Effect of ferrochrome slag and fly ash on the mechanical properties of concrete

B P R V S Priyatham¹, D V S K Chaitanya², G Prasanna Kumar³

¹Assistant Professor, Department of Civil Engineering, GMR Institute of Technology, Rajam, Andhra Pradesh, India
²Assistant Professor, Department of Civil Engineering, Acharya Nagarjuna University, Guntur, India
³Research Scholar, Department of Civil Engineering, Andhra University, Visakhapatnam, India
E-mail: priyatham.phani@gmail.com

Abstract: Now a day’s construction industry is focusing on various wastes from other industries to use them as substitutes for construction materials which will reduce their initial cost and impact on the environment. Use of industrial waste materials in concrete is a substitute for the shortage of natural resources. Waste disposal from steel manufacturing industries and power plants are increasing day by day and creating a lot of environmental pollution due to lack of utilizing them. There is a lot of wastes from industries like fly ash, GGBS, and slag-based compounds which can be used as replacement materials for aggregates. The present experimental investigation examines the possibility of replacing coarse aggregate with ferrochrome slag waste obtained from steel manufacturing industries and cement with fly ash obtained from power plants in concrete mix design for many construction practices. The experiments were conducted on the concrete mix in which natural coarse aggregate is replaced with ferrochrome slag to achieve optimal replacement of ferrochrome slag and the effect of fly ash along with the optimal ferrochrome slag on the mechanical properties of concrete.

1. Introduction
Increased infrastructure projects due to rapid industrialization, population growth and continuous dependence on conventional materials of concrete making results in the scarcity of the construction materials which increases the construction costs. Natural resources were used to produce various construction materials from traditional methods. Due to the heavy development in the industrial and urban management systems, the generation of the wastes was more. These wastes were disposed of in the open places which lead to pollution of the entire environment resulting in the hazardous effects [1]. Hence as an alternative, those industrial wastes can be recycled and reused in concrete. Industrial wastes like fly ash, GGBS, steel slag [2], copper slag [3], bagasse ash and ferrochrome slag [4] etc. are generated from various industries like thermal power plants, steel plants, sugar industries etc. By utilizing these industrial wastes as alternative building materials in concrete may reduce some impact on the environment.

Concrete is an eco-friendly material in the environment throughout its life span in all the stages considering from the starting stage of production of raw materials to the ending stage of demolition thus results in converting it into a natural choice for the construction purposes to make it sustainable. Concrete primarily constitutes of cement, coarse aggregate and fine aggregate. Usually, cement is used as a binder, natural river sand and conventional stone are used as fine aggregate and coarse aggregate. Usage of cement in concrete leads to the emission of CO₂ into the environment which further leads to the greenhouse effect and global warming. Hence, we can choose alternative materials for concrete
constituents to reduce the scarcity of natural resources and as well as adverse effects on the environment. The main purpose of this work is to study the efficient usage of different industrial solid wastes for aiming sustainable concrete.

FeCr alloy is a primary constituent in stainless steel manufacturing. During this process, the major by-product obtained is ferrochrome slag. About 1.1 –1.6 tons of slag is generated for a ton of ferrochrome production [5]. Majorly Ferrochrome slag constitutes silica, alumina, magnesium and chromium oxides which give strength to the ferrochrome slag. We can use this slag material as coarse aggregate in concrete and its applications [6]. Ferrochrome slag is obtained as a liquid at 1700 Degree Celsius, which comprises of chrome, ferrous/ferric oxides and CaO. Ferrochrome slag is used for recycling, reuse and in addition to this, the slag plays a vital role in attaining unique properties like strength and stability. Ferrochrome slag exhibits more advantages when compared to other materials based on physical properties. This slag is porous and hence have a high-water absorption rate. It has good adhesion and good abrasion resistance.

Fly ash is a substance which is consisting of finely divided particles. It is waste material that is formed during the pulverized coal-burning process in power plants for generation of electricity. It constitutes silica, alumina, calcium oxide contents and some metal oxides. Fly ash is a pozzolana which contains aluminous materials as well as siliceous materials that result in the formation of cement in the water presence. Hence, fly ash is considered as replaceable material for cement as it has some binding properties. It is of two types (class C, class F), based on the calcium oxide content and the type of coal. Generally, in India Class F fly ash will be available and it is having minimum CaO content.

2. Literature Review
Naga Rajesh et al 2019 researched on sustainable micro-concrete. Devi and Gnanavel studied the properties of Concrete Manufactured Using Steel Slag. Wei et al. determined the optimum content of copper slag as a fine aggregate in high strength concrete. Panda et al. assessed the feasibility of ferrochrome slag as a concrete aggregate material. Kumar et al. 2014 studied the effect of industrial waste ferrochrome slag in conventional and low cement castables. Rajashekar, et al. (2015) had attempted replacing the natural coarse aggregate in concrete with ferrochrome slag and tested for compressive strength, which has shown the increased strengths of concrete. Ponnada 2014 experimented on the combined effect of flaky and elongated aggregates on strength and workability of concrete.

3. Materials and Methodology

3.1. Cement
Cement is a binding material which binds the fine and coarse aggregate particles together by setting as well as hardening firmly when water is added. In this experimental work, OPC 53 grade confining to IS: 12269 - 2013 is used. Tests on the cement were performed according to IS: 4031 - 1988 and the properties of cement are listed in table 1.

| Test Specifications     | Test Result | Recommended Values |
|-------------------------|-------------|-------------------|
| Specfic Gravity         | IS 4031 (XI)| 3.12              | 3.0 - 3.2          |
| % Finess                | IS 4031 (I) | 2%                | < 10%              |
| Normal Consistency      | IS 4031 (IV)| 32%               | 27 - 33%           |
| Initial Setting Time    | IS 4031 (IV)| 46 min            | > 30 min           |
| Final Setting Time      | IS 4031 (V) | 330 min           | < 10 hrs           |
| Soundness               | IS 4031 (III)| 2 mm             | < 10 mm            |

3.2. Fine Aggregates
The fine aggregate used in the study is river sand collected from Nagavali river region, the sample is sieved through 4.75mm IS sieve to remove deleterious and oversized particles and tested for its properties as per IS 383 2016. Tests on the fine aggregate were performed according to IS 2386 1963 and fine aggregate properties are shown in table 2.
Table 2. Properties of Fine Aggregate.

| Test                        | Test Specifications | Result | Recommended Values |
|-----------------------------|--------------------|--------|--------------------|
| Specific Gravity            | IS 2386 (III)      | 2.66   | 2.50 - 3           |
| Sieve analysis              | IS 2386 (I)       | Zone - III | N. A            |
| Fineness modulus            | IS 2386 (I)       | 2.4    | 2.2 - 2.6          |
| Water absorption            | IS 2386 (III)     | 1%     | 0.1 - 2%           |

3.3. Coarse Aggregate

The coarse aggregate in the present study is the crushed granite stone collected from a quarry at Rapaka village. It acts as a crucial constituent in developing strength. Its properties are tested as per IS 383 2016. 20mm and 10mm sized aggregates are used in the study. Coarse aggregates were tested according to IS 2386 1963 and coarse aggregate properties are tabulated in table 3.

Table 3. Properties of Coarse Aggregate.

| Test                        | Test Specifications | Result   | Recommended Values |
|-----------------------------|--------------------|----------|--------------------|
| Specific Gravity            | IS 2386 (III)      | 2.87     | 2.50 - 3.0         |
| Impact Value                | IS 2386 (IV)       | 15.9%    | < 35%              |
| Flakiness Index             | IS 2386 (I)       | 8.42%    | < 15%              |
| Elongation Index            | IS 2386 (II)      | 14.28%   | < 15%              |
| Water Absorption            | IS 2386 (III)     | 0.4%     | 0 – 2%             |

3.4. Ferrochrome Slag

Ferrochrome slag (FC) is the byproduct obtained from the manufacturing of stainless steel in which chromium is the important constituent. It is collected from the dumping yard of Facor Alloys Limited, Garividi. Ferrochrome Slag is of different sizes and is crushed manually to obtain 20mm and 10mm sized particles as coarse aggregates. The specific gravity of slag is 2.94, impact value is 13.7% and water absorption is 0.5%

Preliminary tests on the materials are carried out and the mix design is done as per IS: 10262 – 2019. The replacement of ferrochrome slag for coarse aggregate is optimized and for that mix, the replacement is done for cement with fly ash and properties of concrete were studied.

Figure 1. Ferrochrome Slag

4. Mix Proportions

Mix design is performed as per IS 10262 2019 and the grade of concrete adopted is M25. Coarse aggregate is replaced by 25%, 50%, 75% and 100% of ferrochrome slag to get the optimum mix. For this optimum mix, cement is replaced by 10%, 20% and 30% of fly ash to study the concrete properties.
To maintain the workability, superplasticizer is added. The details of quantities for mix design are detailed in table 4

| Ingredients (kg/m³) | CC | FC25 | FC50 | FC75 | FC100 | FC75 + FA10 | FC75 + FA20 | FC75 + FA30 |
|--------------------|----|------|------|------|-------|-------------|-------------|-------------|
| Cement             | 375| 375  | 375  | 375  | 375   | 337.5       | 300         | 262.5       |
| Fly ash (%)        | 0  | 0    | 0    | 0    | 0     | 10          | 20          | 30          |
| Ferrochrome Slag (%)| 0  | 25   | 50   | 75   | 100   | 0           | 0           | 0           |
| Fly ash            | 0  | 0    | 0    | 0    | 0     | 37.5        | 75          | 112.5       |
| Ferrochrome Slag   | 0  | 322.5| 645  | 967.5| 1290  | 967.5       | 967.5       | 967.5       |
| Fine Aggregate     | 661| 661  | 661  | 661  | 661   | 661         | 661         | 661         |
| Coarse Aggregate   | 1290| 967.5| 645  | 322.5| 0     | 322.5       | 322.5       | 322.5       |
| Water              | 180| 180  | 180  | 180  | 180   | 180         | 180         | 180         |

5. Preparation of samples
Strength characteristics of the samples replaced with ferrochrome slag and fly ash for coarse aggregate and cement respectively are studied by casting the prisms, cubes and cylinders. As per the quantities calculated based on mix design from table 4, the quantities of different ingredients are weighted and concrete is prepared using the mixer and the samples are cast in the moulds and compacted in three different layers using the tamping rod to remove the air voids and the top surface is finished with the trowel. For each mix 6 cubes (150x150 mm), 6 prisms (500x100x100 mm) were cast to find out the compressive strength and flexural strength respectively and cylinders (150 mm diameter x 300 mm height) were cast for fly ash mixes to know the split tensile strength. After 24 hours the casted samples are demoulded and placed in the tank for water curing. The samples are taken out and are dried before testing for 7- and 28-days strengths.

6. Experimental Results and Discussion
6.1. Compressive Strength
Compressive strength of the specimens are determined using ACTM which is having a capacity of 2000kN and the rate of loading is applied at 140kg/cm²/min as per IS: 516 – 2004. The test result for the strength of concrete in compression at 7 and 28 days of concrete is shown in table 5 and the strength variation is plotted in figure 2.
Figure 2. Variation of Compressive strength of cubes with ferrochrome slag

| Mix  | Compressive Strength (MPa) | 7 days | 28 days |
|------|---------------------------|--------|--------|
| CC   | 19                        | 32.65  |
| FC25 | 17.59                     | 31.72  |
| FC50 | 21.83                     | 35.46  |
| FC75 | 24.26                     | 37.86  |
| FC100| 24.01                     | 36.94  |

Table 5. Compressive Strength for Ferrochrome Slag replaced mixes.

6.2. Flexural Strength
Flexural strength of concrete is determined by using UTM which checks the resistance of concrete towards bending. If the beam is stressed uniformly along with one-third of its mid surface then beam fails in its weakest point of that one-third parts, so three-point loading is used here. The load is applied at the rate 1.8kN/m and the test are performed in as per IS: 516 – 2004. Table 6 represents the strength of concrete in flexure at 7 and 28 days of curing.

| Mix  | Flexural Strength (MPa) | 7 days | 28 days |
|------|-------------------------|--------|--------|
| CC   | 3.78                    | 4.95   |
| FC25 | 3.71                    | 5.03   |
| FC50 | 3.89                    | 5.27   |
| FC75 | 4.27                    | 5.4    |
| FC100| 3.91                    | 5.31   |

Table 6. Flexural Strength for Ferrochrome Slag replaced mixes.

Figure 3. Variation of flexural strength with ferrochrome slag

From figure 2 and 3 corresponding to the test results at 7 and 28 days, the optimal replacement of ferrochrome slag is found to be 75% both in compression as well as flexural. The compressive strength is increased by 8.6%, 15.95% and 13.93% for FC50, FC75 and FC100 respectively and decreased by 2.8% for FC25 when compared with the conventional mix. The flexural strength is increased by 1.6%, 6.46%, 9.09% and 7.27% for FC25, FC50, FC75 and FC100 respectively when compared with
conventional mix. Now for the optimum ferrochrome slag mix, cement is replaced with fly ash at proportions of 10%, 20% and 30%. Table 7 represents the strength characteristics of concrete.

**Table 7.** Strength characteristics of concrete for optimum ferrochrome slag and fly ash replaced mixes.

| Mix          | Compressive Strength (MPa) 7 days | Compressive Strength (MPa) 28 days | Flexural Strength (MPa) 7 days | Flexural Strength (MPa) 28 days | Split Tensile Strength (MPa) 7 days | Split Tensile Strength (MPa) 28 days |
|--------------|----------------------------------|-----------------------------------|-------------------------------|-------------------------------|-----------------------------------|-----------------------------------|
| CC           | 19                               | 32.65                             | 3.78                          | 4.95                          | 2.29                              | 2.99                              |
| FC75         | 24.26                            | 37.86                             | 4.27                          | 5.4                           | 2.49                              | 3.58                              |
| FC75 + FA10  | 19.51                            | 29.18                             | 3.77                          | 4.82                          | 2.28                              | 3.25                              |
| FC75 + FA20  | 15.6                             | 24.82                             | 3.26                          | 4.35                          | 2.19                              | 2.7                               |
| FC75 + FA30  | 12.19                            | 20.75                             | 2.95                          | 4.16                          | 2.01                              | 2.28                              |

**Figure 4.** Test setup for flexure and compression

**Figure 5.** Variation of compressive strength with optimum ferrochrome slag and fly ash
From figure 5, 6 and 7 it is noticed that the strengths in compression, flexural and split tension decrease for the optimum ferrochrome slag mixes with the replacement of cement by fly ash. From figure 5 it was inferred that the compressive strength is decreased by 10.6%, 23.9% and 36.4% for FC75+FA10, FC75+FA20 and FC75+FA30 respectively when compared with the conventional mix. From figure 6, the strength of concrete in flexure is decreased by 2.62%, 12.12% and 15.95% for FC75+FA10, FC75+FA20 and FC75+FA30 respectively when compared to conventional mix. From figure 7, the split tensile strength is increased by 19.7%, 8.7% for FC75, FC75 + FA10 respectively and decreased by 9.7%, 23.7% for FC75+FA 20, FC75+FA 30 respectively when compared with conventional mix.

Concrete which is obtained from the optimum mix of ferrochrome slag has exhibited higher compressive strength values when compared to conventional mix, as FeCr is having more specific gravity than the coarse aggregate. This shows that it is suitable for replacing coarse aggregate to achieve sustainable concrete. As the surface of ferrochrome slag is rough, the cement paste has a tendency to fill the rough surfaces which leads to an increase in the strength. On the other side when the optimum mix with ferrochrome slag in replaced by fly ash, the strength decreases gradually.
7. Conclusions

Nowadays in most of the civil engineering practices, many industrial waste materials are used as alternatives to produce sustainable concrete. The strengths of concrete in compression and flexure increases significantly when ferrochrome slag is replaced with the coarse aggregate of up to 75%. The concrete loses its strength as the cement replacement with fly ash increases. The strength in flexure and tension also decreases with the increase of fly ash to the ferrochrome slag mix. Hence ferrochrome slag is recommended as a substitute material for natural coarse aggregate replacement as it yields better strength properties.

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