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Effect of steel fibres and nano silica on fracture properties of medium strength concrete

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Abstract. This study presents the fracture properties of nano modified medium strength concrete (MSC). The nano particle used in this study is nano silica which replaces cement about 1 and 2% by weight, and the micro steel fibers are added about 0.4% volume of concrete. In addition to fracture properties, mechanical properties, namely, compressive strength, split tensile strength, and flexural strength of nano modified MSC are studied. To ensure the durability of the MSC, durability studies such as rapid chloride penetration test, sorptivity test, and water absorption test have been carried out for the nano modified MSC. From the study, it is observed that significant performance improvement in nano modified MSC in terms of strength and durability which could be attributed due to the addition pozzolanic reaction and the filler effect of nano silica. The incorporation of nano silica increases the fracture energy about 30% for mix without nano silica. Also, size independent fracture energy is arrived using two popular methods, namely, RILEM work of fracture method with P–δ tail correction and boundary effect method. Both the methods resulted in nearly the same size-independent G_F irrespective of the notch to depth ratio of the same specimen. This shows evidence that either of the two procedures could be used in practice for analysis of cracked concrete structures.

Keywords: steel fibre; nano silica; mechanical properties; fracture properties; durability

1. Introduction

In the present scenario, concrete is the second most used materialall around the world after water. Infact concrete is an engineer’s choice inspite of its drawbacks like heterogeneity, shrinkage, and somedurability issues due to aggressive environmental. Nearly twenty trillion kilograms of concrete have been produced every year which utilize cement as themain ingredient (Singh *et al*. 2013). It contributes significantly in the global carbon emission which paves an environmental issue. In the construction sector, researchers developed various supplementary cementitious materials (SCMs) in concrete to reduce the carbon footprint and also to improve the concrete performance in both fresh and hardened properties. The performance of convention concrete is mainly attributed byportland cement which could cause cracking in the hardened state due to exothermic process during hydration. Those micro cracks originate from nano scale forms absolute distress for the concrete structure which may prolong and cause many problems during the service life. The structural collapse happens by the fracturing of concrete due to stress developed in the cracking zone. Hence, fracture properties of medium strength concrete (MSC) with the inclusion of SCMs and steel fibers is essential for the construction sector to design and assess the MSC structures.

Recently, nanotechnology is an emerging avenue in the construction sector which controls the material in molecular level. Application of nanotechnology in concrete by incorporation of nano materials will tend to produce concrete which exhibits new properties (Florence and Konstantin 2010, Said *et al*. 2012, Shiho *et al*. 2013, Nikolaos and Pantazopoulou 2015). Especially the core property of concrete is holding or binding of aggregate by means of glue which is termed as calcium silicate hydrate (CSH). This CSH gel itself a nano material which will be observed only on the nano scale.Nanomodification by the inclusion of nano material enhances the normal concrete properties in terms of strength and durability. There are several nano materials are widely used in different fields based on its properties and functions. Among them, nano silica is a promising materialin the concrete sector. Firstly, it influences the pozzolanic reaction which generates additional CSH gel by utilizing calcium hydroxide formed in the cement hydration process. Secondly, it fills the nano sized pores by its pore filling effect can guide to retard the crack formation in the nano scale itself (Alireza *et al*. 2010, Behfarnia and Salemi 2013, Ganesh *et al*. 2015, Lincy *et al*. 2017).

The cracking of concrete generally exists in different scale starting from nano to micro to macro level.Initially, those cracks are randomly distributedin the system when it is subjected to loading at the service condition. Such cracks exhibit nonlinear behaviour and tend to a gradual increase in a crack over the fracture process zone (FPZ). With the

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Table 1 Chemical composition of FA and GGBS

Properties	Cement
CaO	64.10
SiO_2	21.70
Al_2O_3	5.80
MgO	1.75
Fe_2O_3	3.30
K_2O	0.75
SO_3	1.80
Na_2O	0.20
Cl^-	0.03
Specific Gravity	3.15
Specific Surface Area (m^2/g)	0.32

Table 2 The properties of Nano-SiO_2

Diameter (nm)	Specific Surface Area (m^2/g)	Density (g/cm^3)	Purity (%)
15 ± 5	600	2.2 - 2.6	99.5

increase in load, tension softening behaviour occurs due to the influence of nano materials and steel fibers present in the concrete (Zhang *et al*. 2014). Studies related to fracture properties for nano modified medium strength concrete in combination with steel fibers are very limited in the literature. In the present study, experimental evaluation of mechanical properties, durability properties and fracture properties for nano modified conventional normal strength concreteis carried out.

2. Experimental program

2.1 Materials and properties

In typical concrete, there are four ingredients such as cement, fine aggregate, coarse aggregate, and water. The Ordinary Portland Cement (OPC) of 53 grades conforming to IS 12269 (BIS 2013) is used as received. The physical and chemical properties of OPC are shown in Table 1. The specific gravity and particle size range of fine aggregate used in this study are 2.65 and 1to 3 mm. The specific gravity and particle size range of coarse aggregate used in this study are 2.8 and 4.75 to 12 mm. Apart from the conventional ingredients; amorphous nano silica particles with an average particle size of 15 nm produced from Sigma Aldrich Imports and Exports Trade Co. Ltd. is used as received. The properties of nano silica particles are shown in Table 2. Steel fibers of length 13 mm and diameter 0.18 mm are incorporated in the mixture to study the fracture properties.

2.2 Mix procedures

Mix design has been carried out for the conventional concrete with a characteristic compressive strength of 30 MPa (M30 Grade) as per IS 10262, Bureau of Indian Standards (BIS 2009). The mix ratio of medium strength concrete (MSC) by weight of cement, fine aggregate, coarse aggregate, and water is 1: 1.67: 1.86: 0.45. Three series of

(a) Sonication (c) Dispersed nano silica

Fig. 1 Sonication of nano silica

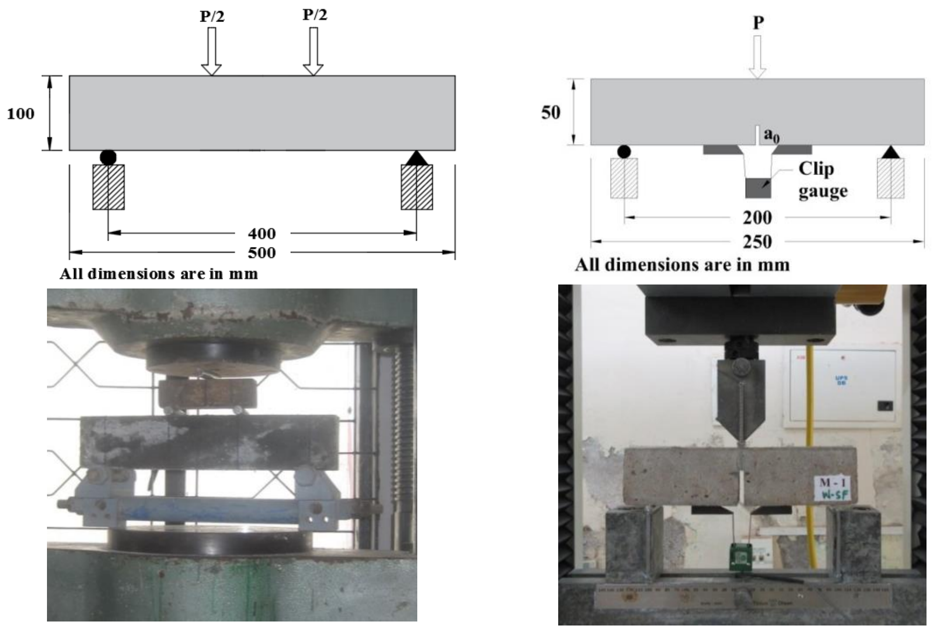
Table 3The mix proportion of nano modified MSC

Mixtures (kg/m^3)	Cement (kg/m^3)	Nano Silica (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)	W/C	Percentage of steel fibre by vol. of concrete (length=13 mm, dia.=0.18 mm)
M-0	481.93	-	804.82	896.39	216.87	0.45	0.4
M-1	477.11	4.82	804.82	896.39	216.87	0.45	0.4
M-2	472.29	9.64	804.82	896.39	216.87	0.45	0.4

MSC mix (with and without steel fibers) are prepared with Nano silica particles of 0%, 1%, and 2% replacement levels in place of cement. The final mix proportion of nano modified MSCis given in Table 3.As shown in Fig. 1, nano silica particlesare dispersed in water with the help of sonicatorwhich provides ultrasound frequency range from 20 kHz to 30 kHz. After sonication, the dispersed nano silica is added to the dry mix. The steel fibers are added about 0.4% volume of concrete at the end of the mixing process. An addition of steel fibers beyond 0.4% could cause poor slump results as a less workable mix. The freshly prepared nano modified MSC mix is poured into the moulds and an externalvibrator is used for compaction to reduce the air voids. The specimens are demoulded after 24 hours and cured in normal water at 20±3℃ till testing.

2.3 Experimental procedures

The Compressive strength and split tensile strength are carried out at 28 days for all the mixes. Compressive strength on cubes of size 100 mm and Split tensile strength on cylinders of size 100×200 mm as per IS 516-1959 and IS 5816-1999 respectively. Two point loading test to evaluate the bending flexural strength on prisms of size 500× 100×100 mm as per IS 516-1959 is shown in Fig. 2(a). Size dependent fracture energy G_f is determined by RILEM work of fracture method (RILEM TCM-85 1985) on the prism of size 250×50×50 mm (Fig. 2(b)). Two different notch depths (0.1d and 0.6d) are made and span-depth ratio is maintained at 4 for all specimens. The durability studies are carried out for the nano modified medium strength concrete by conducting durability tests such as Rapid Chloride Penetration Test, Sorptivity test and water absorption test. Studies are carried out on cylinders of size 200×100 mm which should be cut into three portions of 50 mm thick disc



(a) Flexural strength test (b) Three point bending test (with notch)

Fig. 2 Testing setup

using concrete cutting machine after 28 days of curing. The rapid chloride penetration test (RCPT) is carried out as per ASTM C 1202. The disc specimen which is immersed one side with 3.0% sodium chloride solution and another side with 0.3M sodium hydroxide solution. The concrete disc is subjected to 60 V dc across the specimen ends over the period of 6 hours. The total charge passed in coulombs is measured and it determines the penetration level of chloride into the concrete. The sorptivity test is carried out after 28 days of curing as per ASTM C 1585. Water sorptivity is a measure of water penetration rate over the concrete surface through the pores of concrete by means of capillary suction. The quantity of penetrated water for the 30 minutes interval is measured by subtracting the weight of the specimen over the period. The water absorption test is carried out after 28 days of curing as per ASTM C 642 to measure the water absorption and voids percentage in the concrete.

3. Fracture properties

3.1 Determination of size independent fracture energy

It is known that there are two popular test methods; namely, RILEM work of fracture method with P–δ tail correction and boundary effect method to determine size independent fracture energy. Brief details of the methods are presented.

3.1.1 Method proposed by Elices et al. (P-δ tail)

Measurement of fracture energy G_f by RILEM work of fracture method has many sources of energy dissipation that can influence the results (Elices *et al*. 1992, Guinea *et al*. 1992, Planas *et al*. 1992). Mostly experimental errors are predominant and listed as (i) the machinery and experimental setup, (ii) large specimens pave way for

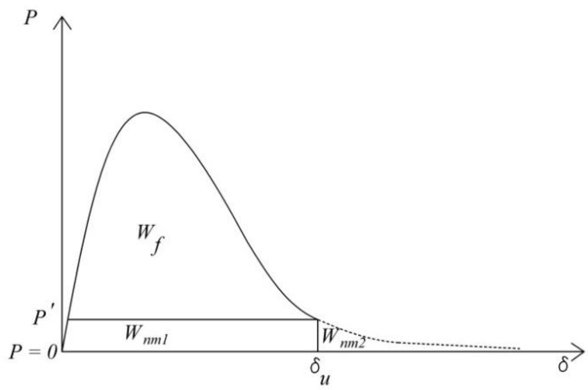


Fig. 3 P-δ curve in a three-point bend test and the measured (W_f) and non-measured (W_{nm1}+W_{nm2}) work of fracture

energy dissipation, and (iii) the un-recorded tail end portion of the load-deflection (P–δ) plot. Proper calibration of machineries and appropriate test arrangement can avoid the first source of error. The second source of error is mainly due to distress at the supports and the loading point, and also due to the high tensile strength of the specimen bulk. Those errors can be corrected by adjusting the initial stiffness of the P–δ plot and measuring the mid-span deflection on the lower half of the beam depth. The energy dissipation in the bulk specimen, W_{db}, cannot be avoided due to high tensile strength; still, it is estimated that this can cause an error of less than 2%. The third source of error is due to the restriction of the tail of the P– δ plot near the end of the test due to practical difficulties and it is found that it has the most significant effect on the size dependency of the measured fracture energy. To estimate this non-measured energy when the test is stopped (W_{nm}=W_{nm1}+W_{nm2} in Fig. 3) at a very little load, it is necessary to model the beam behaviour when the crack is close to the free surface (Elices *et al*. 1992). The size-independent specific fracture energy of concrete or mortar can be calculated as given in Eq. (1).

$$G_F = \frac{\int_0^{\delta_u} P d\delta + W_{nm}}{b(D-a)} \tag{1}$$

where $b(D\text{-}a)$ is the area of the ligament (A_{lig}) of the test specimen that is un-cracked at the start of the test, and b is the width of the specimen.

3.1.2 Boundary Effect Method (BEM)

Hu and Wittmann (1992) observed the effect of the stress-free back boundary of the specimen in the fracture process zone (FPZ) ahead of a real growing crack. The local fracture energy changes along the width of the fracture process zone and as the crack approaches the stress-free back face of the specimen tends to distinct fracture process zone and hence the local fracture energy decreases. The variation in the local fracture energy (g_f) is approximated by a bilinear function, as shown in Fig. 4. The transition from a horizontal line to the sharply inclined line occurs at the transition ligament length, which depends on the material properties, size and shape of the specimen. In this method, the measured RILEM fracture energy, G_f, may be considered as the average of the local fracture energy function (dotted line in Fig. 4) over the initial un-cracked ligament area. The relationship between all the associated variables is given by Eq. (2)

$$G_f(a,W) = \frac{\int_0^{W-a} g_f(x)dx}{W-a} = \begin{cases} G_F\left[1 - \dfrac{a^*{}_l/W}{2(1-a/W)}\right]; & 1\text{-}a/W > a^*{}_l/W \\ G_F\,\dfrac{2(1-a/W)}{2a^*{}_l/W}; & 1\text{-}a/W \le a^*{}_l/W \end{cases} \tag{2}$$

Where, G_f is the specific fracture energy or size dependent fracture energy (RILEM),

G_F is the true or size-independent fracture energy,
W is the overall depth of the beam,
a is the initial notch depth
$a^*{}_l$ is the transition ligament length.

To obtain the values of G_F and $a^*{}_l$ of a concrete mix, the size-dependent specific fracture energy G_f of specimens for different sizes and notch to depth ratios are first determined by the RILEM work-of-fracture method. Then Eq. (2) is applied to each specimen depth and notch to depth ratio. This gives an over-determined system of Equations which is solved by the least squares method to obtain the best estimates of G_F and $a^*{}_l$. In the present study, the simplified boundary effect method proposed by Karihaloo *et al.* (2003) has been used to determine the G_F.

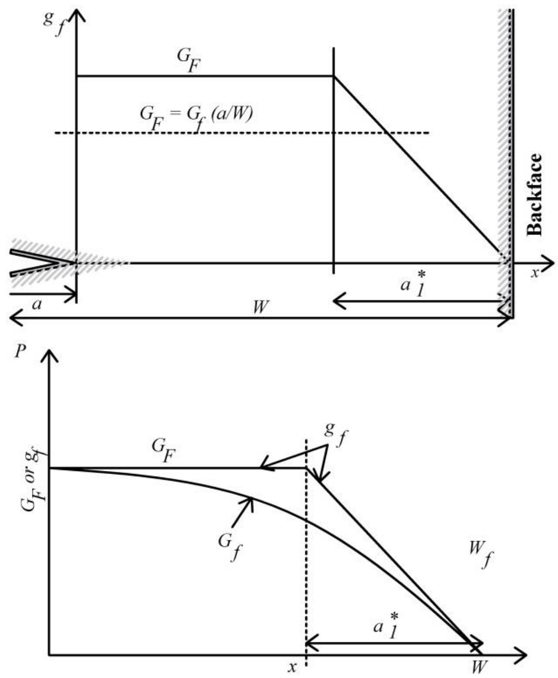


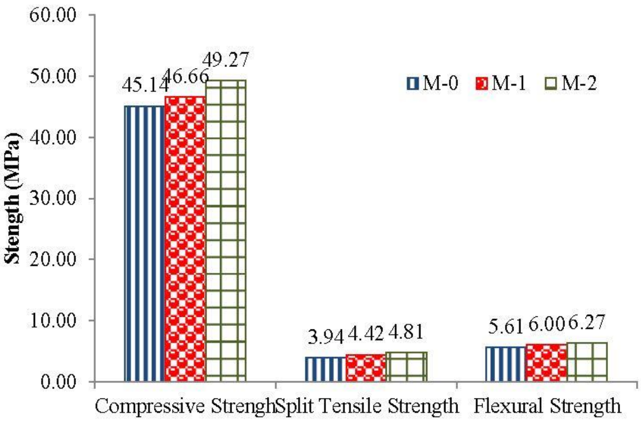
Fig. 4 Variation of local fracture energy g_f and G_F over the ligament length (Karihaloo *et al*. 2003)

4. Results and discussion

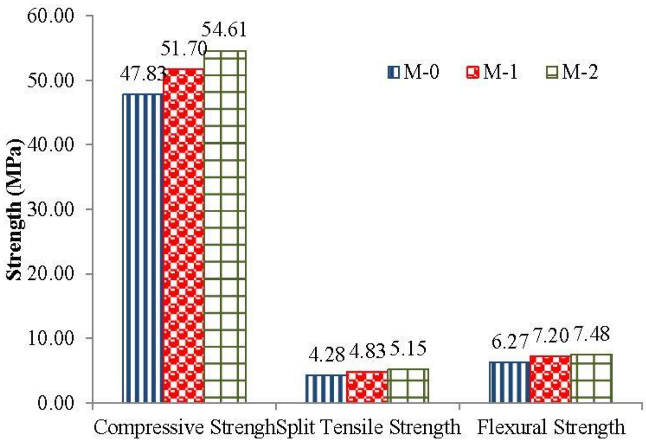
4.1 Mechanical properties

The average 28 days compressive strength, split tensile strength, and flexural strength results for nano modified MSC are given in Fig. 5. All the tests are carried out in the specimens with and without steel fibers to observe the effect of nano silica especially on the strength results of concrete mix with steel fibers. It is observed that the results of compressive, split tensile, and flexural strength improves with the incorporation of nano silica in the convention MSC mix. From Fig. 5(a), it can be observed that the mix without steel fibershas the compressive strength of about 45.1, 46.7, and 49.3 MPa for M-0, M-1, and M-2 mixes respectively. Replacement of nano silica about 1 and 2% by weight of cement increases the compressive strength by 3 and 9% with reference to the control mix (M-0). Similarly, the mix without steel fibershas split tensile strength about 3.9, 4.4, and 4.8 MPa for M-0, M-1, and M-2 mixes respectively. Replacement of nano silica about 1 and 2% by weight of cement increases the split tensile strength by 12 and 22% with reference to the control mix. From Fig. 5(b), it can be observed that the mix with steel fibershas the compressive strength of about 47.8, 51.7, and 54.6 MPa for M-0, M-1, and M-2 mixes respectively. Replacement of nano silica about 1 and 2% by weight of cement increases the compressive strength by 8 and 14% with reference to the control mix. Similarly, the mix with steel fibershas split tensile strength about 4.3, 4.8 and 5.2 MPa for M-0, M-1, and M-2 mixes respectively. Replacement of nano silica about 1 and 2% by weight of cement increases the split tensile strength by 13 and 20% with reference to the control mix.

The 28th day flexural strength result shows significant improvement in strength with the incorporation of nano silica in comparison with the control MSC mix. From Fig. 5(a), it is observed that the mix without steel fibershasa flexural strength of about 5.61, 6.00, and 6.27 MPa for M-0, M-1, and M-2 respectively. Replacement of nano silica



(a) Mix without steel fibers



(b) Mix with steel fibers

Fig. 5 Mechanical properties

about 1 and 2% by weight of cement increases the flexural strength by 7 and 12% with reference to the control mix. From Fig. 5(b), it can be observed that the mix with steel fibers has a flexural strength of about 6.27, 7.20, and 7.48 MPa for M-0, M-1, and M-2 respectively. Replacement of nano silica about 1 and 2% by weight of cement increases the split tensile strength by 15 and 19% with reference to the control mix. The results show that the mix with steel fiber exhibits better improvement in strength with respect to nano silica dosage comparatively which may be due to the combined action of nano silica and steel fibers. The gain in strength of nano modified MSC could be mainly contributed to the chemical reactivity (Pozzolanic reaction) and filler effect of nano silica. The pozzolanic reaction of nano silica consumes the freely available calcium hydroxide present in the hydration product and generates the addition calcium silicate hydrate which influences the pore structure of concrete. The pozzolanic reactivity of nano silica is higher than micro silica which could be due to its larger surface area. Also, the increasing the dosage of nano silica which act as physical filler that fills up the nano and micro pores and makes the concrete denser.

4.2 Durability properties

The rapid chloride penetration test (RCPT) is carried out as per ASTM C 1202, to evaluate the electrical conductance of concrete specimens which delivers the rapid resistance offered to the chloride penetration. Hence, the charge passed for the period of 6 hours test at 30 minutes interval is a measure of electrical conductance of the concrete specimen. The current recorded at regular interval and based on the trapezoidal rule, the total charge passing the specimen is calculated using the Eq. (3).

$$Q = 900\,(I_0 + 2I_{30} + 2I_{60} + ... + I_{330} + I_{360}) \tag{3}$$

Where,

Q -Charge passed (Coulombs),

I_0, I_{30}, I_{60}... I_{330}, I_{360}-Current in amperes at 0, 30, 60... 330, 360 minutes

Table 4 shows the measured chloride ion penetration value about 2869, 1829 and 1311 Coulombs for M-0, M-1, and M-2 respectively. It is observed that both the mixes with 1 and 2% nano silicafall under low chloride ion penetrability class, whereas the control MSC falls under the moderate category. The results indicate that conventional MSC exhibit lower resistance to chloride penetration and higher coulombs compared to nano modified MSC. The water sorptivity test measures the rate of water penetration through the concrete surface by means of capillary suction. The amount of water penetrated through the concrete specimen is measured at 30 minutes interval by differencing the increased weight of the specimen. The Eq. (4) is used to calculate capillary absorption as per ASTM C 1585.

$$I = m_t/(A \times d) \tag{4}$$

where,

I=the absorption,

m_t=the change in specimen mass in grams, at the time t,

A=the exposed area of the specimen, in mm^2,

d=the density of the water in g/mm^3.

The initial rate of water absorption is determined by plotting the cumulative water absorption volume per unit surface area of the specimen exposed to water versus the square root of time of exposure. A best-fit line could approximate the resulting plot and used all the points measured in the period from 1 minute to 6 hours for regression analysis. From Fig. 6, the initial water absorptions rates are found to be 0.121, 0.081, and 0.058 mm/s$^{1/2}$ for M-0, M-1, and M-2 respectively. From the results, it is evident that the rate of water absorption is lesser in the nano modified MSC. Absorption and voids percentage in the hardened concrete has a direct relationship with the concrete weight. The weight of concrete is increasing with the increase of void percentage when it is continuously exposed to a moist environment which may result in durability issues. Absorption test is performed as per ASTM C 642 to arrive the water absorption and percentage of air voids. From Table 5, the water absorptions values are 3.55, 2.86, and 2.32 for M-0, M-1, and M-2 respectively. The result shows that the nano modified MSC have lower water absorption compared to control MSC. From the durability tests, it is observed that the performance of nano modified MSC shows better resistance to chloride penetration, sorptivity and absorption. The performance of nano modified MSC could be attributed mainly due to high pore structure refinement due to filling effects of nano silica. The nano filler makes the pores finer and makes it

Table 4 Rapid Chloride Penetration Test (RCPT) results

Mix	Charge passed (coulombs)		Chloride ion penetrability (ASTM C 1202)	
	Various samples	Average		
M-0	2849 2679 3078	2869	2000-4000	Moderate
M-1	1750 1648 2089	1829	1000 - 2000	Low
M-2	1208 1180 1545	1311	1000 - 2000	Low

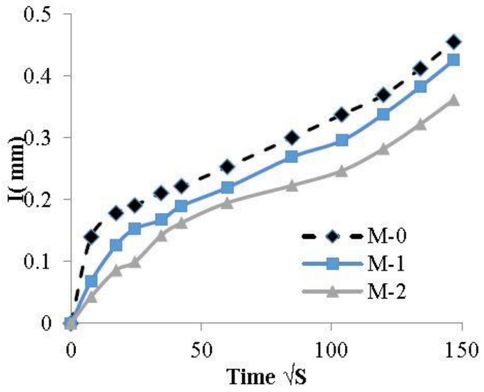


Fig. 6 Absorption (I) vs Time (√S)

Table 5 Water absorption test

MIx ID	Absorption (%)		Voids (%)	
	Different Samples	Average Absorption	Different Samples	Average Voids
M-0	3.56 3.49 3.60	3.55	6.71 6.68 7.06	6.82
M-1	2.96 2.82 2.82	2.86	5.67 5.55 5.55	5.59
M-2	2.30 2.40 2.28	2.32	4.60 4.74 4.91	4.75

discontinuous in the nano modified concrete which exhibits better durability.

4.3 Fracture properties

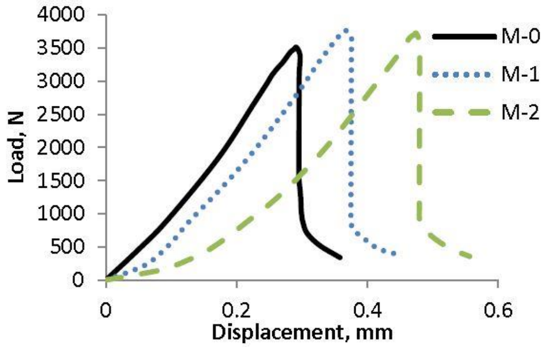
Notched specimens are tested under three point bending in a closed loop servo hydraulic testing machine with online data acquisition system. All the specimens are tested under displacement control at a rate of 0.02 mm/min. Notches are approximately 3 mm in size with two different notch depths 0.1d and 0.6d are cut in prismatic beams using a diamond saw. The load-displacement curves of all specimens are recorded. The span to depth ratio of the specimen is maintained at 4 for all specimens. Figs. 7 and 8 show a typical load-deflection plot and failure pattern of specimens of the nano modified MSC mix (with and without steel fibers).

Table 6 Size dependent and independent fracture energy for nano modified MSC

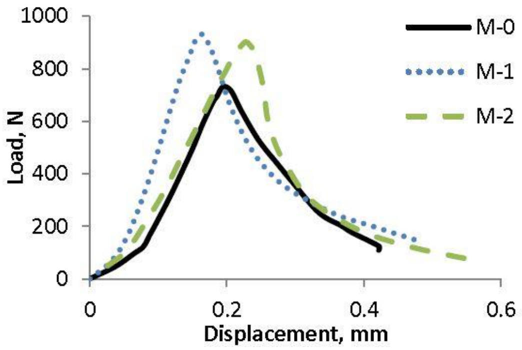
Mix ID	Notch to depth ratio	G_f as per RILEM N/m	G_F (N/m)by			Transition ligament length, a_l (mm)	% diff compared to BEM
			RILEM G_f with P-δ tail segment,	RILEM G_f with P-δ tail segment (Average)	Boundary Effect Method (BEM)		
M-0	0.1	251.19	373.65	308.47	331.47	21.8	7.46
	0.6	150.85	243.28				
M-1	0.1	300.18	475.56	366.61	391.57	21.4	6.81
	0.6	185.95	257.66				
M-2	0.1	323.95	521.86	402.23	430.53	22.3	7.03
	0.6	190.74	282.62				
M-0-S	0.1	1757.41	2617.08	2078.94	2172.02	17.2	4.48
	0.6	1239.30	1540.80				
M-1-S	0.1	2097.52	3229.20	2606.11	2779.32	16.7	6.65
	0.6	1499.27	1983.02				
M-2-S	0.1	2110.26	2600.66	2311.83	2409.63	11.3	4.23
	0.6	1738.00	2023.00				

From Table 6, the nano modified MSC concrete shows significant improvement in size dependent fracture energy for the control mix without nano silica. The replacement of cement by 2% nano silica increases the fracture energy is about 30% for the mix without steel fibers and increase in fracture energy is about 20% for the mix with steel fibers with the notch to depth ratio of 0.1d. Similarly, the replacement of cement by 2% nano silica increases the fracture energy is about 26% for the mix without steel fibers and increase in fracture energy is about 40% for the mix with steel fibers with the notch to depth ratio of 0.6d. The improved energy absorption can be due to the additional pozzolanic reaction of nano silica which consumes portlandite present in the hydration product. The addition C-S-H gel enhances the pore structure of concrete by bridging the nano level crack. Also, the filler effect of nano silica which modifies the nano and micro level pores and makes the concrete denser.

Table 6 also shows that the size-dependent fracture energy determined by RILEM work of fracture method G_f (i.e., Eq. (1) without the correction term for P–δ tail), the size-independent specific fracture energy (G_F) and G_F obtained by using simplified boundary effect method and Transition ligament length, a_l (mm). RILEM work of fracture method with P-δ tail correction, assumes to vary linearly from to P' to zero loads and δ is computed using the known slope of the P-δ at δ_u from the recorded readings (refer Fig. 3). The simplified boundary effect method proposed by Abdalla and Karihaloo (2003) has been used to determine the G_F and transition ligament length a_l as the notch to depth ratios are well separated. Table 6 highlights the dependency of the RILEM specific fracture energy on the notch depth. The specific fracture energy decreases with an increase in the notch to depth ratio for the same beam depth. From Table 6, it is clear that G_F values are almost the same for a particular mix i.e., M-0, M-1, and M-2 irrespective of notch depth. Further, it can be noted that the G_F obtained from both the methods resulted in nearly the

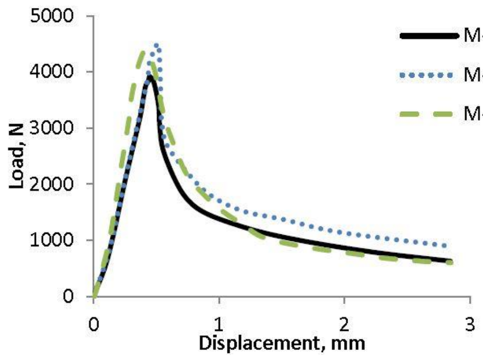


Notch Depth-0.1d

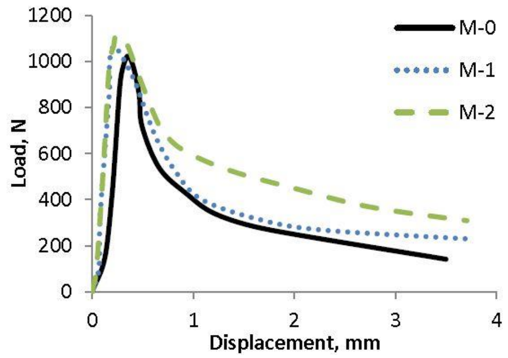


Notch depth-0.6d

(a) Load vs Displacement (Without Steel Fibers)



Notch Depth - 0.1d



Notch depth - 0.6d

(b) Load vs Displacement (With Steel Fibers)

Fig. 7 Typical load-displacement plots

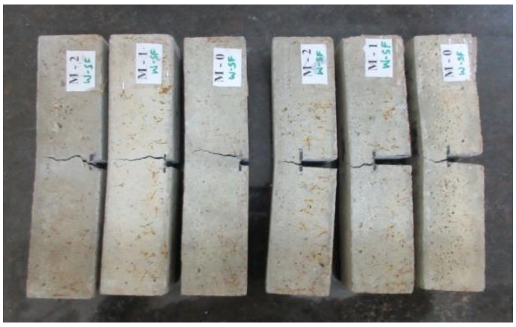


Fig. 8 Failure pattern of notched specimens

same value. This important conclusion shows the further evidence that either of them can be employed for estimation of size independent fracture energy for analysis of cracked concrete structural components. It might appear at first sight that these two methods use very different experimental procedures, but in reality, they are closely interrelated. Both procedures apply some corrections to the final part of the P–δ diagram in the work-of-fracture test (Vydra *et al*. 2012, Murthy *et al*. 2013, Murthy *et al*. 2015). Fig. 9 shows the typical failure patterns of the nano modified MSC specimens.

5. Conclusions

The incorporation of nano silica upto 2% by cement weight in convention normal strength concrete exhibits improvement in mechanical properties like compressive, split and flexural strength. The replacement of cement by 2% nano silica increases the compressive strength about 14%, split tensile strength about 20% and flexural strength about 19%. This strength enhancement could be significantly attributed to the additional pozzolanic reactivity and the filling ability of nano silica. Especially concrete with steel fibers shows better strength enhancement with respect to the nano silica dosage. The durability studies of nano modified normal strength concrete show better resistance to chloride penetration, sorptivity, and water absorption. The filling ability of nano silica promotes the dense pore structure which enhances the resistance of concrete to chloride penetration, sorptivity, and water absorption.

The nano modified MSC concrete shows significant improvement in fracture energy for the control mix without nano silica. The replacement of cement by 2% nano silica increases the fracture energy by about 30% for the mix without steel fibers, and an increase in fracture energy is about 20% for the mix with steel fibers. The improved energy absorption can be due to the additional pozzolanic reaction of nano silica which consumes portlandite present in the hydration product. The addition C-S-H gel enhances the pore structure of concrete by bridging the nano level crack. Also, the filler effect of nano silica which modifies the nano and micro level pores and makes the concrete denser. The specific fracture energy G_f measured using the RILEM work-of-fracture procedure is found dependent on the notch to depth ratio. The correction of the size-dependent G_f by the two models namely, RILEM work of fracture method with $P–\delta$ tail correction and boundary effect method resulted in nearly the same size-independent G_F irrespective of the notch to depth ratio of the same specimen. This shows further evidence that either of the two procedures could be used in practice for analysis of cracked concrete structures.

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