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Experimental Study of Fresh Concrete Properties of Fibre Reinforced Concrete with Metakoalin

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Abstract: *The use of metakaolin and steel fibre in reinforced concrete to enhance the properties of concrete. In the present day construction industry needs of finding effective materials for increasing the strength of concrete structures. In this present investigation the attempt has been made to study the fresh concrete properties of high strength fibre reinforced concrete with metakoalin. It includes wet density, Temperature and workability by addition of crimped steel fibres at 0%,2.5%,5%,7.5% and 10% of weight of cement and metakoalin at 0%,5%,10%,15% and 20% to the weight of cement. The fibers considered in this study was crimped steel fibre having aspect ratio85. Experimental investigation was done using M60 mix with w/c ratio 0.3.*

Keywords: *High Strength Concrete, Crimped Steel Fibre, Metakoalin,Workability.*

1. Introduction

The primary difference between high-strength concrete and normal-strength concrete relates to the compressive strength that refers to the maximum resistance of a concrete sample to applied pressure. Although there is no precise point of separation between high-strength concrete and normal-strength concrete, the American Concrete Institute defines high-strength concrete as concrete with a compressive strength greater than 6000 psi (41 MPa). Manufacture of high-strength concrete involves making optimal use of the basic ingredients that constitute normal-strength concrete. Producers of high-strength concrete know what factors affect compressive strength and know how to manipulate those factors to achieve the required strength. In addition to selecting a high-quality portland cement, producers optimize aggregates, and then optimize the combination of materials by varying the proportions of cement, water, aggregates, and admixtures.

It has been recognized that the addition of small, closely spaced and uniformly dispersed fibers to the concrete would act as crack arrester and would substantially improve its compressive and flexural strength properties. This type of concrete is known as fiber reinforced concrete. Fiber reinforced concrete can be defined as composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fiber

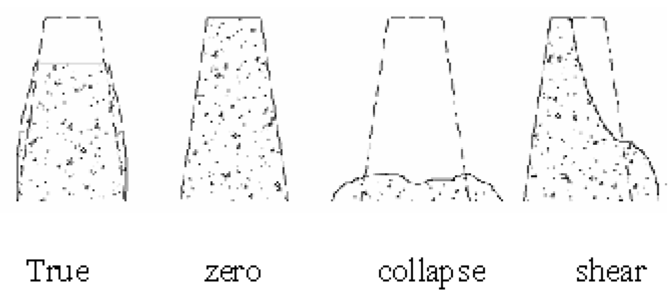
The utilization of high strength and high performance concrete has been increasing throughout the world. Amongst the various methods used to improve the strength and performance of concrete, the use of Cement Replacing Material like Metakaolin is a relatively new approach. There are several advantages of incorporating metakaolin to produce high strength for high rise building. Metakaolin added to concrete improves its strength and durability aspects. Hence Metakaolin is considered in the present investigation, because of the following primary actions .To improve the tensile strength of concrete. addition of small, closely spaced and randomly oriented fibres, dispersed uniformly in the matrix. The fibres act as crack arrestor in the continuum and would substantially improve its static and dynamic properties.

Slump tests were carried out to determine the workability and consistency of fresh concrete. The efficiency of all fiber reinforcement is dependent upon achievement of a uniform distribution of the fibers in the concrete, their interaction with the cement matrix, and the ability of the concrete to be successfully cast or sprayed (Brown J. & Atkinson T.2012) . Essentially, each individual fiber needs to be coated with cement paste to provide any benefit in the concrete. Regular users of fiber reinforcement concrete will fully appreciate that adding more fibers into the concrete, particularly of a very small diameter, results in a greater negative effect on workability and the necessity for mix design changes. The slump changed due to the different type of fiber content and form. The reason of lower slump is that adding steel fibers can form a network structure in concrete, which restrain mixture from segregation and flow. Due to the high content and large surface area of fibers, fibers are sure to absorb more cement paste to wrap around and the increase of the viscosity of mixture makes the slump loss (Chen and Liu, 2000).

2. WORKABILITY TEST METHODS

2.1. Slump Cone Test

The slump test is the most well-known and widely used test method to characterize the workability of fresh concrete. The inexpensive test, which measures consistency, is used on job sites to determine rapidly whether a concrete batch should be accepted or rejected. The test method is widely standardized throughout the world, including in ASTM C143 in the United States and EN 12350-2 in Europe. The apparatus consists of a mold in the shape of a frustum of a cone with a base diameter of 8 inches, a top diameter of 4 inches, and a height of 12 inches. The mold is filled with concrete in three layers of equal volume. Each layer is compacted with 25 strokes of a tamping rod. The slump cone mold is lifted vertically upward and the change in height of the concrete is measured. Four types of slumps are commonly encountered, as shown in Figure 3. The only type of slump permissible under ASTM C143 is frequently referred to as the “true” slump, where the concrete remains intact and retains a symmetric shape. A zero slump and a collapsed slump are both outside the range of workability that can be measured with the slump test. Specifically, ASTM C143 advises caution in interpreting test results less than ½ inch and greater than 9 inches. If part of the concrete shears from the mass, the test must be repeated with a different sample of concrete. A concrete that exhibits a shear slump in a second test is not sufficiently cohesive and should be rejected.



The slump test is not considered applicable for concretes with a maximum coarse aggregate size greater than 1.5 inches. For concrete with aggregate greater than 1.5 inches in size, such larger particles can be removed by wet sieving. Additional qualitative information on the mobility of fresh concrete can be obtained after reading the slump measurement. Concretes with the same slump can exhibit different behavior when tapped with a tamping rod. A harsh concrete with few fines will tend to fall apart when tapped and be appropriate only for applications such as pavements or mass concrete. Alternatively, the concrete may be very cohesive when tapped, and thus be suitable for difficult placement conditions.

2.2. The Compaction Factor Test

The compaction factor test (Powers 1968; Neville 1981; Bartos 1992; Bartos, Sonebi, and Tamimi 2002) measures the degree of compaction resulting from the application of a standard amount of work. The test was developed in Britain in the late 1940s and has been standardized as British Standard 1881-103.The apparatus, which is commercially available, consist of a rigid frame that supports two conical hoppers vertically aligned above each other and mounted above a cylinder, as shown in Figure 2. The top hopper is slightly larger than the bottom hopper, while the cylinder is smaller in volume than both hoppers. To perform the test, the top hopper is filled with concrete but not compacted. The door on the bottom of the top hopper is opened and the concrete is allowed to drop into the lower hopper. Once all of the concrete has fallen from the top hopper, the door on the lower hopper is opened to allow the concrete to fall to the bottom cylinder. A tamping rod can be used to force especially cohesive concretes through the hoppers. The excess concrete is carefully struck off the top of the cylinder and the mass of the concrete in the cylinder is recorded. This mass is compared to the mass of fully compacted concrete in the same cylinder achieved with hand rodding or vibration. The compaction factor is defined as the ratio of the mass of the concrete compacted in the compaction factor apparatus to the mass of the fully compacted concrete. The standard test apparatus, described above, is appropriate for maximum aggregate sizes of up to 20 mm. A larger apparatus is available for concretes with maximum aggregate sizes of up to 40 mm.

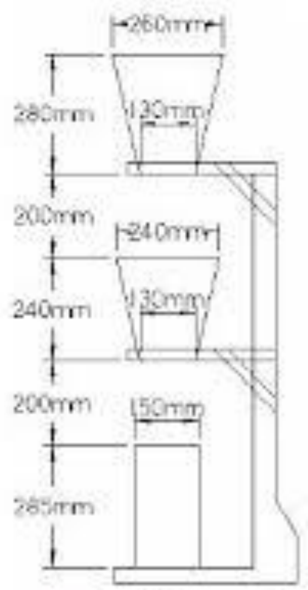


Figure 1: Compaction Factor Test Apparatus

The results of the compaction factor test can be correlated to slump, although the relationship is not linear. Table 5 relates the results of the compaction factor test to slump and the sample's degree of workability.

The compaction factor test has been used more widely in Europe than in the United States, although the overall use of the test seems to be declining. The test has typically been used in precast operations and at large construction sites. Compared to the slump test, the apparatus is bulky and a balance is required to perform measurements. In addition to these practical drawbacks, the test has several flaws that reduce the accuracy of the results. Some of the work imparted into the concrete is lost in friction between the hoppers and the concrete. The magnitude of this friction varies between different concrete mixtures and may not reflect field conditions. Further, the compaction factor test does not utilize vibration, the main compaction method used in the field (Bartos 1992).

Table1. *Interpretation of Compaction Factor Test Results as Described in British Road Note 4 (Wilby 1991)*

Degree of Workability	Slump, mm	Compaction Factor	
		Small Apparatus	Large Apparatus
Very Low	0-25	0.78	0.80
Low	25-50	0.85	0.87
Medium	50-100	0.92	0.935
High	100-180	0.95	0.96

2.3. Inverted Slump Cone Test

The inverted slump cone test (Tattersall and Banfill 1983; McWhannell 1994; Johnston 1994; ASTM C995-01; Bartos, Sonebi, and Tamimi 2002) was developed as a simple and inexpensive field test to measure the workability of fiber-reinforced concrete. Although fiber-reinforced concrete can show increased workability, the individual fibers act to increase concrete thixotropy. McWhannell (1994) has shown that mixes incorporating polypropylene fibers show a slight decrease in slump but an increase in workability as measured with the compacting factor test. Indeed, SI Concrete Systems, a large manufacturer of steel and synthetic fibers for concrete, advises against using the slump test for measuring the workability of fiber-reinforced concrete. The test apparatus is comprised of readily available jobsite equipment—an internal vibrator, slump cone, and bucket. The test is standardized in ASTM C995: "Standard Test Method for Time of Flow of Fiber-Reinforced Concrete through Inverted Slump Cone." A specially constructed wood frame, shown in Figure 13, holds the slump cone in an inverted position above the standard bucket described in ASTM C29/C29M for determination of unit weight. A 4 inch gap is left between the bottom of the inverted slump cone and the bottom of the bucket. The dampened slump cone is then filled with concrete in three layers. Although the concrete should not be compacted, each layer of concrete should be leveled off to minimize entrapped air. To keep the concrete from falling through the bottom of the slump cone, the ASTM standard recommends placing a sufficiently large volume of concrete in the bottom of the cone to bridge the opening.

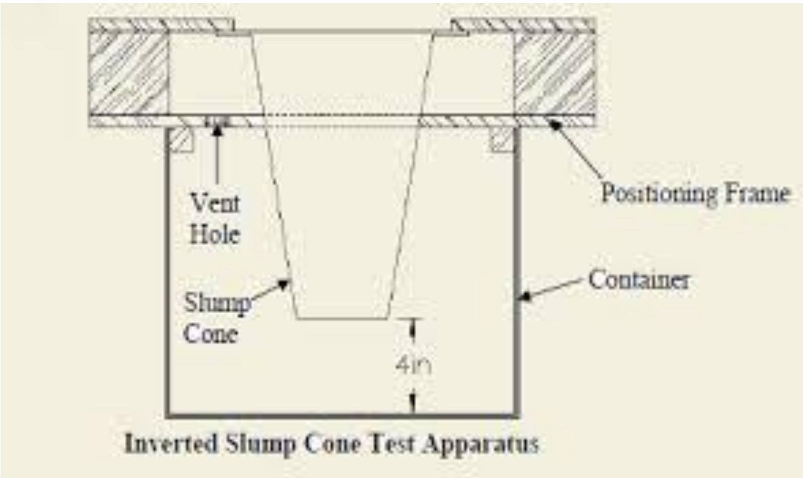


Fig3. *Inverted Slump Cone Test Apparatus*

With the slump cone full and leveled off at the top, a one-inch diameter internal vibrator is inserted into the top of the concrete and allowed to descend at a rate such that the vibrator comes into contact with the bottom of the bucket in 3 +/- 1s. The vibrator is then held in a vertical position and the total elapsed time from the insertion of the vibrator until all the concrete has passed out of the slump cone is recorded.

ACI Committee 544 (1989) on fiber-reinforced concrete recommends the use of the inverted slump cone test. The use of vibration has been deemed appropriate since the fiber-reinforced concretes that are tested with the inverted slump cone test are commonly vibrated during placement. Research has shown that the inverted slump cone test can successfully detect changes in coarse aggregate fraction, fiber content, fiber length, and fiber aspect ratio (Johnston 1994). Although the test is improvements on static tests that do not take into account the higher thixotropy of fiber-reinforced concrete, the inverted slump cone test has several important restrictions on its usefulness. The test applies only to concretes with flow times greater than 8 seconds and slumps less than 2 inches. More fluid concretes can flow through the bottom of the cone without vibration and cannot be measured with sufficient precision. The size of the apparatus also restricts the use of some concretes. The small gap of 1 ½ inches around the vibrator at the bottom of the cone limits the maximum aggregate size and the use of long, stiff fibers with high aspect ratios. Tattersall and Banfill (1983) state that the gap between the cone and vibrator should be 10 times the maximum aggregate size. Additionally, long fibrillated and monofilament fibers can wrap around the vibrator and distort results. In order to allow the use of readily available job equipment to conduct the test, the ASTM standard only specifies that the internal vibrator be 1 +/- 1/8 inch in diameter. Variations in the diameter, frequency, and amplitude of the vibrator prevent the direct comparison of test results and the development of specifications for fiber-reinforced concrete in terms of inverted slump cone time. The precision of the test is influenced by operator error in properly inserting the vibrator and determining the correct start and stop times for the test. Since the concrete is not consolidated prior to the start of the test, the cone can contain large volumes of entrapped air.

3. EXPERIMENTAL PROGRAM

The test materials used for this investigation given below

3.1. Cement

In this experimental work “Ultratech 53 grade Ordinary Portland Cement” has been used for casting.. All properties of cement are tested by referring IS 12269 – 2013.

Table2. *Test on cement*

No.	Property	Value observed	Standard value
1	Fineness	5.5	Not exceed 10
2	Standard consistency	29.5	
3	Specific gravity	3.15	
4	Initial setting time (min)	105	30
5	Final setting time (min)	210	600

3.2. Test on Aggregate

Locally available coarse aggregates having the maximum size of 12.5 mm and 20.5mm are used in the present work. Testing of coarse aggregates is done as per IS: 383-1970.

- specific gravity- 3.06
- water absorption- 0.6%

- fineness modulus- 6.56

Natural sand obtained from Krishna River is used throughout the experimental work. Sieve Analysis of the fine aggregate was carried out in the laboratory as per IS 383:1970. The sand was first sieved through 4.75 mm sieve to remove any particle greater than 4.75 mm and then was washed to remove the dust.

- specific gravity- 2.85
- water absorption- 1%
- fineness modulus- 2.7
- silt content – 1.50%

3.3. Water

Potable water available in laboratory is used for mixing & curing of concrete.

3.4. High Range Water Reducer

Use of fiber in concrete mix reduces the workability. To increase workability water reducing admixture is essential. A high range water reducing admixture (super plasticizer) (10 Top) is used in order to increase the workability of concrete in fresh state.

3.5. Physical Properties of Steel Fiber

ISO 9001: 2008 certified crimped steel fibers conforming to ASTM A820 M04 Type I Standard are used for experimental work. Fibers are made available from Stewols India Pvt. Ltd., Nagpur. Details of fiber are given in following

- Diameter – 0.70 mm
- Length- 60mm
- Aspect ratio-85
- Modulus of Elasticity- 200GPa
- Tensile Strength- 1000MPa

3.6. Metakoalin

The metakaolin used in this study is obtained from Golden Micro Chemicals, Thane.

3.7. Mix Design

IS method (10262-1982) of mix design is used for mix design of M-60 grade of concrete. The quantities of ingredient materials and mix proportions as per design are shown in table 3.

Table3. *Mix design proportion*

Water (lit)	**Cement (kg/m^3)**	**Fine Aggregate (kg/m^3)**	**Coarse Aggregate (kg/m^3)**		**Super Plasticizer (By wt. of Cement)**
			20mm	12.5mm	
166.14	553.813	471.78	635.84	635.84	1%
0.3	1	0.8518	1.1481	1.1481	

4. Result and Discussion

The ingredients were thoroughly mixed over a G.I. sheet. The sand, cement and aggregate were measured accurately and were mixed in dry state for normal concrete. For steel fiber reinforced concrete, the required quantities of steel fibers (i.e. from 2.5 % to 10%) were measured by weight of cement. The required weighted quantity of steel fibers was then uniformly sprinkled by hands on dry concrete mix containing CA, FA, metakaolin and cement. The dry concrete mix was then thoroughly and uniformly mixed till uniform and homogeneous mixing of fibers in dry mix was observed. Care has taken to avoid balling i.e. agglomeration of fibers. The following test results were obtained.

4.1. Wet Density

Table4. *Wet density of SFRMC*

Sr. no.	Mix designation	Density in kg/m^3
1	NC	2189.33
2	NC+2.5% SF+5%MK	2396.53
3	NC+5% SF+10%MK	2437.42
4	NC+7.5% SF+15%MK	2456.00
5	NC+10% SF+20%MK	2498.37

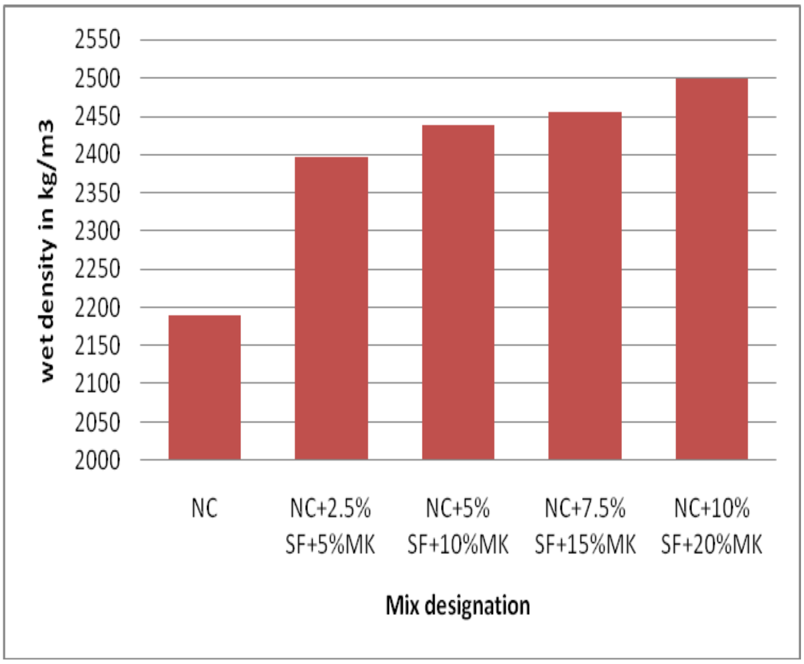


Fig4. *Variation of wet density*

4.2. Temperature

Table5. *Temperature result of SFRMC*

Sr. no.	Mix designation	Temp. in ^{0}C
1	NC	29
2	NC+2.5% SF+5%MK	28
3	NC+5% SF+10%MK	27.5
4	NC+7.5% SF+15%MK	27
5	NC+10% SF+20%MK	26

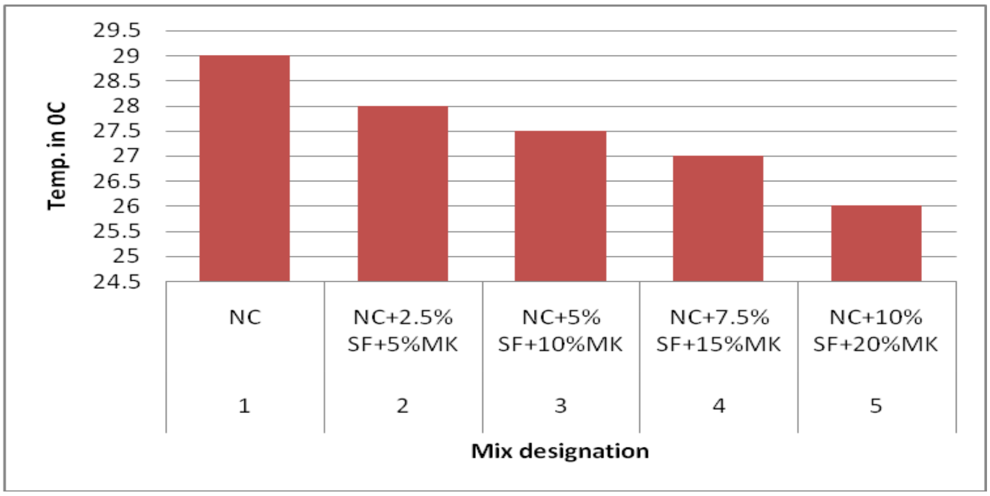


Fig5. *Variation of temperature*

4.3. Workability

Workability of concrete was governed by water content, chemical composition of cement and its fineness, aggregate/cement ratio in concrete, size and shape of aggregate, porosity, water absorption of aggregate, use of admixture etc. More use of water facilitates easy placing and compaction of concrete it may cause bleeding. The designed degree of workability (very low, low, medium, high) depends upon the several factors such as method of mixing, method of compaction, size and shape of structure, amount of reinforcement.

Workability of concrete with and without fiber and metakaolin is measured by slump cone test, compaction factor test and inverted slump cone test.

Table6. *Different workability test results*

Sr. no.	Mix designation	Slump in mm	Compaction factor	Inverted slump in sec.
1	NC	22	0.84	5.36
2	NC+2.5% SF+5%MK	16	0.81	4.43
3	NC+5% SF+10%MK	0	0.787	3.15
4	NC+7.5% SF+15%MK	0	0.768	2.40
5	NC+10% SF+20%MK	0	0.758	1.96

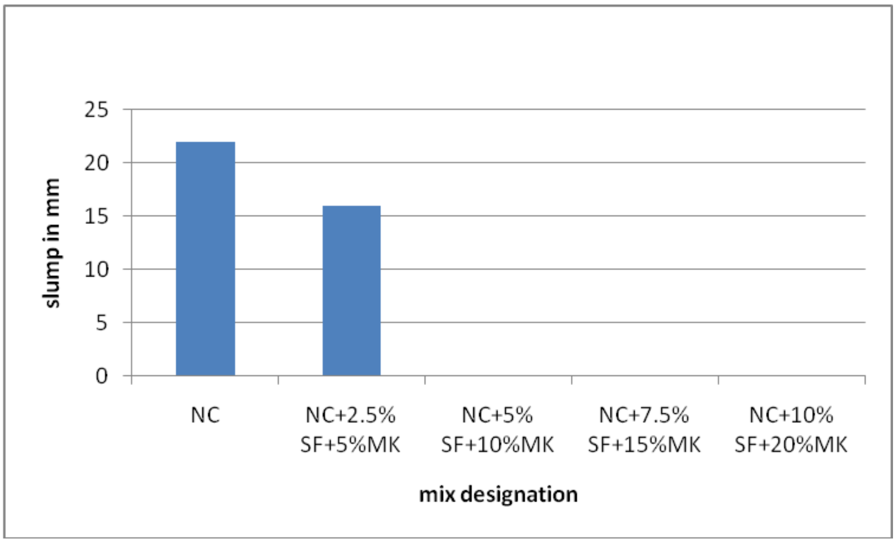


Fig6. *Workability by slump cone test*

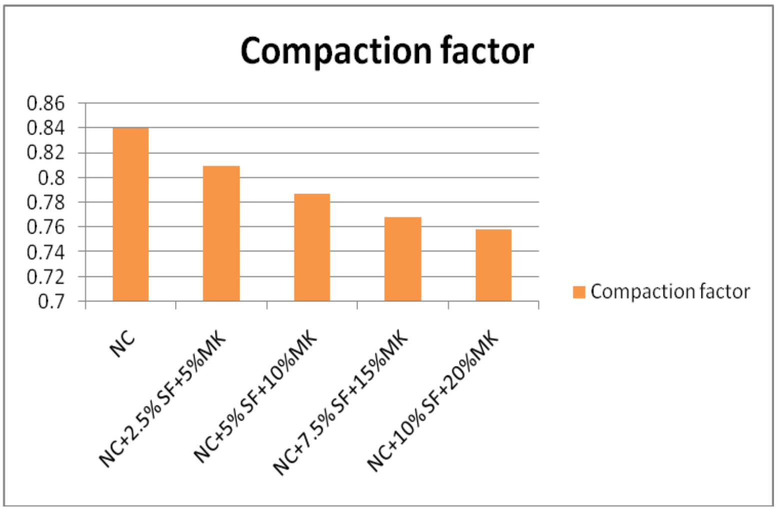


Fig7. *Workability by compaction factor*

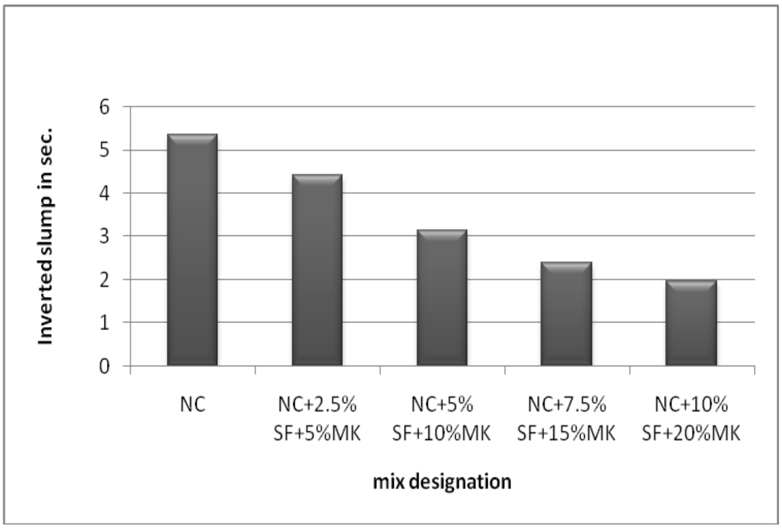


Fig8. *Workability by inverted slump cone test*

5. Conclusion

1. Wet density of fibre reinforced metakoalin concrete goes on increasing with increase in % of fibre and metakoalin.
2. Addition of metakoalin results in reduction in temperature of fresh concrete. i.e hydration reaction slows down due to addition of metakoalin.
3. As increase in % of metakoalin the fresh matrix becomes dry.
4. Workability of fibre reinforced metakoalin concrete by slump cone test not gives proper result. Shear failure takes place during test.
5. Due to dry matrix compaction factor and inverted slump test gives good results of workability.

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Mixing of fibre and metakoalin in concrete.

Inverted slump

Temperature measurement

Shear failure during slump test

Compaction factor test

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