An Experimental Study of Use of Fly Ash (Type-C & Type-F) For Shell Moulding

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Abstract. Usage of fly ash in foundry has long been established for casting processes like sand casting & ceramic shell moulding. However, no effort was made if fly ash can be a successful replacement for shell moulding. Shell moulding is a thin-walled shell created from applying a sand-resin mixture around a pattern. Shell moulding finds vast application in automobile, automotive and locomotive industries owing to its versatility, accuracy and surface finish. This paper presents by comparison the effect of fly ash on various moulding properties like strength, permeability, hardness and surface finish. The properties of various weight percentages of fly ash and shell sand reveal rule out of fly ash as a complete substitute for shell sand but can be a partial substitute for shell sand contributing to the cost reduction in procurement of shell sand. The castings obtained were checked for quality and the weight percentage of fly ash to shell sand established.

Key words Fly ash types, class “F”, class “C”, Shell sand, Mechanical Properties

1 Introduction

Shell moulding, also known as shell-mould casting, is an expendable mould casting process that uses a resin covered sand to form the mould. This process can cast simple or complex near net shapes, maintaining close tolerances and a high degree of dimensional stability. Wide ranges of alloys are cast with greater flexibility in design and at a cost lower to investment casting. The process is restricted to small & medium castings. However the process as compared to sand casting is costlier owing to the cost of shell sand.

EPA has classified Fly ash as a non-hazardous product. Fly ash is a product of burning coal, which is collected on an electrostatic precipitator and varies in composition as per the type of coal intake. As indicated by the MSDS (Material Safety Data Sheet), it is relatively a inert material. In recent years, the benefits of utilizing fly ash have become even more important as we strive to reduce our impact on the environment and improve sustainability. According to ACAA (American Coal Ash Association), use of fly ash reduces greenhouse gas emissions equivalent to removing 2.5 million cars from the road every year. Fly ash generation has already crossed 200 million tons/year and by 2017 it is expected to
cross 300 million tons. At present nearly 56% fly ash is utilized and balance is deposited in ponds or disposed ineffectively [1]. A review report by S. Dhadse et al. and T.R. Naik et al. discusses various ways of generation and utilization of fly ash in purview of policies of Govt of India [2,3]. Fly ash is now a potential material in various fields like construction, cement factories, foundry and as a filler material in MMC and PMC. Fly-ashes are a potential alternative sand binder for production of foundry sand moulds. They have previously been evaluated as binders for the main body of the mould, where they displayed suitable properties [4]. Studies on fly ash as an alternate to green sand in sand casting has been established with experimental results [5, 6]. However, fly ash as an alternate to shell sand in shell moulding is not explored. The fly-ash which generated disperses into the air and hence pollutes the atmosphere. This gets deposited on the surrounding land, thereby making the land infertile. It causes breathing problems for humans in the surrounding area [7]. Hence it becomes essential to look for all possible opportunities of disposing it economically and safely.

Fly ash is of two types-Class “F” and Class “C”. “F” is produced from burning anthracite and/or bituminous coal, and “C” is made out of lignite or sub bituminous coal. Also, according to ASTM C 618, if the combined percentages of silicon dioxide, Aluminium oxide and iron oxide exceed 70%, it is termed as class “F”.

The present paper focuses on replacing shell sand in Indian foundries to the maximum possible weight% without compromising on quality parameters like surface finish, permeability, tensile, compression, bending strengths and compactness. The sand under consideration is coated with 4% resin. The work presented in the paper compares the usage of both “F” and “C” types of fly ash as a potential replacement for shell sand.

2 Experimental Details

2.1 Chemical composition of Fly ash
Type “F” fly ash is procured from Raichur Thermal Power Station (RTPS), located in the Raichur district of the state of Karnataka, India. Type “C” fly ash is procured from Vasavadatta Cement factory (VCF), Sedam, Karnataka. X-ray fluorescence studies were conducted with the equipment: ICP-OES, Perkin Elmer and the results tabulated in tables 1 and 2. Table 1 represents class “C” fly ash and Table 2 represents class “F” fly ash.

2.2 Physical Properties of fly ash
Grain Fineness: It is one of the physical properties which relates to pozzolanic activity. Greater the fineness number, greater is the pozzolanic activity. Pozzolanic activity is the ability of the silica and alumina fly ash to react with available calcium and/or magnesium. Blaine’s air permeability apparatus is used to determine the fineness fly ash [8]. The fineness is expressed in units of square centimeters per gram. The Fineness of class “C” ranged between 3000cm²/gm to 4300 cm²/gm while that of class “F” between 3300 cm²/gm to 3900 cm²/gm. The % of retention on sieve number 21 is almost 30% for both types.

Specific gravity: specific gravity for class “F & C” is between 2.15 -2.42
Moisture Content: Moisture content is as per ASTM International C618 i.e. below 3%.

2.3 Methodology
Different shells of various weight percentages of fly ash and shell sand (resin coated 4%) were prepared. Compositions of various samples are:
Sample 1: 0% fly ash (class “F”) + Remaining Shell sand
Sample 2: 6% fly ash (class “F”) + Remaining Shell sand
Sample 3: 8% fly ash (class “F”) + Remaining Shell sand
Sample 4: 10% fly ash (class “F”) + Remaining Shell sand
Sample 5: 15% fly ash (class “F”) + Remaining Shell sand
Sample 6: 20% fly ash (class “F”) + Remaining Shell sand
Sample 7: 5% fly ash (class “C”) + Remaining Shell sand
Sample 8: 10% fly ash (class “C”) + Remaining Shell sand
Sample 9: 15% fly ash (class “C”) + Remaining Shell sand
Molten metal (ferrous & non ferrous) is poured into sample shells and components tested for various casting defects. Surface finish of the castings is also found by profilometer. Different patterns were used for the fly ashes. Figure 1 represents the pattern for class “F” & figure 2 represents mould for class “C”. Figure 3 represents the shell moulds of varying weight percentages of fly ash and figure 5 represents the cast after breaking the shell. The samples were prepared to determine various properties of strength (tensile, compression, bending & shear) and permeability according to AFS standards and the properties evaluated. Figure 5-7 represents the same.

### Table 1: Basic chemical composition of fly ash from VCF by XRF test

| SNO | Components | % in fly ash |
|-----|------------|--------------|
| 1.  | Al₂O₃      | 15.9         |
| 2.  | Fe₂O₃      | 0.54         |
| 3.  | CaO        | 32.34        |
| 4.  | MgO        | 5.36         |
| 5.  | Cr₂O₃      | 0.34         |
| 6.  | MnO        | 0.39         |
| 7.  | TiO₂       | 0.57         |
| 8.  | ZnO        | 0.06         |
| 9.  | NiO        | 0.33         |
| 10. | SnO₂       | 0.05         |
| 11. | SiO₂       | 43.65        |

### Table 2: Basic chemical composition of fly ash from RTPS by XRF test

| SNO | Components | % in fly ash |
|-----|------------|--------------|
| 1.  | Al₂O₃      | 14.7         |
| 2.  | Fe₂O₃      | 19.48        |
| 3.  | CaO        | 18.1         |
| 4.  | MgO        | 3.3          |
| 5.  | MnO        | 0.16         |
| 6.  | TiO₂       | 1.02         |
| 7.  | K₂O        | 1.79         |
| 8.  | BaO        | 0.27         |
| 9.  | SrO        | 0.11         |
| 10. | SO₃        | 1.5          |
| 11. | SiO₂       | 38.8         |
Figure 1. Pattern for class “F”

Figure 2. Pattern used for class “C”

Figure 3. Shell moulds of varying weight % of fly ash

Figure 4. Breaking of shell mould

Figure 5. Shear specimen under evaluation
3 Results & Discussion

The average grain size distribution of shell sand is 150microns (100 mesh) and the Blaine fineness of fly ash is between 3000cm²/gm to 4300 cm²/gm. The specific gravity for class “F & C” is between 2.15 -2.42 and the moisture content below the 3%.

Table 3 & 4 represents the variation of strengths with varying percentages of fly ash of class F and C respectively. It is observed from the values that strength (Tensile, Compression, Shear, and Bending) and permeability decreases with increase in percentage of fly ash in shell sand. The % variation (decrease) of strength and permeability when compared to green sand is comparatively higher.

Table 3 Variation of properties with varying percentages of fly ash(Class-F)

| Properties              | 0%   | 6%   | 8%   | 10%  | 15%  | 20%  |
|-------------------------|------|------|------|------|------|------|
| Tensile strength (kg/cm²) | 7    | 6.2  | 5.8  | 5.5  | 3.7  | 2.5  |
| Compression strength (kg/cm²) | 25.2 | 21   | 19   | 17.3 | 14.7 | 10.33|
| Shear strength (kg/cm²)  | 19   | 12.9 | 10.2 | 8.4  | 5.8  | 3.8  |
| Bending strength (kg/cm²)| 26   | 21.8 | 18.9 | 16   | 12.3 | 9.8  |
| Permeability (Pₐ)        | 142  | 128  | 119  | 105  | 7 (small orifice) | 5.1 (small orifice) |

Table 4 Variation of properties with varying percentages of fly ash(Class-C)

| Properties            | %    | 5%   | 10%  | 15%  | 20%  |
|-----------------------|------|------|------|------|------|
| Tensile strength (kg/cm²) | 7.0  | 5    | 3.0  | 1    |
| Compression strength (kg/cm²) | 9.5  | 8.4  | 7.6  | 6.5  |
| Shear strength (kg/cm²)   | 3.5  | 3.45 | 3.4  | 3.3  |
| Bending strength (kg/cm²) | 0.78 | 0.8  | 0.88 | 1    |
| Permeability (Pₐ) (small orifice) | 29   | 24.2 | 20   | 2.9  |

The figures 8-11 represents variation in strength & permeability of class F and class C fly ash.
It is observed from the graphs that there is a steep decrease in compression, shear and bending strength of class F fly ash compared to decrease in class C. The percentage variation of strength (except Tensile) with increasing percentage of fly ash is higher for class F when compared to class C, whereas the case reverses with tensile strength. Permeability values also decreases with increase in fly ash percentages for both classes. Permeability is higher in class “F” samples compared to class “C”.

It is also observed that the surface finish values improved with increase in fly ash till 10% weight of fly ash for class “C” and till 15% of weight for class “F”. The surface finish values of shell sand was in the range of 120-140 Rms while the surface finish for 10% fly ash was in the range 100-110 Rms. As the % of fly ash increased beyond a value, the surface finish values dropped. Also visible were casting defects. Figure 12 shows porosity in casting made of 15%fly ash of class “C” and Figure 13 indicates the burn out and porosity as well in the casting made of 20%fly ash of class “F”. Figure 14 represents a shell cast of 15%fly ash of class F with improved surface finish.

![Figure 8. % fly ash Vs Tensile strength](image8)

![Figure 9. % fly ash Vs Shear strength](image9)

![Figure 10. % fly ash Vs Compression strength](image10)

![Figure 11. % fly ash Vs Bending Strength](image11)
4 Conclusions

1. The various characteristics, physical, chemical & mechanical of Fly ash are established.
2. Strength (Tensile, compression, shear, bending) of fly ash class “F” is comparatively higher to class “C”.
3. Fly ash of class “F” can replace shell sand to 18% by weight and quality of casting is found to be satisfactory.
4. Fly ash of class “C” can replace shell sand to 15% by weight without compromising on quality of casting.
5. A considerable amount of cost can be saved by reducing procurement of shell sand.
6. Fly ash of any type increases surface finish of casting when used under prescribed limits of weight percent.
7. This Project demonstrates FAUP (Fly Ash utilization Programme) initiated by Indian Government by effective way of Fly ash utilization.

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