EXPERIMENTAL INVESTIGATION ON THE EFFECT OF METAKAOLIN AND IRON SLAG ON THE STRENGTH OF SELF COMPACTING CONCRETE

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ABSTRACT

Cement and fine aggregate are the reliable raw materials used for concreting. Due to the shortage and high price of river sand led to the use of M sand in construction. *Iron slag is a by-product produced in large quantity all over the world and about 17 thousand tons of iron slag is produced annually in India. Also large volume of iron slag disposed of in open land in near-by areas can cause great threat to living beings. Use of iron slag as a fine aggregate is a good alternative to M sand and a better remedy to the disposal of iron slag. The use of Metakaolin becomes an ample ingredient in the production of concrete where service environments, exposure conditions or life cycle cost considerations define the use of Self Compacting concrete. Metakaolin is used in oil well cementing to improve the compressive, flexural strength and reduces the permeability of the hardened cement. In this study mechanical behaviour of self-compacting concrete with partial replacement of cement by metakaolin and fine aggregate by iron slag is carried out.*

Keyword – *Self compacting concrete, metakaolin, iron slag, compressive strength, split tensile strength, flexural strength etc.*

1. INTRODUCTION

Cement is the most commonly used material in concrete. Use of concrete is increasing day by day due to increase in the construction works. Usually Concrete is compacted by vibrations in order to expel entrapped air, making it denser and homogeneous because compaction is necessary to produce durable concrete. Full compaction is difficult due to heavy reinforcement, as a result self-compacting concrete (SCC) was developed. Self-compacting concrete (SCC) can be defined as a concrete which can be placed with its own weight with or without vibration. It facilitates and ensures proper filling and good structural performance of heavily reinforced congested members.

The optimization of self-compacting concrete mixtures aims at the reduction of the paste volume and consequently the reduction of the production cost. The cement and fine aggregate are the most reliable materials used for concreting, plastering and masonry work. The main problems such as acute shortage, high price and enormous usage of M sand in the construction. Iron slag can be used as an alternative to M sand since iron slag is produced in large quantity all over the world. About 17 thousand tons of iron slag is produced annually in India. Large volume of iron slag disposed off in open land in near-by areas which can cause great threat to living beings. Use of iron slag in the preparation of concrete is the good remedy to its disposal. With continuous increase in the production of iron slag, it is necessary and appropriate to use it in concrete rather than disposal.

Due to their high pozzolanic activity and filling effect, SCMs can lead to the production of a more consistent, cohesive and dense concrete, which exhibits enhanced mechanical characteristics and reduced permeability. Among other cementitious materials, such as silica fume, granulate blast-furnace slag and fly ash, that are frequently used for the production of concrete, metakaolin is a material with a feasible growing implementation in the concrete industry. Metakaolin is a thermally activated pozzolanic material that is obtained by the calcination of kaolinitic clay at moderate temperatures ranging from 650 to 800 ^{0}C. The main characteristic of metakaolin is its high reactivity with calcium hydroxide, $Ca(OH)_2$, and its ability to accelerate cement hydration. Compared to other SCMs, like silica fume or fly ash, the pozzolanic action of metakaolin is expected to be more significant due to its high concentration of silica and alumina. Additionally to the sustainable performance enhancement of concrete, through its improved durability, metakaolin is also considered as a sustainable and environmental-friendly material, due to the limited CO_2 emissions during its production process. Thus, when it is used as a replacement material of Portland cement, a significant reduction of the total CO_2 emissions is achieved. The major disadvantage of metakaolin is the high cost of production, compared to cement.

2. Material Properties and Experimental Investigation Sub Title-1

2.1 Cement

A cement is the binder substance that used in construction which hardens and adheres to other materials, binding them together. Cement is used with fine aggregate to produce mortar for masonry, or with sand and gravel aggregates to produce concrete. In this study OPC 53 grade was used. 53 grade cement provides long lasting durability due to the presence of high Tri Calcium Silicate (C_3S) content. As per the Bureau of Indian standards (BIS) IS 12269 1987 (reaffirmed 2008), grade of cement highlights the minimum compressive strength that is expected to attain within 28 days. The main characteristics of cement (53 Grade) used are given in the table 1.

Table -1: Properties of cement

Sl.No.	Characteristics	Values obtained
1	Specific gravity	3.15
2	Standard consistency	32%
3	Fineness of cement	5%
4	Initial setting time (min)	35
5	Final setting time(hr)	10

2.2. Fine Aggregate (M-Sand)

Fine aggregate is a reliable material used for concreting, plastering and masonry work. The main problem of fine aggregate is acute shortage, high price and enormous usage of sand in the construction. The manufactured sand (M-sand) is a better substitute to river sand because it has no silt or organic impurities and is mostly well graded. M-sand with proper gradation shall be used in this project for casting the concrete. As per IS 383:1970 (reaffirmed 2016) the size of fine aggregate should ranges from 4.75mm to 75µ and shall have a maximum water absorption of 2.3%. For the preparation of SCC the fine aggregate content will be more compared to coarse aggregate. The tests done on M-sand are water absorption test and specific gravity test.

Table -2: Properties of fine aggregate

Sl.No.	Characteristics	Values obtained
1	Specific gravity	2.73
2	Water absorption	2.0 %

2.3. Coarse Aggregate

The coarse aggregates generally occupy 60% to 75% of the concrete volume (70% to 85% by mass) and strongly influence the concrete's freshly mixed and hardened properties, mixture proportions, and economy. Coarse aggregates consist of one or a combination of gravels or crushed stone with particles predominantly larger than 5 mm and generally between 9.5 mm and 37.5 mm. Crushed stone is produced by crushing quarry rock, boulders, cobbles, or large-size gravel. The aggregates are usually washed and graded at the pit or plant. Some variation in the type, quality, cleanliness, grading, moisture content, and other properties is expected. The sieve analysis, specific gravity and water absorption tests are done on coarse aggregate.

Table -3: Properties of coarse aggregate

Sl.No.	Characteristics	Values obtained
1	Specific gravity	2.80
2	Water absorption	0.4 %

2.4. Iron slag

Iron slag is screened to remove the oversized particle and material passing through 4.75 mm sieve was used in manufacturing of concrete. The major chemical compounds in iron slag are. Iron slag is brittle and lighter than river sand. River sand and iron slag were dried in oven at 100 ^{0}C for 24 h and then cooled down to room temperature before using in concrete.

Fig -1: Iron slag

Specific gravity : 2.52

2.5 Metakaolin

Metakaolin (MK) is a pozzolanic material. It is obtained by the calcination of kaolinitic clay at a temperature ranging between 500 °C and 800 °C. The raw material input in the manufacture of metakaolin ($Al_2 Si_2 O_7$)is kaolin. Metakaolin on reaction with $Ca(OH)_2$, produces CSH gel at ambient temperature and reacts with CH to produce alumina containing phases, including $C_4 AH_{13}$, $C_2 ASH_8$, and $C_3 AH_6$. In this study the metakaolin was obtained from English India Clay Limited industries (EICL), Trivandrum.

Specific gravity : 2.60

3. MIX DESIGN

The mix design of SCC shows a rapid difference between normal concrete and SCC. SCC has more fine aggregate content than coarse aggregate to compact by its own self weight. The fresh and hardened properties of SCC was affected by the addition of mineral admixture. The size of specimen to find compressive strength and split tensile strength are of 150 x 150 x 150 mm cubes and 150 mm diameter x 300 mm length cylinder respectively. The size of specimen used to find the flexural strength are of 100 x 100 x 500 mm prisms. Fly ash was added as a replacement material for cement at a concentration of 20% in order to reduce the cement content while preparing conventional SCC.

Table -4: Mix design of SCC

Material	Cement	Fine aggregate	Coarse aggregate	Water	Fly ash
Quantity(Kg/m^3)	472	858	783	200	118
Ratio	1	1.754	1.65	0.423	0.25

4. EXPERIMENTAL INVESTIGATION

Various tests were done for the constituent materials of SCC and the test results obtained for the same. In this chapter the results and discussion of the tests conducted on fresh and hardened SCC modified with metakaolin and iron slag are presented**.**

4.1 Tests on fresh concrete

4.1.1 Slump flow test

The slump flow test is used to assess the horizontal free flow of SCC in the absence of obstructions. It is the most commonly used test and gives a good assessment of filling ability. It gives no indication of the ability of the concrete to pass between reinforcement without blocking but may give some indication of resistance to segregation. A highly flowable concrete is not the prime point of self-compacting because SCC should not only flow under its own weight but should also fill the entire form and achieve uniform consolidation without segregation. Table 5 shows the slump flow values for metakaolin based SCC and Table 6 shows Slump flow values of metakaolin based SCC with iron slag**.**

Table- 5: Slump flow values of SCC with metakaolin

Sl .No.	Mixes	Largest diameter (mm)	Perpendicular diameter (mm)	Slump flow (mm)
1.	SCC MK-0	685	675	680
2.	SCC MK -5	690	680	685
3.	SCC MK -10	698	680	689
4.	SCC MK -15	697	693	695
5.	SCC MK- 20	702	698	700

Table -6: Slump flow values of metakaolin based SCC with iron slag

Sl. No.	Mixes	Largest diameter (mm)	Perpendicular diameter (mm)	Slump flow (mm)
1.	SCC MK15 I10	695	685	690
2.	SCC MK15 I20	690	680	685
3.	SCC MK15 I30	685	675	680

4.1.2 Passing ability test

Passing ability describes the capacity of the fresh mix to flow through confined spaces and narrow openings such as areas of congested reinforcement without segregation, loss of uniformity or causing blocking. The passing ability of SCC with metakaolin and iron slag is determined by using the J-Ring in combination with a slump cone mould. The test method is limited to concrete with a maximum size of coarse aggregate of 10-12.5 mm which is the size used in this study. The J ring test is done to investigate the resistance of SCC to segregation. Table 7 shows the passing ability of metakaolin based SCC with iron slag.

Table -7: Passing ability of SCC with metakaolin

Sl. No	Mixes	Slump Flow (mm)	J- Ring (mm)	Passing ability (mm)	Remarks (as per ASTM 1621/C 1621M)
1	SCC MK-0	680	671	9	No visible blocking since passing ability values are between 0-25mm.
2.	SCC MK -5	685	675	10	
3.	SCC MK -10	689	680	9	
4.	SCC MK -15	695	687	8	
5.	SCC MK- 20	700	692	8	

Table -8: Passing ability of metakaolin based SCC with iron slag

Sl. No	Mixes	Slump Flow (mm)	J- Ring (mm)	Passing ability (mm)	Remarks 9as per ASTM 1621/C 1621M)
1	SCC MK15 I10	690	681	9	No visible blocking since passing ability values are between 0-25mm.
2.	SCC MK15 I20	685	678	7	
3.	SCC MK15 I30	680	672	8	

4.1.2 Passing ability test

Passing ability describes the capacity of the fresh mix to flow through confined spaces and narrow openings such as areas of congested reinforcement without segregation, loss of uniformity or causing blocking. The passing ability of SCC is determined by using the J-Ring in combination with a slump cone mould. The test method is limited to concrete with a maximum size of coarse aggregate of 10-12.5 mm which is the size used in this study. The J ring test is done to investigate the resistance of SCC to segregation.

The superplasticizer content is kept constant as the binder content remains constant. The passing ability is determined using standard tests like flow table test and J-Ring test. Slump flow test and J ring test are conducted only to determine passing ability and resistance to segregation since the laboratory facilities are limited. Table 9 shows the passing ability of metakaolin based SCC.

Table -9: Passing ability of SCC with metakaolin

Sl. No	Mixes	Slump Flow (mm)	J- Ring (mm)	Passing ability (mm)	Remarks (as per ASTM 1621/C 1621M)
1	SCC MK-0	680	671	9	No visible blocking since passing ability values are between 0-25mm.
2.	SCC MK -5	685	675	10	
3.	SCC MK -10	689	680	9	
4.	SCC MK -15	695	687	8	
5.	SCC MK- 20	700	692	8	

4.2 Tests on hardened concrete

4.2.1 Compressive strength test

Compressive strength test on cubes of M40 grade equivalent SCC and SCC with Metakaolin as a partial replacement of cement. The compressive strength of concrete was assessed by crushing to the destruction of the test cubes by means of compression testing machine according to IS 516:1959 (Reaffirmed 2004). Cubes of 150 mm size were used for the testing. Load at the failure divided by area of specimen gives the compressive strength of concrete. Fig 2 shows the compressive strength testing of the specimen.

$$\text{Compressive strength} = \frac{\text{load applied}}{\text{cross sectional area}}$$

Fig -2 Compression test

Table -10: Compressive strength of Metakaolin based SCC

SL.NO.	Mix	7-day compressive strength(N/mm^2)	28-day compressive strength(N/mm^2)	Percentage variation in 28 day strength
1.	SCC MK 0	38.34	50.22	-
2.	SCCMK 5	39.74	51.35	+2.25

3.	SCCMK10	40.87	53.40	+6.33
4.	SCCMK15	42.50	56.09	+11.68
5.	SCCMK 20	40.53	52.82	+4.92

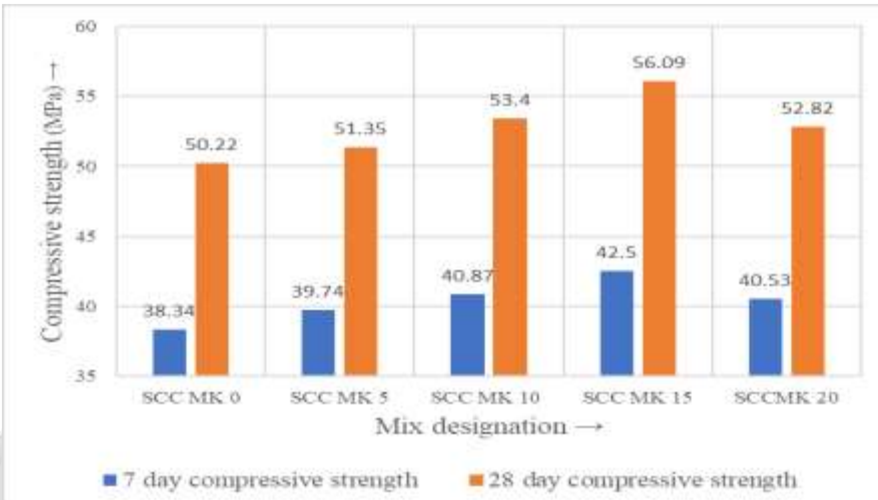

Fig -3: Compressive strength of Metakaolin based SCC

Table -11: Compressive strength of metakaolin based SCC with iron slag

SL.NO.	Mix	7days Compressive strength(MPa)	28 days compressive strength(MPa)	Percentage variation in 28 day strength
1	SCC MK 0	38.34	50.22	-
2	SCC MK15 I10	42.183	54.80	+9.11
3	SCC MK 15 I20	44.11	57.28	+14.06
4	SCC MK 15 I30	41.77	53.90	+7.33

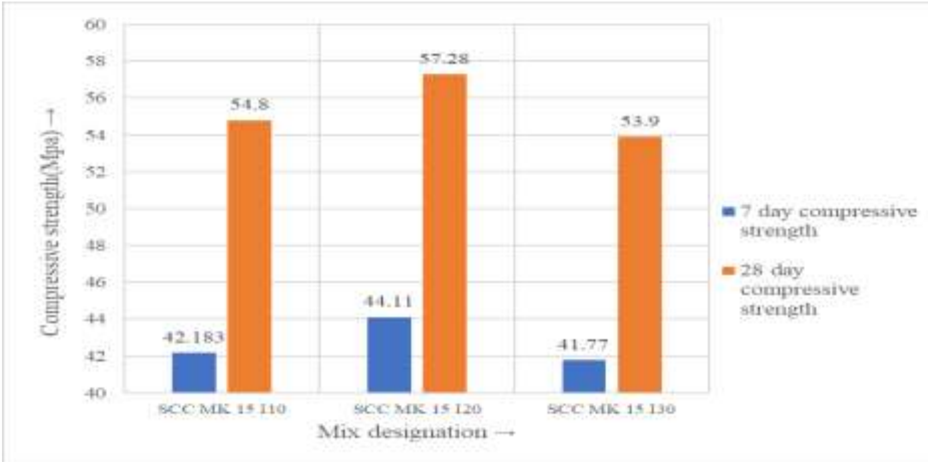

Fig.-4: Compressive strength of metakaolin based SCC with iron slag

4.2.2 Split tensile strength test

The tensile strength of concrete is one of the basic and important properties. Splitting tensile strength test on the concrete cylinder is a method to determine the tensile strength of concrete. The concrete is very weak in tension due to its brittle nature and is not expected to resist the direct tension. The concrete develops cracks when subjected to tensile forces. Thus, it is necessary to determine the tensile strength of concrete to determine the load at which the concrete members may crack. The split tensile test was carried out as per IS 5816-1999 by placing the cylindrical specimen horizontally between the loading surfaces of compression testing machine and then load was applied until the failure of the cylinder along the vertical diameter. This is an indirect method for determining the tensile strength of concrete Cylindrical specimens of diameter 150 mm and height 300 mm were used for this test.

The split tensile strength was calculated by,

Where

P = applied load

D = diameter of the cylinder

L= length of the cylinder

Fig -5: Split tensile strength test

Table -12: Split tensile strength of Metakaolin based SCC

SL.NO.	Mix	7-day split tensile strength(N/mm^2)	28-day split tensile strength (N/mm^2)	Percentage variation in 28-day strength
1.	SCC MK 0	3.81	4.71	-
2.	SCC MK 5	3.954	4.87	+3.28
3.	SCC MK 10	4.271	5.03	+6.79
4.	SCC MK 15	4.52	5.81	+23.35
5.	SCC MK 20	4.067	5.31	+12.74

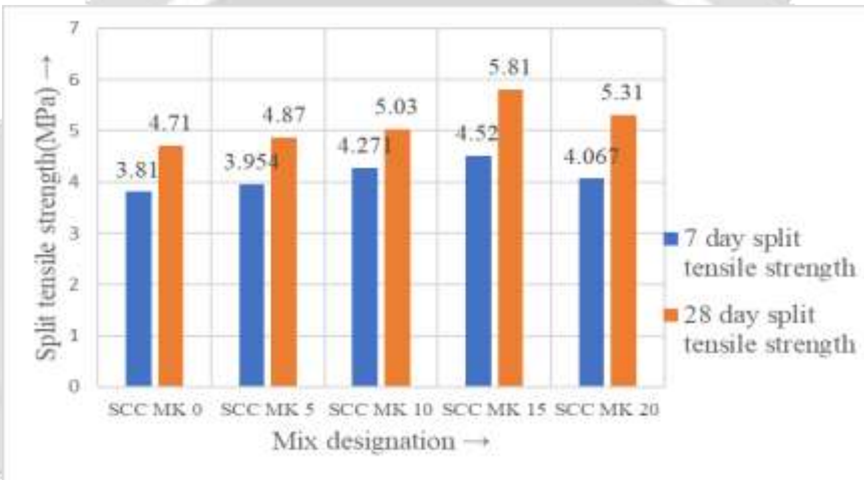

Fig -6: Split tensile strength of Metakaolin based SCC

Table -13: Split tensile strength of metakaolin based SCC with iron slag

SL.NO.	Mix	7 days split tensile strength (MPa)	28 days split tensile strength (Mpa)	Percentage variation in 28 day strength
1.	SCC MK 0	3.81	4.71	-
2.	SCC MK 15 I10	4.15	5.35	+13.59
3.	SCC MK 15 I20	4.43	5.71	+21.23
4.	SCC MK 15 I30	4.089	5.32	+12.95

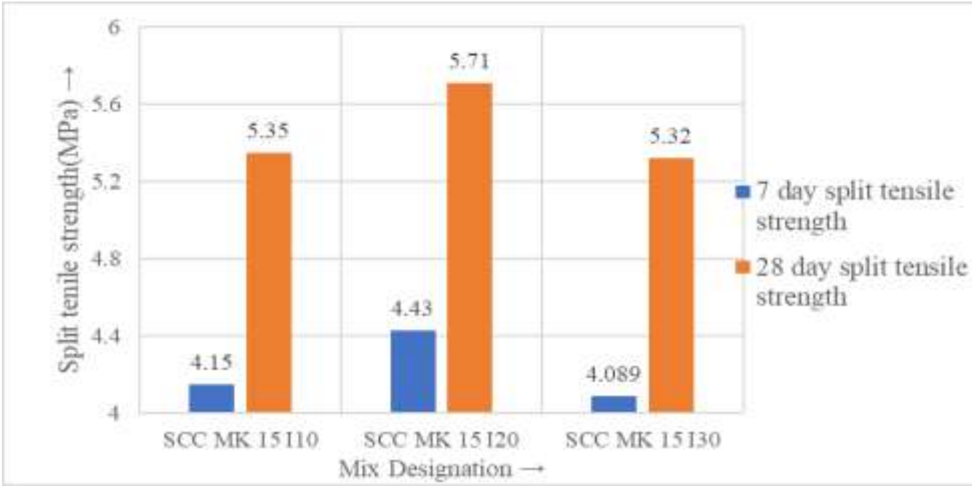

Fig.-7: Split tensile strength of metakaolin based SCC with iron slag

4.2.3 Flexural strength test

The flexural test was carried out in accordance with IS 516:1959 (reaffirmed on 2004) on reinforced SCC beams700 mm long and 150 x 150 mm in cross section. The testing was conducted on Universal Testing Machine (UTM) with two point loading setup. The load increased continuously without shock until the specimen failed and the maximum load was recorded as P. Figure 8 shows the flexural strength testing of the specimen.

The flexural strength is given by,

$$\text{Flexural strength} = \frac{Pl}{bd^2}$$

Where

l = length of specimen

b = width of specimen

d = depth of specimen

Fig -8: Flexural strength test

Table -14: Flexural strength values of metakaolin based SCC.

Sl. No	Mix	28day flexural strength(MPa)	Percentage variation in 28-day strength
1	SCC MK 0	6.1	-
2	SCC MK 5	6.38	+4.59
3	SCC MK 10	6.632	+8.69
4	SCC MK15	6.82	+11.80
5	SCC MK 20	6.43	+5.41

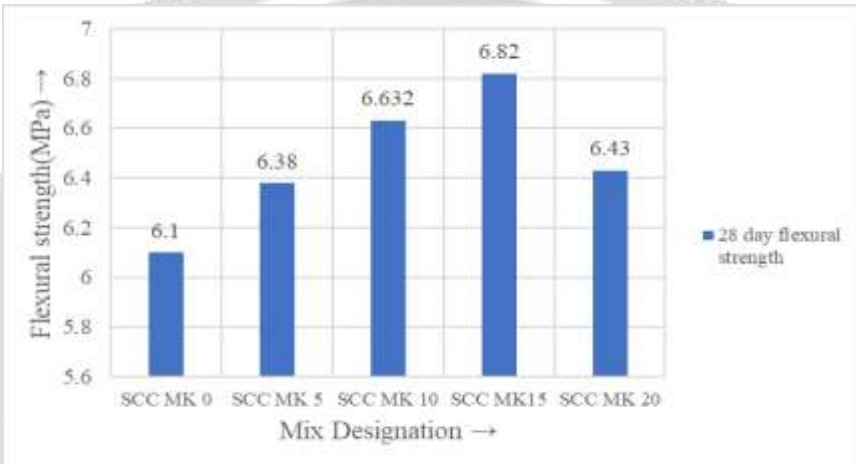

Fig -9: Flexural strength of metakaolin based SCC

Table- 15: Flexural strength of metakaolin based SCC with iron slag

Sl. No	Mix	28 day flexural strength (MPa)	Percentage variation in 28 day strength
1.	SCC MK 15	6.1	-
2.	SCC MK 15 I10	6.35	+4.09
3.	SCC MK 15 I20	6.64	+8.85
4.	SCC MK 15 I30	6.42	+5.24

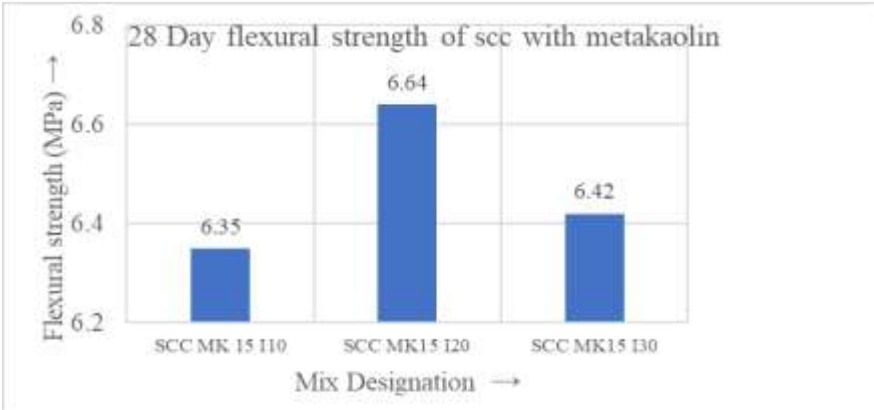

Fig -10: Flexural strength of metakaolin based SCC with iron slag

5 CONCLUSION

Based on the experimental investigation conducted in this work, the following conclusions were drawn.

- SCC can be effectively used where compaction is very difficult due to the presence of heavy reinforcements like beams, columns and for structural members with typical architectural requirements.
- The SCC containing 15% metakaolin as a partial replacement material for cement increases the 28th day compressive strength by 11.65%, split tensile strength by 23.35% and flexural strength by 11.8%. This mix was taken up for future study with partial replacement of fine aggregate with iron slag.
- The SCC containing 15% metakaolin as a partial replacement material for cement and 20% iron slag as a partial replacement material for fine aggregate gives maximum 28th day compressive strength by 14.05%, split tensile strength by 21.23% and flexural strength by 8.85%. The durability study was done on this sample.
- SCC containing 15% metakaolin and 20% iron slag gives low flexural strength when compared to SCC containing 15% metakaolin. This could be due to the presence of iron slag which is used as a partial replacement material for fine aggregate.

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