt becomes impurity to find aggregate while handling fine aggregate by the scrapper that can also scrap ground clay with fine aggregate.

1.2 Indian Standard Tests for Aggregate

As per IS 2386-1963

Part 1 for Particle size and shape

Part 2 for Estimation of Deleterious material and organic

Part 3 for specific gravity, density, voids Absorption, and bulking

Part 4 for mechanical property

Part 5 for Soundness

Part 6 for Measuring Mortar making property of Fine aggregate

Part 7 for Alkali Aggregate Reaction

Part 8 for Petrographic Examination

Here we Discuss the test for silt content in fine aggregate according to IS 2386-1963 part 2 the maximum allowable silt content in any sand sample which is going to be used for construction should not exceed standard limits [25].

2. Literature Review

Bashir and Kour [19] studied Jhelum's sand with varied silt content from different locations in different casted cubes to find out the consequence of silt content changes influencing the property of concrete strength. They found that the strength decreases with the increase in silt content. 1.85% of the increase in silt in the sand can cause a 1.4% reduction in strength. Flexural strength is also reduced by some amount as an increase in silt content [19].

Gashahun [26] evaluated the allowed minimum siliceous content and organic impurities in sand provided at Debre Markos and its environs was 5.53 percent and organic plate number 3, respectively. With the increase in parameters, the strength at 28 days of concrete was not achieved. If the impurities in sand is not addressed properly it will lead to structure failure with loss in concrete's compressive strength. It was suggested that if the amount of silt is more than the standard limits then actions such as washing should be taken before use [26].

Olanitori and Olotuah [27] took different clay mixed samples of fine aggregate (sand) and suggested that rock dust can be mixed with the sand if clay content is more in the sand. On testing cubes in universal testing machine (UTM), it was found that increase in clay content impurities the strength of concrete declined simultaneously. Based on study The Nigerian Standard Organisation specifies an acceptable maximum percentage of clay in the sand of 3.4 percent, not 8 percent (as per standards) [27].

Olanitori and Makanju [28] proposed if clay/silt was above (3%) in the sand the concrete's strength is affected. On the basis of impurities in sand the mitigation procedure will raise the cost of producing 1m^3 of concrete by 22.5 percent if the washing technique is employed and in case of cement increment method it was found between 2.22 - 27.75 percent [28].

Savitha [29] worked in material quality to be used for construction quality affirmation of building materials and their small and extended effects on structures. At the point when development is arranged structure materials ought to be chosen to satisfy the capacities anticipated from them. Laboratory testing of materials is vital which will assure the construction materials quality for the development of the nation. The objective of testing development materials is to confirm the client on the dependability of the materials [29].

Cho [30] estimated for short-term durability of concrete when silt fine concentration is over 5%, the rapid chloride permeability test (RCPT) showed concrete has a greater chloride ion penetrability. Further after comparing RCPT and compressive strength data, silt fine content has an impact on the durability of concrete, especially when it exceeds also migration coefficient of chloride ion obtained from accelerated chloride migration test (ACMT) got hiked. Furthermore, the proportion of cumulative incursion pore volume at a pore radius higher than 100 nm follows the same pattern as the ACMT findings [30].

Haque [31] studied the potential impacts of silt content on all-in-aggregate strength properties. When compared to silt-free concrete, the increase in silt up to 5% enhance the workability but declined the concrete's strength. As per testing it was found that 28-day strength of continuously air-cured concrete cylinders was only 28 and 79 percent of the of silt-free concrete at 1 and 5% silt content (percent passing 75 µm), respectively [31].

Ayodele, et al. [32] studied on the effect of silt or clay impurities in fine particles on compressive strength of concrete. The incorrect bonding of silt/clay components caused loss in compressive strength. With each passing day of curing, the material compressive strength improves. The sieve examination revealed that fine aggregate samples from various places, except quarry stone dust, included silt/clay percentage, which has a technical impact on concrete strength [32].

Felekoglu [33] compared fines-rich and fines-poor sands in self-compacting concrete (SCC) performance and concluded that for a specific slump-flow of SCC, crushed limestone sand with clay powder (CLC) resulted in a loss of strength and an increase in the amount of additive required. The adsorption value of methylene blue is an excellent predictor of sand-clay content. This test technique may be used to determine the best sand type for integrating significant quantities of fine components [33].

Obafaye, et al. [34] discussed the acceptance limit of silt and clay impurities in concrete made using Abuja Sand. Concretes compressive strength falls as the percentage of silt/clay component rises. This decrease in compressive strength is caused by poor silt and clay material bonding, as well as a faster water absorption rate in concrete with increased silt and clay concentration. The author also recommended that all fine aggregates in Abuja and the surrounding area with more than 7% silt and clay concentration are not recommended for concrete production. The 7 percent recommendation is based on compressive strength (average) findings attained at 7 and 28 days after partial replacement with processed silt and clay of 6 percent and 8 percent, respectively [34].

Yool, et al. [35] investigated methylene blue dye test for problematic clay in aggregates for concrete and mortar. They concluded that in 1:5 ratio, kaolinite & smectite are linked to a decrease in mortar compressive strength. Smectite reduces compressive strength five times more than an equivalent amount of kaolinite in mortars with the same workability. Kaolinite lowers compressive strength by 2% for every 1% accumulation of clay by mass of cement. Smectite diminishes compressive strength by 10% for every 1% increase in clay by mass of cement [35].

Table 1: Variation in silt content and its effect on strength based on various literatures reviewed.

Sl.No.	Sample source/Name	Silt Content (%)		Methodology	Effect on Strength	Key Findings	Reference
1.	Qamarwari Lasjan Pampore.	6.65 4.65 4.8		Flexural, Split tensile, and compressive strength test for varying silt content.	Qmarwari sample shows a significant decrease in strength as compared to Lasjan and Pampore.	As silt content increases the strength of concrete decreases.	[19]
2.	The sand was used from seven different places in Ethiopia.	Varies from 5.9 to 12.18		Fresh and hardened concrete properties were tested.	The compressive strength of concrete failed to match the desired value when the silt content increased.	For construction sand available at Jigga and Kuye should be washed thoroughly.	[26]
3.	Ten (A to J) samples from different locations in Nigeria.	0.96 1.45 2.63 3.00 3.22	4.89 7.01 8.00 12.07 12.63	150 cubes were tested under UTM conforming to British standard 1881, parts 108 & 116.	With the increment in clay content, there was a decrement in compressive strength.	The extreme clay percentage is 3.4% beyond this stone dust should be mixed.	[27]
4.	Nigeria	Silt varies linearly from 0 to 10 (sample A1 to A11).		Field settlement test prescribing mix method with 1:2:4 mix ratio & w/c 0.55.	For 0 and 10 percent silt fines upper and lower limit of compressive strength was 22.35N/mm^2 & 10.15 N/mm^2.	The destructive impact has been seen in concrete for silt content of more than 3%.	[28]
5.	River sand of Taiwan.	Varies from 0 to 9		Mixture proportion, ACMT, RCPT, and pore structure observation.	Decrement in compressive strength from 3-5 MPa for increment from 7-9 %.	For silt content over and above 5% durability of concrete is affected.	[30]
6.	Naas River, Australia.	5 to 10		Ultrasonic pulse velocity test on cylindrical and cubic moulds.	Concrete's compressive strength is affected by silt fraction in it.	An increment in silt fines resulted in shrinkage, cracking in concrete.	[31]
7.	Five separate areas in Ado-Ekiti, Ekiti State Nigeria.	A B C D E	0 6.69 7.01 8.5 9.88	Slump test, compressive strength test & sieve analysis.	Improper binding of silt materials resulted in decreased compressive strength.	Inadequate aggregate bonding or too much water in the mix compromises durability and strength.	[32]
8.	Washed natural sand & crushed	12 to 12.5		Particle size distribution and	For a specified slump flow of	Crushed sand rich in fines (15-	[33]

	limestone sand, crushed limestone sand with silt powder and crushed limestone sand with clay powder sand.		properties of fresh and hardened concrete were examined.	self-compacting concrete, crushed limestone sand with clay powder caused strength loss and increased additive need.	20 % by weight) can be utilized to improve fine particles of SCC.	
9.	The river bed sourced Abuja (fine aggregate).	Varies from 2.9 to 15.38	Slump test, compressive strength test & sieve analysis.	Water absorption rate increases for more silt and clay content and compressive strength falls.	Cubes cracked completely with over and above 10% processed silt content on load application.	[34]
10.	Laporte Absorbents, Mineral Colloid montmorillonite (smectite), and Rem-blend China clay were the clay minerals utilized (kaolinite).	Pure sand, Sand with 1% & 2% silt, Sand with 1% & 2% kaolinite and Sand with 1% & 2% smectite.	Consistency test, flow table test, and methylene blue adsorption test.	Strength reduction due to smectite is 5 times that of strength reduction due to kaolinite.	The loss in compressive strength of mortar caused by kaolinite and smectite is on the order of 2% & 10% for kaolinite and for smectite.	[35]
11.	Yellow River in Shandong, China.	Varies from 0 to 40	Triaxial shear experiments.	Higher silt content could potentially reduce the shear strength.	For silt content hiked by 10%, the strength parameters pulled down by 12%.	[36]
12.	Dongying, China.	20	The electronic UTM for the compressive strength test.	Compressive strength, flexural strength, and modulus of elasticity all pulled down as silt concentration increased.	The addition of silt to foamed concrete changed the structure of the air voids.	[37]
13.	Njiru, Kitengela, Mlolongo, Kawangare, Dagoretti Corner, Kiambu, Kariobangi, and Thika are eight sand supply stations in Nairobi City Country, Kenya.	Maximum clay and silt content was 42 & 3.3.	Compressive strength testing, slump testing, and Laser Diffraction and Particle Size Analysis.	The presence of impurities in sand reduces compressive strength and causes the structure to collapse.	The degree of contamination in sand obtained directly from the source (river, pit, or sea) to sand sourced at supply points (market locations) should be checked.	[38]
14.	Silt samples were taken from a variety of sources. King	6 clays were combined with the following	Effect of curing in yield strength, the permeability coefficient of	It's reasonable to infer that the presence of silt in clay enhances	Due to thorough interaction between cement and soil particles	[40]

	Mongkut's University of Technology North Bangkok of Natural Clay provided samples of natural clay. (Bangkok's KMUTNB).	quantities of silt: 0:100, 15:85, 30:70, and 45:55 silt to clay.	clay, and recompression index of natural clay.	the yield strength of natural clay because of its hardness and durability.	at 28 days than at 7 days, the yield strength of fine-grained soil with cement concentrations of 7.5 and 15% improved as the curing period increased.	

Zhang, et al. [36] evaluated triaxial shear behaviours of silt-based foamed concrete in an experimental setting. Foamed-based concrete's shear strength and compressive strength were tested via triaxial test for different silt fines content and wet densities. For an increase in 10% of silt content, the residual strength and peak strength decrease by a mean value of 12.3% and 16.8%. Similarly for an average increase in density of 100kg/m^3 the residual strength and peak strength increase by 0.62MPa and 0.82MPa. It has also been evaluated by the author that if silt content is increased the pore size of foamed concrete is also increased due to which strength is reduced [36].

Zhang, et al. [37] analyzed soil type and silt content on silt-based foamed concrete with different densities. The mechanical and physical characteristics of foamed concrete was examined based on silt and coarse particle content. The mechanical qualities of concrete deteriorated when cement was partially replaced by silt also its concentration increases. For the same density and silt concentration, an increase in compressive strength is twice as much as an increase in coarse particle content. To make foamed concrete more cost-effective and high-quality it is recommended to use foamed concrete with a coarse particle content of 40%, a wet density of 700 kg/m^3, and a silt content of 40%, taking into account material performance and cost [37].

Ngugi, et al. [38] investigated the superiority of building sand obtained from eight delivery points in Nairobi County and its surroundings, as well as the consequences of these sand impurities on concrete's compressive strength. Organic impurities varied between 0.029 to 0.738 photometric ohms in the sand samples (unwashed), whereas silt and clay concentrations ranged from 42 percent to 3.3 percent. At 28 days, 38% of the cubes (concrete) made from sand containing varied sand impurities failed to meet the necessary strength of 25MPa because the presence of these impurities had a considerable impact on concrete's strength, hence it must be avoided throughout the production process, necessitating the use of sand that is free from impurities [38].

Sun, et al. [39] worked on adfreezing strength at the silt concrete interface also orthogonal direct shear test and orthogonal tensile tests were done at different water content, dry density, and temperature. Water content and temperature play an important role in determining the tensile and shear strength of the silt concrete contact surface. The moisture content of the silty soil utilized in the test was designed for the ideal moisture content of the soil samples, which were 13, 16, 18, and 20 percent. With the absolute value of temperature between -2 and -6ºC, the tensile strength of the contact surfaces for the four moisture content samples increased sharply. Below -6ºC, the rate of tensile strength growth reduced substantially [39].

Teerawattanasuk and Voottipruex [40] looked upon the connection between fine-grained soil silt and clay proportions and the technical attributes of the soil (fine-grained) after it had been equilibrated with cement. Basic features of clay samples, in a laboratory test, parameters such as liquid limit, plastic limit, specific gravity, and particle size distribution were measured. The specimens with a 55:45 ratio of clay to silt and 15% cement yielded the highest yield strength of 800kPa. The recompression index of Bentonite0.50+ Kaolinite0.50 (28 days) decreases as the amount of silt and cement is increased. Between the compression and recompression indices, empirical relationships have been discovered. [40].

3. Key Finding from Review

- Impurities such as clay and silt in fine aggregate directly affect concrete's strength.
- Testing should be done before the use of materials.
- In case of impurities like silt exceeds the limit then washing should be done before use.
- It is better to use good quality aggregate instead of treating it.
- Based on literatures reviewed following are the measures to improve the quality of fine aggregates.
    - Proper quality inspection is necessary not only for fine aggregate but for all the construction material especially for those who govern the strength of the structure.
    - Sand and rock dust are commonly used fine aggregate but may contain very fine particles such as silt and clay when they exceed the allowable limits special measures must be taken to remove them.

3.1 Research Gap

All literatures were about silt content and its direct effect on strength and durability characteristics of concrete but none of the literatures shows experimental work of silt content including different admixtures such as plasticizer retarder etc.

3.2 Effects of silt content in sand

Several experiments are already conducted by the researchers and based on their results following points can be drawn:

i. Silt can reduce the strength of concrete
ii. Increases water demand
iii. Reduces workability
iv. Reduces Durability
v. Sometimes increases Drying Shrinkage

3.3 Suitable Methodology

The idea to write this review paper has been put into action with the help of journals available at Elsevier, Springer, Science Direct, News Articles, Google Scholar, etc. The papers have been selected based on silt content and strength parameter. The articles were studied thoroughly and have been summarised to get the result and conclusion. Determination of silt content in fine aggregate is very essential because it hinders the compressive strength of concrete. Various experiments and research work has been done to evaluate the silt fines in aggregates.

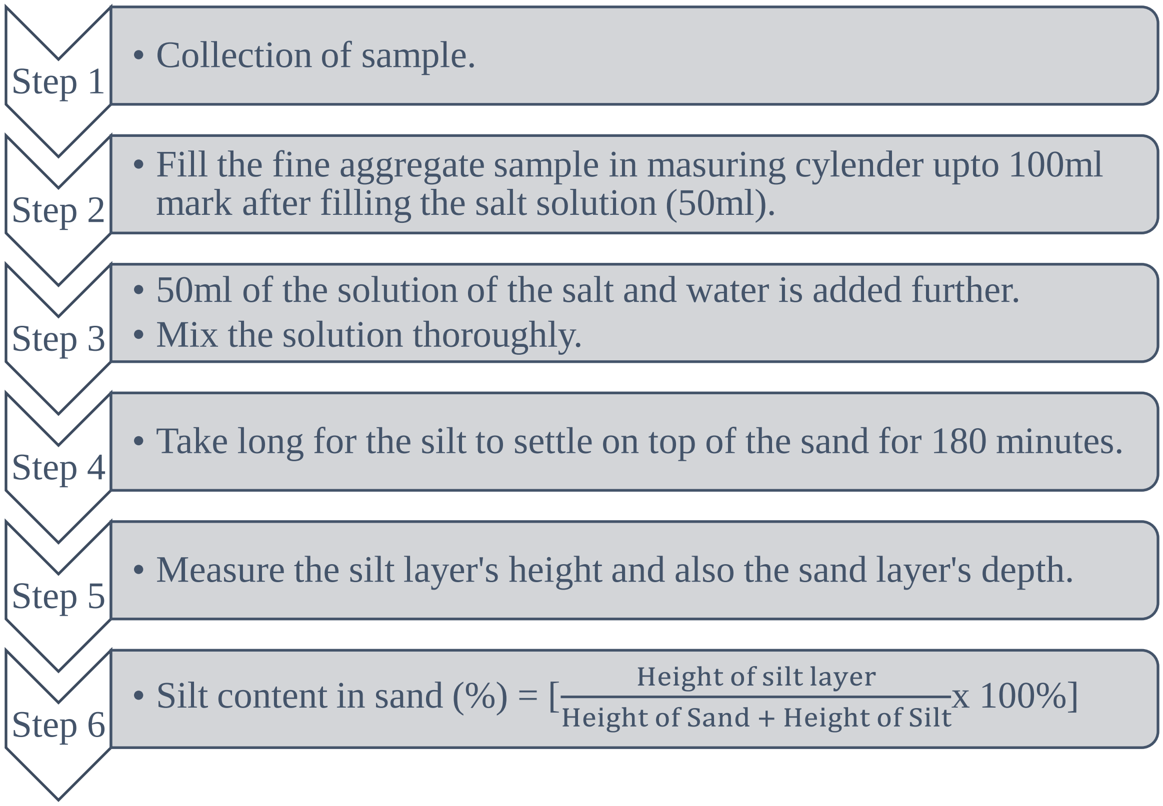

Fig. 1 Suitable Methodology

Most of the authors have adopted this methodology for the determination of silt content in fine aggregates (Figure 1). A glass measuring cylinder 250 ml (pycnometer can be taken), saltwater is used to fill the cylinder (concentration 1 tea-spoon common salt for 570ml of water), fill the water up to 150ml mark after filling the sand up to 100ml mark but before that fill saltwater 50ml. Mix the specimen thoroughly and after three hours take the measurement and calculate the volume of silt and clay by the simple mathematical formula [25].

Conclusions

The aim of this study included the determination of the vital factors of silt impurities which influence the concrete's compressive strength and statistical analysis of data presented in the literature, which enabled us to standardized the link between the strength loss of concrete and quality of FA used in its manufacturing. The important inferences drawn from this study are given below.

- Impurities in fine aggregate reduce the strength. With an increase in silt content, concrete allows chloride and sulphate to move hence durability is also reduced.
- Few impurities such as clay and silt require more water so workability also decreases as the increase in impurities in aggregate. It is suggested that aggregate with impurities should be avoided as far as possible, in case of lack of availability of the good quality of aggregate washing of aggregate should be done before use.
- Washing of fine aggregate is done directly by spraying water for less silt content or by water drum for more silt content. The blowing of air cannot be adopted to blow impurities it is only effective in coarse aggregate.
- Water cement ratio: in general, 38% of water by weight is required for complete hydration and workability of concrete. As the silt has more surface area it requires more water and the actual

water content (38%) required for complete hydration of cement is insufficient hence strength is minimized.

- Workability: with the increase in silt fines over 3-5% the workability reduces due to absorption of water by silt fines hence concrete shrinks.
- Durability: the durability of concrete reduces with an increase in silt content is above 5% as a result of improper binding between particles and concrete becomes porous.
- Strength beyond 5% of silt fines the compressive strength of concrete reduces drastically.
- Shrinkage and Cracking: increase in the percentage of silt fines beyond 3-5% causes the formation of voids and thereafter causes shrinkage and cracking in concrete.
- Organic contaminants have harmful effect on the strength of concrete as they tend to hinder the bond of concrete particles.
- Both smectite and kaolinite are linked with the reduction of compressive strength of mortar. The loss of strength due to smectite is double that of loss of strength due to kaolinite.

From the above-mentioned points, it can be inferred that presence of impurities in FA leads to overall damage to concrete and structure as well. As per the literatures reviewed it can be suggested that silt content above 3-5% lead to undesirable properties in concrete therefore, the impurities in FA should be kept as least as possible.

Conflict of interest

The author declares no conflict of interest.

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