

Experimental Study on Plastic Shrinkage of M-sand Concrete

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Due to faster dwindling of river sand, nowadays, the use of alternative aggregates such as manufactured sand (M-sand) is inevitable in concrete. Though the positivity of M-sand is reported in many literature, few literature report the drawback of angular shape and gradation of the M-sand in altering the properties of cement/concrete. Especially, the properties at fresh state are affected by the size, shape and volume of the fine and coarse aggregates. The properties at fresh state include plastic shrinkage, if unattended this will lead to durability issues. Most of the studies concentrate on strength parameters and influence of M-sand on properties such as plastic shrinkage is rarely addressed. In order to consider this important property, in the present study, the influence of M-sand on plastic shrinkage is investigated. The strength and plastic shrinkage properties of various mixes with M-sand and river sand are compared. It is found that the angular shape and coarser gradation of M-sand helps in reducing the plastic shrinkage compared to river sand. Further, it is found that when using M-sand as fine aggregate in the concrete, the composition of the fine and coarse aggregate is same that has positive effect on the plastic shrinkage. Hence, this study shows that M-sand can be considered as a successful alternative, not only in strength but also in controlling the plastic shrinkage.

Keywords: Aggregate, Durability, Fly ash, River sand, Steel fibre

Introduction

Due to high demand and scarcity of natural sand, nowadays, it is inevitable to look for an alternative for the fine aggregate in concrete. Different types of alternative aggregates are nowadays emerging to address the problems arise due to the demand of natural sand.^{1,2} Manufactured sand (M-sand) is one such alternative, the usage of that keeps increasing in the concrete industry at present.³ The characteristics of concrete made of M-sand is different from that of river sand owing to the variation in shape, gradation, composition etc. Due to the wearing and tearing of particles during transportation by wind and water to a long distance, the surface of the river sand is rounded off whereas the shape of M-sand is angular as it is prepared artificially by crushing the rocks. Further, M-sand has the chemical characteristics of the parental rock that differs based on the origin.^{4,5} Angular shape of M-sand particles compared to rounded river sand yield a low-density granular packing, higher friction angle and low strain stiffness.⁶ Better interlocking of the M-sand particles result in the dense granular packing thus improving the strength of concrete.⁷ However, it is also reported

that for the mixes with river sand and M-sand having same water content, angular M-sand particle increases the water demand thus lowering the workability compared to concrete made of river sand.^{8,9} The compensation for increased water demand is achieved by the increased water to binder ratio or by the use of superplasticisers.¹⁰

Shrinkage leads to development of cracks in the structure resulting in loss of integrity and reduced service life. Hence, like many other properties affecting structural integrity, shrinkage property of concrete is also of importance as it affects the durability of concrete.¹¹ Shrinkage of concrete occurs mainly at two stages: early age (at fresh state) and later age (at hardened state).¹² At various stages of cement hydration in concrete, the volume changes happen and are referred by different names as a) drying shrinkage b) chemical shrinkage c) thermal shrinkage d) plastic shrinkage e) autogenous shrinkage f) carbonation shrinkage etc. Among the types of shrinkage reported, plastic, chemical and autogenous shrinkage are formed at fresh state. Evaporation of bleed water is the main reason for the plastic shrinkage, whereas change in volume of hydration products than the initial reactants (cement and water) is the reason for autogenous and chemical shrinkage. Many factors such as water to binder ratio,

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type and replacement level of mineral admixtures, ambient conditions etc. affect the shrinkage of concrete. Particularly, the plastic shrinkage that happens immediately after casting is affected by the gradation of aggregates and morphology of the aggregates used in concrete besides all other factors mentioned earlier.¹³ Higher the surface area of the aggregate, more is the requirement of water for aggregate. Owing to the variation in the gradation and shape, the use of M-sand is different from river sand in concrete and greatly influences the plastic shrinkage property. The specific surface area of aggregate is one important factor that controls the volumetric changes arising due to shrinkage.¹⁴⁻¹⁶ Most of the studies reported on shrinkage are pertaining to river sand and studies using M-sand and slag fine aggregate are very few.¹⁷

Works have been carried out extensively to understand the influence of M-sand on the properties of concrete.^{18,19} Shen *et al.*¹⁸ studied the characteristics of M-sand such as shape and surface properties and its behavior in concrete and reported that the shape of the particle and surface texture has less significance on the behavior of concrete than the gradation of M-sand. They concluded that the modification in the production process brings M-sand of proper gradation and shape to have better behavior in concrete than river sand. Prakash *et al.*¹⁹ studied the comparison of mechanical properties of M-sand and river sand concrete and concluded that the mechanical properties of M-sand concrete are better than the river sand concrete. Donza *et al.*⁸ investigated the effect of M-sand on the mechanical properties of concrete. They reported the advantage of M-sand in enhancing the interlocking between the paste and aggregate for the improvement of the compressive strength. Rheological properties of the mortar containing M-sand is studied and reported that shape of the aggregates mainly influences the plastic viscosity of the mortar. Sirajuddin and Gettu²⁰ studied the influence of mineral admixtures on early age cracking and concluded that the inclusion of mineral admixtures increases the susceptibility to cracking owing to the higher fineness of binder.

Mechanism of Plastic Shrinkage

Plastic shrinkage is generally measured at two stages: a) When the concrete is still plastic, just after finishing and b) Early hardening, several hours after finishing.²¹ Mainly, the mechanisms of shrinkage at plastic state is physical, hence, the chemical changes

in concrete have minimal influence on the plastic shrinkage.²² If the bleeding rate is higher than the evaporation rate, the water accumulates and forms a thin layer at the concrete surface. When bleeding rate is lower than the evaporation rate, the water film on the surface starts to decrease, until it completely disappears and the concrete surface is dry²³ and forms the surface cracks. This surface cracks called as plastic shrinkage cracks are typically observed on the large horizontal surfaces exposed to the atmosphere. The depth and width of the plastic shrinkage cracks differentiate it from other cracks formed during the early ages. Plastic shrinkage cracks are typically 2 to 5 cm in depth and its width measures up to 0.3 cm.²³ Lengthwise it extend for several cms (5-300), generally following the crows-foot pattern. These cracks normally forms in the concrete at fresh state, before the aggregate particles develops bonding with the mortar. Due to this reason, the cracks tend to develop through the easiest path along the edges of aggregates or reinforcing bars and never break through the aggregate particles.

Early Age Cracking

In concrete, occurrence of early-age cracking is common and it does not lead to failure of structures. Though the early-age cracking is not detrimental to the structure, it affects the aesthetics and when unattended, in the long run, it allows the ingress of water and chemicals into the structure leading to the failure of the structures. Hence, cracking developed during the fresh state in concrete causes a significant damage to concrete structures as it may propagate leading to reduced service life. The ingress of aggressive chemicals such as chlorides and carbonates induce the corrosion of steel reinforcement in concrete and reduce the service life of the concrete structures. Especially in some special structures like nuclear power plants, nuclear containment vessels, water reservoirs, waste disposal structures etc. cracking will lead to leakage of harmful chemicals to the environment, hence not allowed. This shows that early age cracking is as important as that of the cracking at hardened state to address.

Research Significance

Aggregates play a major role in restraining shrinkage in cement mortar or concrete. The shrinkage measured in mortar/concrete is actually due to the shrinkage of cement paste and its interaction with inert aggregates. Hence, the aggregates, in

general, help in reducing the shrinkage of concrete by functioning as an internal water reservoir. Further, the higher stiffness of aggregates compared to cement paste helps in restraining the shrinkage. This study attempts to investigate the influence of M-sand on the plastic shrinkage of concrete. As the shape, size and gradation of M-sand is different from the natural aggregate (river sand), M-sand influences the shrinkage properties in a different way compared to river sand. Hence, this study finds significance in understanding the effect of M-sand on plastic shrinkage of concrete.

Materials and Methods

Cement and Class F fly ash obtained as per the specification of IS 12269 (2015) and ASTM C618 (2009) respectively are used in this study. Table 1 shows the chemical composition of cement and fly ash used in this study. As per the chemical composition of fly ash, the type of fly ash used is Class F.

Two different types of fibers (basalt and steel) are used in plain concretes (without fly ash) to evaluate the efficiency of fibers in mitigating the cracks. Basalt fiber of 24 mm length and 13 μm diameter is used in this study. Steel fiber of 13 mm length and 0.2 mm is used. The source of M-sand used in this study is from crushed granite. As gradation of fine aggregate has major influence on the shrinkage properties, the particle size analysis of river sand and M-sand has been carried out and the results are presented in Fig. 1. The physical properties of fine aggregates are given in Table 2.

The sieve analysis plot of M-sand trials shows the well distributed gradation over the river sand. Trials have been conducted to develop concrete mixes with two different water-to-cement ratios of 0.45 and 0.50. Though there is a variation in the water absorption of

river sand and M-sand, the aggregate is used in as-received state to investigate the effect of water demand of river sand and M-sand on plastic shrinkage. Water correction is not made to use the aggregate in saturated surface dry condition. In the mixtures presented in Table 3, M1 to M6 are made of Ordinary Portland Cement (OPC) and M7 to M9 are made of Portland Pozzolana Cement (PPC). M1, M3 and M5 are the concretes made of river sand and M2, M4 and M6 are the concretes made of M-sand. M1 and M2, M3 and M4, M5 and M6 are almost the same mix proportion with river sand and M-sand, hence, can be compared.

Further, Ordinary Portland Cement (OPC) based mix M6 is replaced with 0%, 15%, 25%, 30%, 35% and 50% of fly ash and designated as M0, M15, M25, M30, M35 and M50 respectively. The details of the mixtures with river sand and M-sand are presented in Table 3. Two different dosages of basalt (0.1% and 0.2%) and steel fibers (0.05% and 0.1%) are attempted in this study. With the higher dosage of basalt fiber (0.2%), no crack formation is noticed in the mixtures. In order to investigate the efficiency of fiber in arresting shrinkage cracks, basalt fiber (0.1% by volume of concrete mix) is used. However, in the mixtures with steel fiber, decrease in width of crack is observed in both 0.05% and 0.1%.

Shrinkage Apparatus

The mould for shrinkage measurement is made using acrylic sheets with the dimensions as specified

Element Oxides	Cement	Fly ash
CaO	64.1	3.61
SiO ₂	21.00	53.9
Al ₂ O ₃	5.10	25.5
Fe ₂ O ₃	3.10	7.56
MgO+ MnO	2.50	1.15
SO ₃	2.20	1.03
K ₂ O	0.70	2.11
Na ₂ O	0.30	1.02
Chloride	0.03	—
Insoluble	0.30	—
Loss on ignition	0.60	1.03

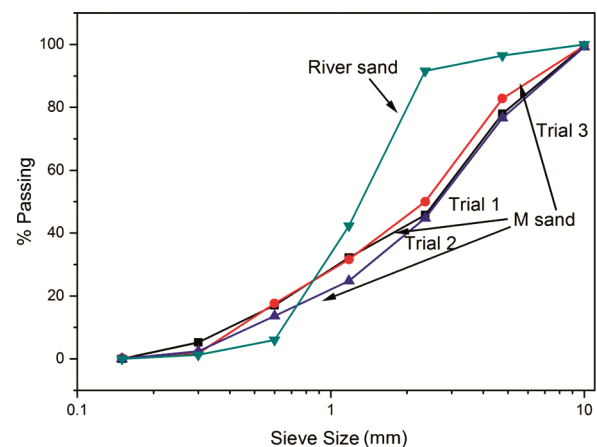


Fig. 1 — Particle size distribution of M-sand and river sand

Properties	River sand	M-sand
Specific gravity	2.7	2.6
Fineness Modulus	2.7	3.2
Water Absorption	2.2	4.4

Table 3 — Mix proportion details of Concrete Mixtures

Material	M1 (R)	M2 (M)	M3 (R)	M4 (M)	M5 (R)	M6 (M)	M7	M8	M9
	PPC+M-sand								
Cement	394	394	413	413	372	372	413	394	372
Fine aggregate	668	668	738	811	752	827	811	668	827
Coarse aggregate (10 mm)	596	596	523	487	533	497	487	596	497
Coarse aggregate (20 mm)	596	596	523	487	533	497	487	596	497
Water	194	194	186	186	186	186	186	194	186
w/c	0.5	0.5	0.45	0.45	0.5	0.45	0.45	0.5	0.5
Paste Volume	588	588	599	599	558	558	599	588	558



Fig. 2 — Mould for Plastic shrinkage testing

in ASTM Standard (ASTM:C1579 (2013)).²⁴ Length of 560 mm, depth of 100 mm and width of 355 mm as shown in Fig. 2 are the dimensions of the apparatus. To stimulate shrinkage cracks, totally three stress risers (two end restraints of 32 ± 1 mm is placed at 90 ± 2 mm from either ends and a stress riser of 63.5 ± 1 mm high at the center) are placed as shown in Fig. 2.

Test Procedure

Evaporative potential of the surrounding atmosphere is considered as significant factor for the cause of plastic shrinkage. A minimum of 1kg/hr/m^2 evaporation rate is prescribed by the ASTM C1579 (2013) for conducting the test. For simulating the condition favorable for the plastic shrinkage crack, an environmental chamber with internal dimension of $100 \times 100 \times 50$ cm is designed. The chamber has provisions to set the temperature and relative humidity ranging from ambient temperature to 50°C and 30% to 60% respectively. Higher rate of evaporation within the environmental chamber is maintained by the horizontal blower. Velocity range of 0.5 to 5 m/s can be generated using the blower.

Results

As compressive strength is considered as the basic property for the concrete, firstly, the concrete mixtures made with OPC and PPC (M1 to M9) are tested for their compressive strength. The compressive strength obtained for all the nine mixtures are plotted and presented in Fig. 3. Comparing the compressive strength of mixtures M1 and M2, M3 and M4 etc., it is observed that the

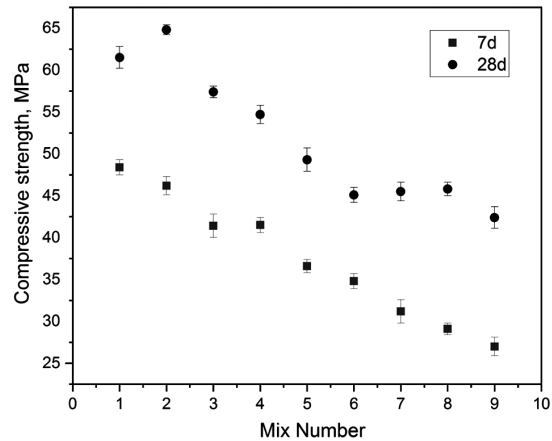


Fig. 3 — Compressive strength of concretes with various mix proportion

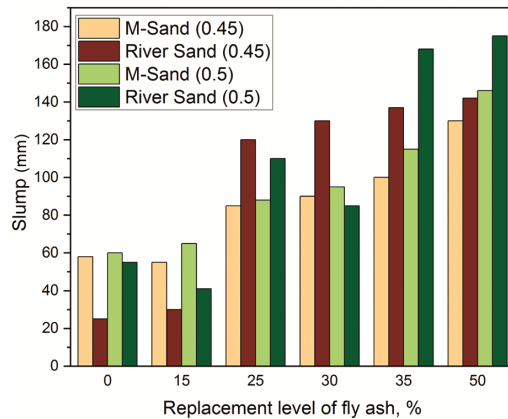


Fig. 4 — Slump values of fly ash mixtures

compressive strength is not significantly affected by the use of M-sand as the fine aggregate used in concrete.

Further, in order to study the influence of fly ash on plastic shrinkage of concrete, M6 with low binder content is taken as the reference and mixtures are developed by replacing cement with 0%, 15%, 25%, 30%, 35% and 50% of fly ash. Two different water-to-binder ratio of 0.45 and 0.5 are used. At fresh state slump values are measured for river sand and M-sand concretes and results are presented as shown in Fig. 4.

For the easy placement and workability, often more amount of water is needed than it is required for the hydration process. When excess water is added for improving the workability, the loss of excess water leads to the reduction in the volume at fresh state causing plastic shrinkage. Hence, the workability and shrinkage can be correlated. Except for plain concrete and 15% FA replaced concrete, Fig. 4 shows that the river sand mixtures are having better slump than the M-sand mixtures. As expected, high-water absorption of M-sand reduced the slump in M-sand concretes.

Further, to investigate the influence of fly ash on compressive strength, river sand and M-sand concrete with various replacements of fly ash are made. Compressive strength of river sand and M-sand mixtures at 7 and 28 days are shown in Fig. 5. It is noticed that the compressive strength of mixtures with M-sand is less compared to river sand mixtures at both 7 and 28 days. However, in the mix with 0% fly ash, the strength is not affected. This observation in the results questions the compatibility of fly ash and M-sand. In Fig. 2, mixtures M7 to M9 made of

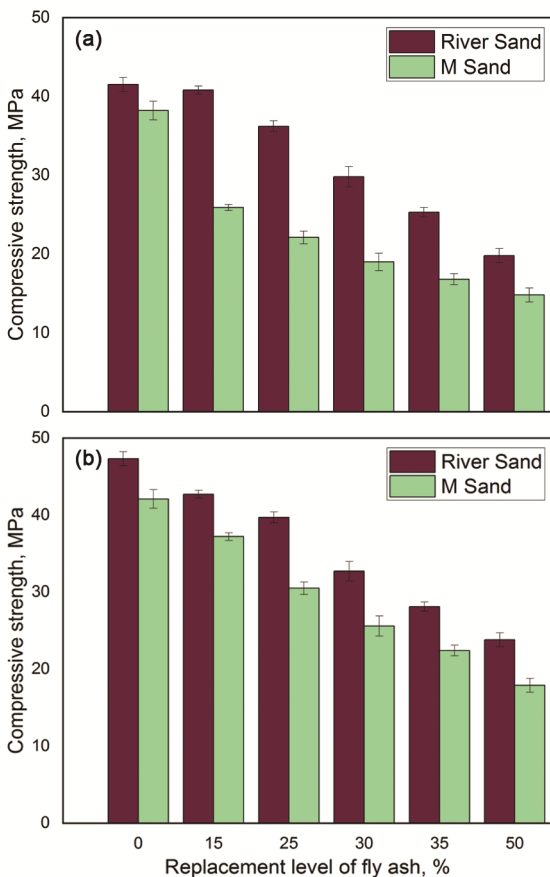


Fig. 5 — Compressive strength of fly ash concrete (a) 7 days, and (b) 28 days

M-sand also showed that the same mix with PPC results in the reduced strength.

Crack Analysis

The plastic shrinkage can be measured using the development of crack width when concrete is in fresh state, time when first crack initiates, rate of evaporation etc. As a first case, crack width and time of first crack measured in this study are analyzed to investigate the extent of plastic shrinkage in concrete. The cracking data observed during first 5–6 hours of casting is considered to be critical for the measurement of plastic shrinkage.^{25–27} Typical crack pattern observed for river sand concrete from 0 to 6 hours is shown in Fig. 6. Observations have been made for every 30 minutes and widths are measured and recorded.

The crack width measured after 6 hours of casting for all the mixtures are presented in Table 4. In the previous work carried out by the authors,²⁷ the crack

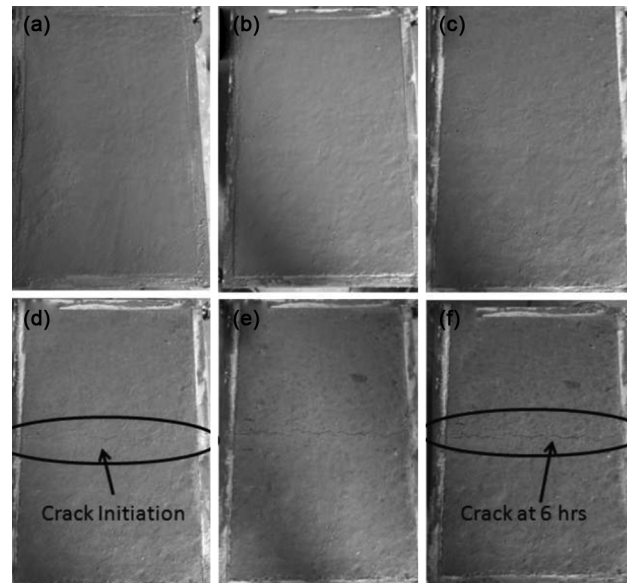


Fig. 6 — Crack formation in river sand mixtures at (a) 0 hour, (b) 30 minutes, (c) 60 minutes, (d) 150 minutes, (e) 240 minutes, and (f) 360 minutes

Mix	0.45		0.5			
	RS	MS	Change in crack width (%)	RS	MS	Change in crack width (%)
Control	2.0	2.12	6	2.2	2.24	1
15FA	2.5	2.12	-15	2.3	2.04	-11
25FA	2.2	1.72	-21	2.3	1.52	-34
30FA	2.2	1.44	-34	2.2	1.88	-15
35FA	2.7	2.00	-26	2.9	1.56	-46
50FA	2.5	1.72	-31	2.3	1.64	-28

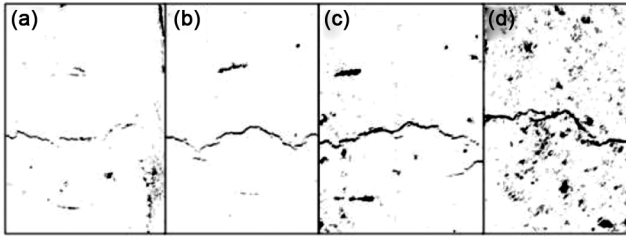


Fig. 7 — Image analysis of typical crack in river sand mixtures at different timings

width is measured by using image analysis technique for the accuracy.

The same procedure is adopted for the crack width measurement in this work. Typical image is presented in Fig. 7 for the conversion of original image to binary image for measuring the crack width. The measured crack widths (Table 4) from M-sand and river sand mixtures using image analysis showed that the widths measured in M-sand mixtures are lesser for both the water to binder ratio of 0.45 and 0.5. The positive values of the change in crack width percentage in Table 4 indicates that crack width is more in M-sand compared to River sand and vice versa. Most of the crack width percentage is negative indicating the effectiveness of M-sand in controlling the plastic shrinkage. This shows that control of crack at early ages in M-sand concrete is better than in river sand concrete. Further, the crack width is lesser in fly ash M-sand mixes than in fly ash river sand mixes.

Time of first visible crack shortly called as Time of First Crack (TOFC) is of importance in shrinkage studies as localized strains results in the formation of visible cracks. If the bleeding rate is not compensated by the evaporation rate, then strain develops in the concrete. Hence, when the bleeding rate is lower than the evaporation rate, the pressure associated with capillarity in the empty pores is more. Moreover, the force exists between the particles in the water filled pores are larger than that between the air-filled pores. When empty pores are penetrated by the air, the cracking due to plastic shrinkage reaches the maximum. TOFC is associated with the evaporation and bleeding rate making it a useful parameter for the plastic shrinkage measurement. The TOFC identified through visual observation for river sand and M-sand mixtures for water to binder ratio of 0.45 and 0.5 are shown in Fig. 8. It is noticed that after 90 and 180 min of casting, the minimum and maximum time of first crack development is observed respectively. Fig. 8 shows that there is no trend observed either in plain and fly ash mixtures or plain and fibre incorporated

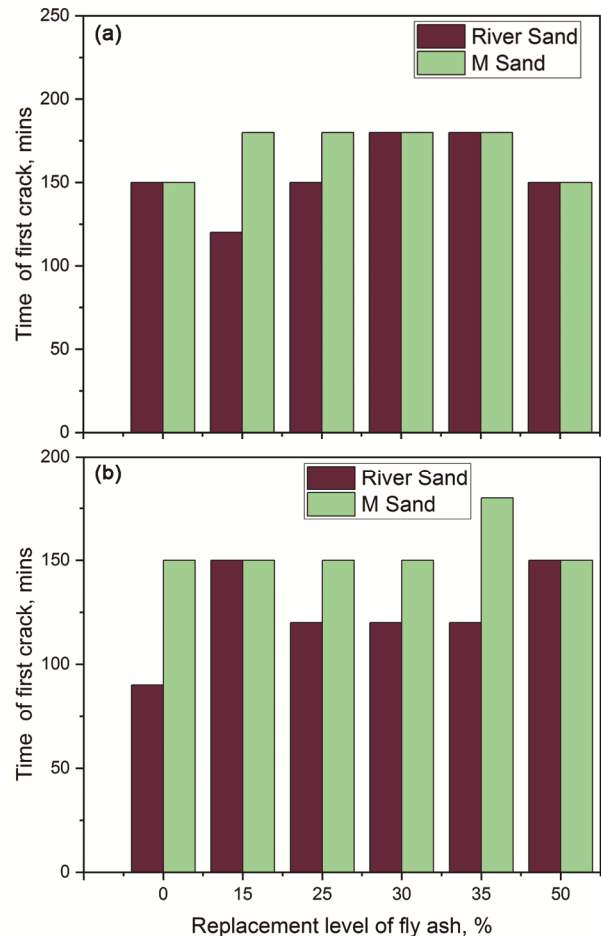


Fig. 8 — Time of first crack in river sand and M-sand Concrete (a) 0.45, and (b) 0.5

mixtures. As a typical case, in concrete with 15% replacement of fly ash, TOFC is high in M-sand concrete with 0.45 w/b whereas TOFC is same for both M-sand and river sand concrete with 0.5 w/b ratio. However, it is noticed that the time of first crack in M-sand concretes are either delayed or same as that of the river sand mixes. This shows that the early age cracking is delayed by the incorporation of M-sand.

Further, it is noticed that compared to plain concrete, TOFC in fly ash concretes are delayed in most of the mixes, especially at low water to binder ratio (0.45). Furthermore, two different types of fibres (basalt and steel) are also used typically in plain concretes (without fly ash) to evaluate the efficiency in mitigating the cracks. It was found that both the steel fibres and basalt fibres are efficient in reducing the crack at early ages. The crack widths measured from typical concrete specimens are presented in Table 5. In the earlier study carried out by the authors, similar observation is reported using the basalt fibres.²⁷

Table 5 — Comparison of crack width of concrete with and without fibres in mm

Mix	0.45		0.5	
	Plain concrete	BF0.1	SF0.05	SF0.1
0.45	2.12	1.84	1.44	1.44
0.5	2.24	1.6	1.8	1.54

BF0.1-Basalt fibre 0.1%, SF0.05-Steel fibre 0.05%, SF0.1-Steel fibre 0.1%

Slump and Plastic Shrinkage

Although slump is not directly related to shrinkage properties, the uniformity of the mix can be detected using the slump obtained. Further, the increased moisture content of aggregate and change in the grading of aggregate influence the slump. As the plastic shrinkage is affected by the uniformity of the mix and grading as well as shape of the aggregates, the slump value obtained for river sand and M-sand concrete can be correlated to the plastic shrinkage. The slump values obtained for the mixtures with 0.45 and 0.5 w/b are presented in Fig. 4. Comparing the slump values of river sand and M sand mixtures, it is observed that except for plain cement and 15% fly ash replacement concrete, the slump values are higher for river sand concrete mixes. At both 0.45 and 0.5 w/b, except for M0 and M15, the slump is higher for river sand mixes. This shows that the resultant slump is due to the combined influence of w/b, replacement level of fly ash and type of aggregates. Low replacement level of fly ash reduces the slump indicating that incorporation of fly ash at higher percentage enhances the workability. As fly ash is spherical in morphology it enhances the workability when incorporated in high volumes in concrete. Further, at 0.45 w/b, the mix is stiffer than 0.5 w/b indicating the availability of water for evaporation is less. As the slump and plastic shrinkage are related to the presence of water, the decrease in slump can be related to the shrinkage measurements in this study.

Evaporation and Plastic Shrinkage

Rate of evaporation of water from the concrete is indicative of the initiation of plastic shrinkage. For measuring the evaporation rate, all the specimens are subjected to the same exposure conditions such as temperature of $42 \pm 1^\circ\text{C}$, RH of $35 \pm 2\%$ and wind speed of 4.5 ± 0.3 m/s. A pan of water with known mass is kept inside the environmental chamber before the start of the test. Then the loss of water is measured at regular intervals, say 30 minutes, by weighing the pan containing water to a precision of 0.01g. Evaporation rate is measured by using formulae and

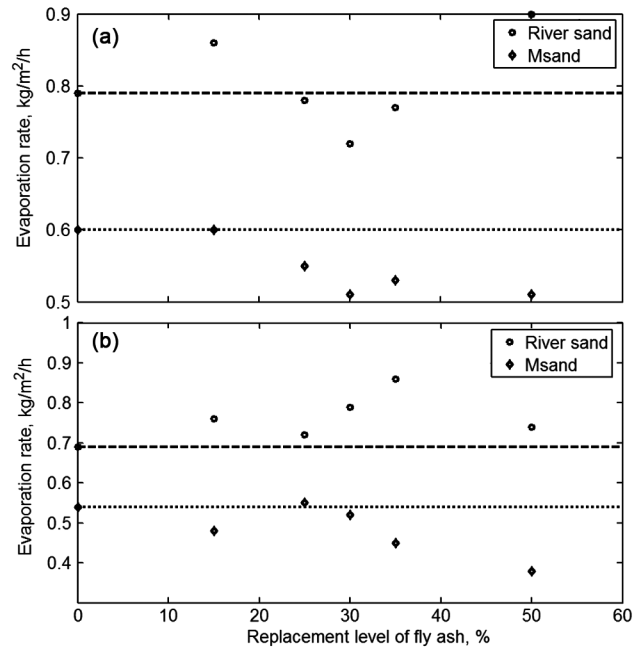


Fig. 9 — Evaporation rate of water for river sand and M-sand concrete for water to binder ratio (a) 0.45, and (b) 0.5

nomographs presented (Uno 1998). The modified version of Menzel's equation as given in Eq. 1 (Uno 1998) has been used in this study to calculate the evaporation rate.

$$E = 0.313 (e_{so} - re_{sa}) (0.253 + 0.06V) \quad \dots (1)$$

where, e_{so} = vapor pressure at concrete surface (kPa); e_{sa} = vapor pressure of air (kPa); r = (RH, percent)/100; V = wind velocity (kph).

Vapour pressure e_{so} and e_{sa} can be calculated from the Eq. 2

$$e_{so} = 0.61 e^{(17.3T/(237.3+T))} \quad \dots (2)$$

where, e_{so} is the saturation vapor pressure (kPa) and T is the temperature ($^\circ\text{C}$).

When the evaporation rate of water in concrete is greater than $0.5 \text{ kg/m}^2/\text{hr}$, there is a likely chance of development of shrinkage cracks. However, when this rate exceeds $1 \text{ kg/m}^2/\text{hr}$, it is certain that the shrinkage will develop. Evaporation of water is considered as one of the major causes of plastic shrinkage, the rate of evaporation in causing plastic shrinkage is of importance in this study. Influence of replacement levels of fly ash as well as M-sand on the rate of evaporation at 5 hours is shown in Fig. 9. The two horizontal lines (upper one for river sand and lower one for M-sand) represent the evaporation rates of water in plain concrete without fly ash. The data point above and below the reference lines indicates that the evaporation rate is higher and lower in fly ash

concrete with reference to plain concrete respectively. Interestingly, it is noticed that M-sand concretes with fly ash have lower evaporation rate compared to plain concrete at both water to binder ratios (0.45 and 0.5). TOFC as shown in Fig. 8 also indicates the time of first crack is delayed in M-sand mixes. However, in river sand concrete, the evaporation rate of fly ash concrete is higher than the plain concrete in almost all the mixes. This shows that some relation exists between the fly ash and the type of fine aggregate used. With the water to binder ratio of 0.45, except for very low (15%) and very high (50%) replacement levels, the evaporation rate is lower than the plain concrete in river sand mixes. However, with higher water to binder ratio, the evaporation rate is higher for all fly ash mixes with river sand.

Discussions

The parameters such as crack width and TOFC in M-sand and river sand concrete show that the shrinkage properties of M-sand concrete are either improved or similar to the river sand concrete. It indicates that the use of M-sand in concrete does not have significant effect on the shrinkage properties and can be used as an alternative for river sand. General perception of M-sand is that it increases the shrinkage owing to its angular shape. There are arguments that spherical/cubical shaped aggregates lower the shrinkage in concrete than the flaky and elongated aggregates.²⁸

Scanning Electron Microscopy (SEM) image of the river sand and M-sand used in this study is shown in Fig. 10. The closer look of these images at different magnification shows that the particles are sharp and angular in M-sand than the river sand. The shape of aggregate greatly influences the fresh properties than hardened properties. To eliminate the negative effect of angular aggregates, generally, more cement content is used when angular aggregates are used. However, in this study, the cement quantity used is almost the same for both the river and M-sand concrete. Further, the presence of micro fines and its geometric characteristics that are reflected by the shape, texture and grading of fine aggregate also affects the shrinkage properties. The particle size distribution of M-sand (Fig. 1) and fineness modulus of M-sand obtained in this study show that the M-sand used is coarser than the river sand. Further, increased water demand and decreased slump in M-sand concrete is noticed as reported by many researchers.^{29,30} They reported the reason for increased water demand as the

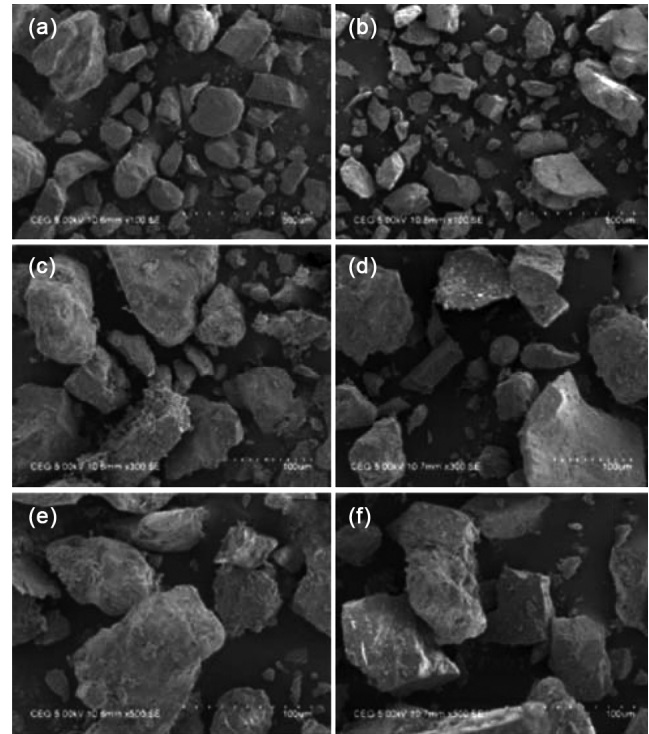


Fig. 10 — SEM image of river sand (RS) and M-sand (MS) at various magnification (a) RS100X, (b) MS 100X, (c) RS300X, (d) MS 300X, (e) RS500X, and (f) MS 500X

presence of finer particles and angular shape of the M-sand. While the M-sand used in this study is coarser in nature, the shape of it is angular. As angular shape of fine aggregate tends to increase the void content and in turn water demand, hence slump is reduced^{28,29} in M-sand concrete. However, researchers^{28,29} suggested the use of water reducing admixtures to overcome the water demand. The decrease in plastic shrinkage in M-sand concrete may also be attributed to the presence of aggregate volume. As M-sand (fine aggregate) and granite (coarse aggregate) belongs to the same parent material, density of both the materials is the same. However, the composition of river sand and coarse aggregate is not the same and their density also varies. This difference in the densities of fine and coarse aggregates also make changes in the fresh property of river and M-sand concretes.

Another observation in this study is that the combined influence of spherical fly ash and angular M-sand. The spherical nature of river sand and fly ash tends to release the available water in the concrete and increases the evaporation rate. In the case of M-sand mixes, the angular shape of M-sand and spherical pattern of fly ash (Fig. 11) tends to reduce the voids

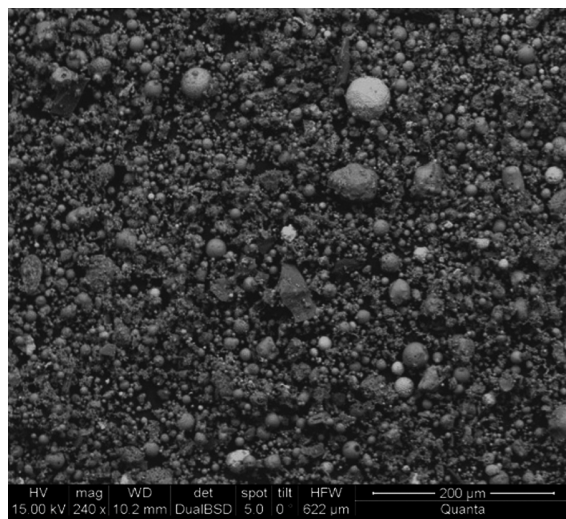


Fig. 11 — Scanning electron microscopy image of fly ash showing the spherical morphology of particles

between the concrete matrix and in turn reduce the release of bleed water in concrete.

The reduced evaporation rate in M-sand concrete compared to river sand is clearly shown in Fig. 8. Further, it is noticed that the evaporation rate is still reduced in fly ash replaced concrete than control M-sand concrete. In the literature, the influence of M-sand on plastic shrinkage is rarely addressed. However, few literatures available discuss the influence of M-sand on drying shrinkage. The reason for reduced drying shrinkage is reported to be higher aggregate volume and lower paste content for the same water-binder and water content.^{31,32} It is also reported that the composition of coarse and fine aggregate, and size of the coarse aggregate may change the restraining action of aggregate.³³ The presence of finer particle increase the density and decrease the aggregate restraint, hence, the increase in M-sand and coarse aggregate lead to increase in aggregate restraint.³⁴ Hence, it is evident that the increase in coarser volume fraction and the shape of the fine aggregate plays vital role in decreasing the shrinkage of concrete. Correlating the reported findings on drying shrinkage with plastic shrinkage results obtained in this study for river sand and M-sand concrete mixes with and without fly ash, it is found that the shape of the fine aggregate and the presence of fly ash have major influence on plastic shrinkage. Angular the shape of the fine aggregate, more will be the packing density.^{35,36} And the presence of fly ash further improves the packing density in M-sand mixes and reduces the evaporation rate and reduce the plastic shrinkage crack.

Conclusions

In M-sand concrete, both the fine and coarse aggregate used have the same composition, as both are derived from the same parent material. This nature of fine and coarse aggregate used is found to be positively responsible for reducing the plastic shrinkage. The combined influence of angular fine aggregate and rounded fly ash in concrete is found to reduce the amount of bleeding water in M-sand concrete. This illustrates that in terms of reducing the plastic shrinkage, concrete made with Portland Pozzolana (PPC) is better than that of Ordinary Portland cement (OPC). Both the basalt as well as steel fibre is efficient in controlling the plastic shrinkage in both the river sand as well as M-sand concrete. Thus, M-sand has positive effect in reducing the shrinkage during early ages. However, further studies are needed to analyze the characteristics of M-sand obtained from different sources.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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