Study of HSC by Using Fly Ash as Partial Replacement of Cement & Incorporating of Steel Fibers

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Abstract. Concrete is one in all the foremost common building materials used. The current study deals with high strength concrete by adding steel (metallic) fiber material in different volume fractions 0%, 0.3%, 0.6%, 0.9%, 1.2% and 1.5% to strengthen the engineering concrete properties and partial replacement of OPC with fly ash in percentages of 0-25% in various ratios. The specimen's exposure periods of 7, 28 and 56 days on numerous tests like compressive, flexural and split tensile strengths. The research has focused on mechanical and durability properties of high strength concrete. It was observed that 20% fly ash replacement produces the max compressive strength parameters with 1.2% crimped steel fibers, but, the split tensile and flexural strength of concrete was maximum at 25% fly ash along with 1.5% steel fibers. Furthermore, the durability of concrete has conducted such as acid attack due to HCl and H\(_2\)SO\(_4\). The minimum loss of weight produces at the 25% fly ash is 2.98% and 2.81% by HCl and H\(_2\)SO\(_4\).

1. Introduction
In our country, concrete business plays a serious role in the development of nation; government pay an enormous amount for building the nation like bridges, buildings and dams etc. The high strength concrete is incredibly expensive. However, it is utilized in the civil industry by substitution of different waste materials like fly ash, plastic, GGBS, E-Waste, fibers results to decrease the effective value increase the mechanical properties of concrete(Barbuta M et al. 2016). In this research work situation, the cement by fly ash and felt fibers in concrete with different percentages. We tend to success performed different experimental investigation tests for obtaining the mechanical features of high strength concrete. This type of research work protects the environment from the release of a high amount of CO\(_2\) due to making of cement production so presenting my research work carried on fly ash waste material with fibres. The manufacturing procedure for cement generates a massive quantity of CO\(_2\). Nearly 8% of these greenhouse gas emissions creates from cement production(Ahmaruzzaman M 2010). ACI 211 committee recommended that the 15-25% substitute of cement by fly ash(FA) in HSC (ACI Committee, 1993). The prosperous use of fly ash is not only going to lower the cement ingestion but in addition, eradicate the waste disposal expenses. Class F fly ash comprises a slight amount of lime. So, compressive strength falls with all the increment of fly ash material. But, as a result of pozzolanic action of fly ash, strength rise in after phases of curing (Sumer M 2012, Mohamed HA 2011). Concrete is a naturally brittle material i.e the concrete weak in tension but strong in compression, this drawback can overcome by the
inclusion of fibers like metallic, synthetic, glass fibers. This paper focused on fly ash along with steel fibers. The steel fibers play a vital role to improve the different properties of concrete like tensile strength and flexural strengths (Kaikea et al. 2014, Afroughsabet et al. 2015). The macro metallic steel fibers used as secondary reinforcement in concrete matrix in addition to the rebar in concrete structural and non-structural applications. They reported the enhanced the flexural strength, ductility and shear resistance in concrete (Lofgren 2005). As a result of the pozzolanic response, the strength of concrete increment lasts to get a lengthier duration of time evaluating into the concrete (Chindaprasirt et al. 2004). The reaction time of fly ash in concrete relatively requires a longer period of time to develop a greater strength. So very low compressive strength has been reported throughout the beginning phases of curing. Nevertheless, the mechanical parameters of concrete are depending upon the fly ash own physical and chemical qualities. According to (Kumar et al. 2007) found that the FA mixture of fine particle size distribution shows greater compressive strength comparing to the ordinary blend mix. The more proportion dose of fly ash (FA) the greater the standards of concrete compressive ability until finally 30% of FA from treated in potable water up to 28days and also the smallest results observed to be specimens were cured in the air (Vinayagam 2012). Even the workability of concrete blends rises has been increased by the dose of fly ash 0-40%. The replacement-level of cement concrete can be raised to more than 10% since there has been an increase at compressive strength for 20-40% FA content material. The substitute material sample listed that the Maximum permeability, whereas the 40% FA sample attained exactly the less permeability (Bahedh et al. 2018). The research work done flexural Strength evaluation on standard size beams. A definite mixture M20 has designed depending on IS 10262:2009 guidelines. The water-cement ratio has maintained as 0.48. The Flexural strength evaluation was conducted at a regular interval. It had been concluded that the 28th day flexural Energy of concrete was raised up to 11.1% with 20% replacement-level of Portland cement by fly ash (Parmar et al.). T.C Yet et al reported that the static and dynamic properties of concrete could be improved by the combined effect of steel fibers and fly ash (T.C yet et al. 2012).

2. Materials used

2.1 Cement
OPC 53Grade is available in India in 3-types-33, 43 and 53. The experimental investigation was done on ultra tech 53 Grade OPC confirming to IS:12269-2013. This brand and has maintained throughout project work. It is available in the locality of Eluru. The properties of cement were illustrated in table.1

| S.No | Physical Properties       | Results of after performing the test                      |
|------|---------------------------|----------------------------------------------------------|
| 1    | Fineness                  | Retained- 5.0% & Fineness-95.0%                          |
| 2    | Specific gravity          | 3.14                                                     |
| 3    | Setting times(Initial & Final) | 43min and 535min                                         |
| 4    | Soundness of cement(mm)  | 5                                                        |
| 5    | Consistency of cement     | 32.0%                                                    |
| 6    | Compressive Strength      | 54.84N/mm²                                                |

2.2 Fine aggregate
In this study, locally available river sand can be used and confirming to IS:383-1970. The various fine aggregates tests were performed and shown in Table.2. The fine aggregates are free from silt, and clay was used for the investigation.
Table 2: Physical parameters of fine aggregate

| S.No | Physical Properties       | Results of FA after the test          |
|------|---------------------------|---------------------------------------|
| 1    | Particle Size             | FA <4.75mm & and Zone of sand is II   |
| 2    | Fineness Modulus          | 2.61                                  |
| 3    | Rodded Bulk density       | 1624Kg/m³                            |
| 4    | Water absorption          | 1.05%                                 |
| 5    | Specific gravity(G)       | 2.71                                  |

2.3 Coarse aggregate
The crushed stones of angular shaped aggregates were used and confirming to IS:383-1970. The aggregates have been from a locally available quarry and satisfy the standard Indian provisions. The coarse aggregates properties have found out by using the different tests and results illustrated in Table.3

Table 3: Physical properties of Coarse aggregate

| S.No | Physical Properties       | Results of CA after the test          |
|------|---------------------------|---------------------------------------|
| 1    | Size of Aggregate         | 10mm and 20mm                         |
| 2    | Fineness Modulus(FM)      | 7.10                                  |
| 3    | Rodded Bulk density       | 1599Kg/m³                            |
| 4    | Water absorption          | 1.15%                                 |
| 5    | Specific gravity(G)       | 2.67                                  |

2.4 Fly ash
According to the type of coal used for combustion, ASTM C 618 widely categorized fly ash into two different types. Inside my analysis class F fly ash can be used and having a specific gravity of 2.2, fineness modulus (FM) is 2.5 and colour is whitish-grey, in this current study, fly ash in NTTPS, Vijayawada can be used.

2.5 Crimped steel fiber
Steel fibers are defined as short, discrete length of steel having an aspect ratio (AR) from 20 to 100 with any cross-section. Aspect ratio means the ratio of length to diameter. The current study adopted an aspect-ratio 50 inside this undertaking. Within this endeavor, we utilize the fiber for increasing the strength of concrete. Crimped steel fibers are have been put into concrete to boost properties such as tensile and flexural strength. The iron content increases the flexural strength up to 25-100% depending upon the ratio of fiber included.

Fig.1. Crimped steel fibers with 1mm diameter & 50mm length.
Table 4: Mechanical properties of steel fibers

| Type of fiber | Shape of fiber | Length l (mm) | Diameter d (mm) | Aspect ratio (l/d) | Density (Kg/m³) | Tensile strength (MPa) |
|---------------|----------------|---------------|-----------------|-------------------|-----------------|------------------------|
| Steel         | crimped        | 50            | 1               | 50                | 7.80            | 1098                   |

2.6 Water
Portable drinking water was used in this work for all the purpose like mix design as well as curing.

3. Tests conducted

3.1 Compressive strength
The compressive strength of concrete is determined by using the CTM (compression testing machine) with a capacity of 3000KN depicted in fig. strength of the concrete found by using the specimens of size 150mm x 150mm x 150mm. further applied the uniform speed of 140kg/sq.cm/minute till the specimen failed. The machinery outcomes tabulated. Strength of the concrete can find out by using the following formula.

\[
\text{Compressive Strength} = \frac{\text{load (P)}}{\text{cross-sectional area (A)}}
\]

![Fig.2. Compression Testing Machine of Capacity 3000KN.](image)

3.2 Flexural strength of concrete
The flexural testing machine is shown in fig.3 used to determine the flexural strength of concrete. The failure of plain and blended mixes bending effect on beams of size 100mm x 100mm x 500mm. The specimens test at room temperature with a regular curing period of 7 and 28days. These prisms were tested four-point loading flexural testing machine after completion of specified curing time. The rate of load is applied uniformly with a face rate of 1.8kN/min till the Specimens break as per "IS 516-1959". The flexural strength evaluated by the following formula.

\[
\text{Flexural Strength} = \frac{Pl}{bd^2} \left( \frac{N}{\text{mm}^2} \right)
\]
3.3 Split tensile strength of concrete
It is an indirect test used to evaluate the tensile strength in concrete and uniformly apply the load axially. The concrete specimens in cylindrical shape of size 300mm(height)×150mm(diameter) was used to determine the splitting tensile strength. The samples are tested after a certain period of curing under the CTM at the age of 7, 28 & 56 days. The load is applied gradually at the loading rate of 1.2 MPa/min until the Specimens will be split/fail according to IS 516-1959.

\[
\text{Split tensile strength} = \frac{2P}{\pi LD} \left( \frac{N}{\text{mm}^2} \right)
\]

4. Mix design
Mix design, depending on IS 10262-2009[18], the concrete mixture was prepared for high strength concrete with water-cement ratio of 0.32. The ratios from the weight of cement, fine aggregate and well-graded aggregate are accessed utilizing the Department of Environment (DOE) system is listed below. DOE method currently is your standard British procedure of concrete mixture design the task involved with this approach is clarified alternatively of outside dated Road Notice no 4 procedure [14]. These proportions are kept rigorously the same through the entire casting process to get a uniform standard and flowability concrete mixture. The compressive, split up tensile and flexure evaluations are investigated. Workability evaluations will also be done in this mixture. The mix proportions are shown in the table.5

5

| S.No | % of fly ash | Cement | Fly ash | Fine aggregate | Coarse aggregate |
|------|--------------|--------|---------|----------------|------------------|
| 1    | 0            | 1.00   | 0       | 1.04           | 1.57             |
| 2    | 5            | 0.95   | 0.05    | 1.13           | 1.69             |
| 3    | 10           | 0.90   | 0.10    | 1.23           | 1.82             |
| 4    | 15           | 0.85   | 0.15    | 1.35           | 1.95             |
| 5    | 20           | 0.80   | 0.20    | 1.46           | 2.06             |
| 6    | 25           | 0.75   | 0.25    | 1.58           | 2.19             |
5. Results and discussion

5.1 Workability test
The workability of concrete measure with the help of the slump cone apparatus. The slump range selected for this test is 90 to 110 mm. The workability of concrete can increase when using the fly ash as a mineral admixture with a water-cement ratio of 0.32.

5.2 Mechanical properties

Table 6: Compressive strength of cubes rate up to 56 days at different fly ash percentages 0-25%.

| % of Replacement | Fiber dose % | 7-d (MPa) | 28-d (MPa) | 56-d (MPa) |
|------------------|--------------|-----------|------------|------------|
| 0                | 0            | 38.57     | 65.25      | 67.98      |
| 5                | 0.3          | 36.50     | 56.47      | 58.57      |
| 10               | 0.6          | 34.10     | 60.45      | 62.65      |
| 15               | 0.9          | 32.33     | 64.32      | 66.02      |
| 20               | 1.2          | 31.58     | 68.12      | 70.32      |
| 25               | 1.5          | 29.51     | 66.22      | 68.72      |

Fig. 4 Compressive Strength of Concrete cubes using Fly ash and steel fibers

The compressive strength of concrete has been measured by the curing age of 7-d, 28-d and 56-d as shown in fig.4 At first, the conventional mix shows the compressive strength of 38.57MPa, 65.25MPa and 67.9Mpa at 7days, 28days and 56days respectively. The graph indicates that the 7 days strength adopted the decreased trend. But, the 28 days of curing shows superior performance at optimum dosage of fly ash at 20% replacement along with crimped steel fibers of 1.2% volume are 68.12MPa which is better compared to the control mix. Even the excess dosage of fly ash beyond 20% also yielded satisfactory results compared to conventional mix properties at 28 days ageing. In the same way, the compressive strength of concrete blocks cured for 56 days had shown the
maximum strength at 20% of fly ash and 1.2% of steel fiber, and it also satisfies the conventional mix properties.

Table 7: Split tensile strength of cylinders rate up to 56 days at different fly ash percentages 0-25%

| S.No | % of Replacement | Fiber dose % | 7-d (MPa) | 28-d (MPa) | 56-d (MPa) |
|------|------------------|--------------|-----------|------------|------------|
| 1    | 0                | 0.0          | 3.30      | 5.98       | 6.87       |
| 2    | 5                | 0.3          | 2.61      | 5.15       | 5.81       |
| 3    | 10               | 0.9          | 3.01      | 5.48       | 6.24       |
| 4    | 15               | 1.2          | 3.32      | 5.81       | 6.32       |
| 5    | 20               | 1.5          | 4.10      | 6.61       | 7.32       |
| 6    | 25               | 1.8          | 4.71      | 6.88       | 7.95       |

Fig.5 Split tensile Strength of Concrete using Fly ash and Steel fibers

Split tensile strength of concrete examines by compression testing machine by compressive load until it breaks. As per the experimental investigation of the split tensile strength of concrete, the trend of the results has significantly increased from 0.3, 0.6, 0.9, 1.2 & 1.5% volume fraction of rounded cramped steel fibers with fly ash of 5%, 10%, 15%, 20% and 25% replacements respectively for the curing period of 7, 28 and 56 days. The slight longitudinal hairline cracks (1mm) observed because of the cramped steel fibers exhibited the bridging action between the concrete matrix. Fig.5 depicted the split tensile strength adopted a gradually increasing trend for all the replacing percentages of fly ash along with incorporated steel fibers. The maximum split tensile strength was 4.10MPa at the age of curing for 7 days. It shows the upward trend, which means it gets increased with the addition of fly ash and round cramped steel fibers and it occurs at 25% of fly ash and 1.5% of steel fibers. The same pattern is followed by the remaining two curing ages that are 28 days and 56 days.
Table 8: Flexural strength of beams rate up to 56 days at different percentages of fly ash 0-25%.

| % of Replacement | Fiber dose % | 7-d (MPa) | 28-d (MPa) | 56-d (MPa) |
|------------------|--------------|-----------|------------|------------|
| 0                | 0            | 4.45      | 6.96       | 7.21       |
| 5                | 0.3          | 3.74      | 6.46       | 6.88       |
| 10               | 0.6          | 4.02      | 6.78       | 7.24       |
| 15               | 0.9          | 4.51      | 7.17       | 7.56       |
| 20               | 1.2          | 4.96      | 7.52       | 7.94       |
| 25               | 1.5          | 5.10      | 7.87       | 8.21       |

Fig. 6 Flexure Strength of Concrete using Fly ash and crimped rounded steel fibers

The fibre-reinforced flexural strength of concrete was found out and plotted in fig. about 7, 28 and 56 days. The results indicated that the static flexural strength could significantly improve by the incorporation of round crimped steel fibers with a volume fraction of 0-1.5% along with fly ash. The flexural strength of concrete depicted in fig. 6, which indicates an increasing trend with the respective curing age of 7, 28 and 56 days. The highest flexural strength in curing age of 7 days was 5.1 MPa at 25% of fly ash along with 1.5% of steel fiber volume in the same way the maximum flexural strength for curing ages of 28 days and 56 days were 7.87 MPa and 8.21 MPa at 25% of fly ash using 1.5% of steel fibers.

5.3 Water absorption test on concrete

Water absorption is one of the main factors affecting the durability of concrete. The water absorption test has performed on the cubical specimens (150×150×150) mm size. The water absorption percentage has a measure of porous material which can be allowed water from one layer of concrete to another layer, it corroding the embedded materials of fibers/steel/reinforcement in concrete due to water bringing the dangerous chemicals into the concrete. So this is one of the most severe problems in concrete. Initially, the samples collected after completion of curing period of 28 days. Determine the standard cubical weight as W1; further, the specimens are dried in an oven at a temperature of nearly 100±5°C. This drying process has been continued until the alteration between the two consecutive weights becomes constant. The final weight of oven-dried specimens
weighed after it reaches room temperature (W2). The formula used to found the water absorption of concrete is given below.

\[
\text{Water absorption(\%)} = \frac{W1 - W2}{W2} \times 100
\]

The fly ash based concrete satisfy the conventional mix properties at proportional at 20% and 25% of fly ash. So the water absorption test is considered for only two dosages.

| Mix id. | Weight before oven (Kg) | Weight after oven (kg) | % water absorption |
|---------|-------------------------|------------------------|--------------------|
| 0%Fly ash+0% SF | 8.401 | 8.045 | 4.23 |
| 20%Fly ash+1.2%SF | 8.656 | 8.410 | 2.84 |
| 25%Fly ash+1.5%SF | 8.678 | 8.435 | 2.80 |

Table 9 reported the lower water value as 2.84, 2.80 at 20% and 25% fly ash respectively along with rounded crimped steel fibers. As per the results increase of fly ash from 20-25% more resistance to the water absorption of concrete.

5.4 Acid attack test

The concrete cubical blocks starting from the traditional concrete mix to the concrete mix combined with crimped steel fibers and fly ash in increased proportions like 0.3-1.5% and 0-25% respectively. The concrete may be deteriorated in the HCl and H2SO4 with 5% concentration. The results illustrated in table.9 were gradually decreased, the final result resolved after 28days. The necessary precaution followed was to dry the samples to avoid water content. After 28 days of 5% (HCl &H2SO4) the results as 2.98%, and 2.81% regarding loss in weight. Similarly, 15.13% and 15.10% considering the loss in compressive strength (25% fly ash +1.5% crimped steel fibers).

| Mix id. | Initial weight before oven (Kg) | weight after oven HCL attack (Kg) | % Loss in weight | % loss in Compressive strength |
|---------|----------------------------------|----------------------------------|------------------|-----------------------------|
| 0%Fly ash+0% SF | 8.32 | 8.01 | 3.87 | 28.31 |
| 5%Fly ash+0.3%SF | 8.38 | 8.07 | 3.80 | 25.12 |
| 10%Fly ash+0.6%SF | 8.42 | 8.13 | 3.56 | 22.13 |
| 15%Fly ash+0.9%SF | 8.55 | 8.27 | 3.38 | 19.45 |
| 20%Fly ash+1.2%SF | 8.63 | 8.37 | 3.10 | 16.07 |
| 25%Fly ash+1.5%SF | 8.71 | 8.46 | 2.98 | 15.13 |
Let the results to be discussed here basically on adding HCL to the concrete mix there is some amount reduction in weight and compressive strength of the samples. It is necessary to know the loss in weight and compressive strength, therefore the addition of 5% of HCL to the samples containing fly ash and steel fibers in quantities like 0%-25% and 0%-1.5% respectively. 3.87% and 28.31% loss by weight and compressive strength for traditional mix sample after that there is a significant decrease identified in both weight and compressive strength. They have approximately common decrement from 5% fly ash + 0.3% fibers to 20% fly ash + 1.5% fibers. But there is the nominal change in the loss of weight, between 20% fly ash and 25% fly ash were 3.10 and 2.98%.

Table 11: Results of "Acid Attack(H₂SO₄)" at conventional and 0-25% Fly ash along steel fibers.

| Mix id.       | Initial weight before oven (Kg) | weight after oven HCL attack (Kg) | % Loss in weight | % loss in Compressive strength |
|---------------|---------------------------------|-----------------------------------|-----------------|--------------------------------|
| 0% Fly ash+0% SF | 8.38                            | 8.10                             | 3.45            | 26.77                          |
| 5%Fly ash+0.3% SF | 8.49                            | 8.22                             | 3.28            | 24.31                          |
| 10% Fly ash+0.6% SF | 8.52                            | 8.26                             | 3.14            | 22.09                          |
| 15%Fly ash+0.9% SF | 8.60                            | 8.35                             | 2.99            | 18.89                          |
| 20%Fly ash+1.2% SF | 8.72                            | 8.48                             | 2.83            | 15.99                          |
| 25%Fly ash+1.5% SF | 8.76                            | 8.52                             | 2.81            | 15.10                          |

Fig.7: Acid attack (HCl) test for 0-25% fly ash along with steel fibers

Fig.8: Acid attack (H₂SO₄) test for 0-25% fly ash along with steel fibers.
In the same way, the acid attack caused by H$_2$SO$_4$ was also same as HCL, it follows the decreased trend, and the loss in weight was 3.45%, and loss in compressive strength is 26.77% for the conventional mix, and it shows a nominal change between 20% fly ash + 1.2% steel fibers and 25% fly ash +1.5% steel fibers. The comparison between the results obtained by the addition of HCL and H$_2$SO$_4$, there is a nominal change in weight and compressive strength occurred.

6. Conclusions

- The workability of concrete has increased by the addition of fly ash content from 0-25% with a water cement ratio of 0.32. when the fiber is used at 1.2% the target strength of concrete is reached at 20% fly ash compared to control mix, in addition, to get a good improvement in workability.
- The superior performance observed at 20% optimum of fly ash along round crimped steel fibers 1.2% dosage. The results indicated that the compressive strength of concrete is increasing gradually from 5-20% then starts to decrease.
- The early age strength of concrete decreased from 5-25% dose, but, the strength has significantly increased from 5-20% then start to decrease at 25% fly ash. The maximum compressive strength obtained at 20% optimum fly ash as 68.12MPa at 28days than conventional mix.
- The flexural and split tensile strength of the concrete increased by using rounded crimped steel fiber content of 0-1.5%. Engineering concrete properties like split and flexural strengths observed to rise for 7 and 28 days gradually, but particularly less improvement after a curing period of 56days. It is noticed that hairline cracks are formed in split tensile test longitudinally. Maximum all the mechanical properties of concrete is continuously increased for a curing period of 56 days.
- The more water resistance observed at 20 and 25% shown in table.9 The lower water resistance value as 2.92, 2.88 at 20% and 25% fly ash respectively along with fibers.
- The fly ash based concrete shows more resistance to the effects of acid attack plotted in fig.7 & 8.

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