Study on Strength of Hybrid Mortar Synthesis with Epoxy Resin, Fly Ash and Quarry Dust Under Extreme Conditions

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Abstract: Blend and characterization of Bisphenol-A diglycidyl ether based thermosetting polymer mortar comprising an epoxy resin, Fly ash and Quarry dust are presented here for the strength study. The specimens have been prepared by means of an innovative process in Extreme conditions of commercial epoxy resin, Fly ash and Quarry dust based paste. In this way, thermosetting based hybrid mortars characterized by a different contents of normalized Fly ash and Quarry dust by a homogeneous distribution of the resin have been attained. Once hardened, these new composite materials show improved compressive strength and toughness in respect to both the Fly ash and Rock sand pastes since the Resin provides a more cohesive microstructure, with a reduced number of micro cracks. The micro structural characterization allows pointing out the presence of an Interfacial Transition Zone similar to that observed in cement based mortars. A correlation between micro-structural features and mechanical properties of the mortar has also been studied in Extreme conditions.

Key words: Fly-ash, Quarry Dust, Epoxy Resin, Compressive Strength

1. INTRODUCTION

The use of fly ash in mortar is desirable because of benefits such as useful disposal of a by-product, increased workability, sulphate resistance, resistance to alkali-silica reaction and decreased permeability. Quarry dust is a by-product obtained from the crushing process of granite in the quarry. The concurrent use of the two by-products will lead to a range of economic and environmental benefits. Quarry dust has been proposed as an alternative to river sand that gives additional benefit to mortar. Quarry dust is known to increase the
strength of mortar over mortar made with equal quantities of river sand. When examining the above qualities of fly ash and quarry dust, it becomes apparent that if both are used together, the loss in early strength due to one may be improved by the gain in strength due to the other, and the loss of workability due to the one may be partially negated by the improvement in workability caused by the inclusion of the other.

Epoxy is a term used to denote both the basic components and the cured end products of epoxy resins, as well as a colloquial name for the epoxide functional group. Epoxy resins, also known as poly-epoxides are a class of reactive pre-polymers and polymers which contain epoxide groups. Epoxy resins may be reacted (cross-linked) either with themselves through catalytic homopolymerization, or with a wide range of co-reactants including polyfunctional amines, acids (and acid anhydrides), phenols, and alcohols. These co-reactants are often referred to as hardeners or curatives, and the cross-linking reaction is commonly referred to as curing. Reaction of poly-epoxides with themselves or with polyfunctional hardeners forms a thermosetting polymer, often with high mechanical properties, temperature and chemical resistance. Epoxy has a wide range of applications, including metal coatings, use in electronics / electrical components, high tension electrical insulators, fiber-reinforced plastic materials and structural adhesives.

2. Materials and Methods

2.1. Physical properties, SEM and EDS report of Quarry dust:

Physical properties of Quarry dust are determined in the laboratory and reported in Table 1.

| S. No | Property                  | Quarry dust       | Code of practice |
|-------|---------------------------|-------------------|------------------|
| 1     | Specific gravity          | 2.38              | IS: 2386 (Part III) |
| 2     | Sieve analysis            | Zone II (coarser) | IS: 383          |
| 3     | Bulking                   | 30% @ 8% water content | IS: 2386 (Part III) |
| 4     | Bulk density              | 1670 kg/m³        | IS: 2386 (Part III) |

Figure 1.1. SEM analysis images of Quarry dust
SEM analysis of Quarry dust which reveals us from the above Figure 1.1, that the Quarry dust particle are relatively angular in shape and also sharp edge pin headed faces found all around the particle surface at the stage of microstructural investigation up to 100 to 50, micron scale view.

![Figure 1.2](image-url)

**Figure 1.2.** EDS analysis report of Quarry dust

EDS analysis report of Quarry dust which reveals us from the above Figure 1.2, that the quarry dust sample having the following chemical compositions like Al\((\text{Al}_2\text{O}_3)\) is about 20%, Si-(\text{SiO}_2) is about 70%, Potassium(K) is about 10% are available.

### 2.2. Chemical properties, SEM and EDS report of Fly ash:

The fly ash was procured from National Thermal Power Corporation (NTPC) in Visakhapatnam. The properties of Fly ash are as follows. Fineness of test Fly ash: 98%, Specific gravity of test Fly ash: 2.55, The chemical properties of fly ash are given in Table 2.

#### Table 2. Chemical properties of Fly ash (Courtesy: NTPC, Visakhapatnam)

| Chemical | SiO₂ | Al₂O₃ | Fe₂O₃ | Na₂O | MgO | CaCO₃ | SO₃ |
|----------|------|-------|-------|------|-----|-------|-----|
| %        | 61.24| 25.00 | 8.71  | 0.09 | 0.05| 4.42  | 0.49|

![Figure 2.1](image-url)

**Figure 2.1.** SEM analysis image of Fly ash

SEM analysis of Fly Ash which reveals us from the above Figure 2.1, that the Fly Ash particle is of spherical in shape, its particle size is varying between 2-11-micron meter. The following are the particle sizes noted from above pictures at the stage of micro structural investigation in between 50 to 20-micron scale view is, 3.683, 4.66, 5.16, 5.40, 5.665, 5.998, 6.54, 7.449, 7.998, 8.421, 9.814, 10.602, 12.47, 15.929-micron meter.
EDS analysis report of Fly Ash which reveals us from the above Figure 2.2, that the Fly Ash sample having the following chemical compositions like Al-(Al$_2$O$_3$) is about 30%, Si-(SiO$_2$) is about 55%, Calcium(Ca) is about 5%, and Iron(Fe) is about 10% are available.

2.3. Mix ratio, SEM and EDS report of Epoxy resin (Hardened):

Araldite AW 106 resin/Hardener HV 953U epoxy adhesive is a multi-purpose, viscous material that is suitable for bonding a variety of materials including metal, ceramic and wood. Araldite AW 106 resin/Hardener HV 953U epoxy adhesive cures at temperatures from 68°F (20°C) to 356°F (180°C) with no release of volatile constituents.

Table 3. Mix proportion of Epoxy resin and Hardener are as follows,

(Courtesy: HUNTSMAN, USA)

| MIX RATIO               | PARTS BY WEIGHT | PARTS BY VOLUME |
|-------------------------|-----------------|-----------------|
| Araldite AW 106         | 100             | 100             |
| (Specific Gravity: 1.17) |                 |                 |
| Hardener HV 953 IN      | 80              | 100             |
| (Specific Gravity: 0.92) |                 |                 |

SEM analysis of Epoxy resin which reveals us from the above Figure 3.1, that how compactly resin is bonded with hardener and forming a massive structure with no micro level crack and voids at the stage of microstructural investigation in between 100 to 10 microns’ scale view.
EDS analysis report of Epoxy resin which reveals us from the above Figure 3.2, that the resin sample having the following chemical compositions like Carbon (C) is about 70%, Oxygen(O) is about 30% are available.

2.4. Methodology adopted for the compression strength test:

1. The compressive strength tests on mortar cubes of size (70.7mm X 70.7mm X 70.7mm) compacted as per Code of Practice: Is: 4031 – (Part-6)
2. The compressive strength tests on mortar Specimens prepared as per ASTM standards D695. The typical blocks are (12.7 x 12.7 x 25.4mm), and the cylinders are 12.7mm in diameter and 25.4mm long.

3. RESULTS AND DISCUSSIONS

Various combinations of mixes are tried and the same are shown in Table 4. The compressive strength values for 24 hrs curing period at a temperature of 50ºC and 3 hrs curing period at a temperature of 100ºC for all mixes are shown in Tables 5.1 and 5.2. The relative comparison of compressive strengths of all mixes are shown in Figures 4 to 6 for 24 hrs specimens and compressive strengths of all mixes are shown in Figures 7 to 9 for 3 hrs curing specimens. Totally for the above study (45 + 45) number of cubes are casted.

Table 4. Various Mixes prepared with different combination of Innovative materials

| VARIATIONS | QUARRY DUST (grm) | FIYASHI (grm) |
|------------|-------------------|--------------|
|            | 4.75 2.36mm | 2.36 1.18mm | 1.18 600mic | 600 90mic | 90 mic passing |
| 1          | 150           | 150         | 150         | 150   | -              |
| 2          | 150           | 150         | 150         | -     | -              |
| 3          | -             | 150         | 150         | -     | -              |
| 4          | -             | -           | -           | -     | 360            |
| 5          | -             | -           | -           | -     | 600            |
3.1. Compressive strength test for mortar cubes according to Indian Standards:

Table 5.1. Average compressive strength of all variations in MPa at the age of 24 hrs. (50°C).

| Epoxy Percentage | V-1  | V-2  | V-3  | V-4  | V-5  |
|------------------|------|------|------|------|------|
| 20               | 57.6 | 64.1 | 67.6 | 68.9 | 69.9 |
| 25               | 65.5 | 73.1 | 74.3 | 77.3 | 83.4 |
| 30               | 77.5 | 78.5 | 84.4 | 87.1 | 94.2 |

Table 5.2. Average compressive strength of all variations in MPa at the age of 3 hrs. (100°C).

| Epoxy Percentage | V-1  | V-2  | V-3  | V-4  | V-5  |
|------------------|------|------|------|------|------|
| 20               | 56.5 | 63.5 | 66.7 | 67.4 | 68.2 |
| 25               | 65.1 | 72.5 | 73.8 | 76.1 | 82.8 |
| 30               | 76.4 | 77.4 | 82.2 | 88.8 | 92.9 |

(According to Table 5.1)

Figure 4, 5, & 6. Comparison of Compressive strength of all Variations with 20, 25, & 30% of epoxy
Figure 7, 8, & 9. Comparison of Compressive strength of all Variations with 20, 25, & 30% of epoxy

From Figure 4, variations 3, 4, and 5 with 20% of epoxy shows relatively same strength with quarry dust combination of fly ash. From Figure 5 and 6, variations 4, and 5 shows more strength when compared to all design variations. From Figures 4, 5, and 6 fly ash with 30% of epoxy shows more strength i.e. 94.2 MPa.

From Figure 7, variations 3, 4, and 5 with 20% of epoxy shows relatively same strength with quarry dust combination of fly ash. From Figure 8 and 9, variations 4, and 5 shows more strength when compared to all design variations. From Figures 7, 8, and 9 fly ash with 30% of epoxy shows more strength i.e. 92.9 MPa.

3.2. Compressive strength test for mortar specimens according to ASTM (D695):

3.2.1. Cylindrical Sample: Specimens prepared for the v - 5 (Fly ash with 30% of epoxy)

Table 6. Average compressive strength of cylindrical specimens in Mpa

| Variation 5 (Fly ash with 30% Epoxy) | Strength in Mpa | Average strength for 24 hrs in MPa | Average strength for 3 hrs in MPa |
|--------------------------------------|-----------------|----------------------------------|----------------------------------|
|                                      | 24 hrs (50°C)   | 3 hrs (100°C)                    |                                  |
| S1                                   | 113.1           | 109.6                            |                                  |
| S2                                   | 112.6           | 110.2                            |                                  |
| S3                                   | 112.4           | 111.4                            | 112.7                            | 110.4                      |
3.2.2. **Block Sample:** Specimens prepared for the variation-5 (Fly ash with 30% of epoxy)

**Table 7.** Average compressive strength of Block specimens in MPa

| Variation 5 (Fly ash with 30% Epoxy) | Strength in MPa | Average strength for 24 hrs in MPa | Average strength for 3 hrs in MPa |
|-------------------------------------|-----------------|----------------------------------|----------------------------------|
|                                     | 24 hrs (50°C)   | 3 hrs (100°C)                    |                                  |
| S1                                  | 110.1           | 108.3                            |                                  |
| S2                                  | 109.7           | 107.5                            |                                  |
| S3                                  | 109.6           | 108.6                            |                                  |

3.3. **SEM and EDS Analysis:**

**Figure 10.1.** SEM analysis of Fly Ash with 30% epoxy (Variation–5)

**Inference of Figure 10.1:** SEM analysis of Fly Ash with 30% Epoxy on its weight of (Variation–5), it reveals us that how compactly Fly Ash particle is bonded with epoxy and forming a massive structure with no micro level crack and no voids in it from above figure at the stage of microstructural investigation in between 10 to 5, micron scale view. From above figure, it reveals that the fly ash particles having size 1.782 and 2.684, micron meter having bond length is less than 1.0, micron meter length and also reveals that the fly ash particles having size 2.853 and 3.30, micron meter having bond length 0.691, micron meter length which supports the high strength mortar results.

**Figure 10.2.** EDS report of Fly Ash with 30% epoxy (Variation–5)

**Inference of Figure 10.2:** Above is the EDS analysis report of Fly Ash with 30% of epoxy of mix variation-5, which reveals us that the sample having the following chemical compositions like Al-(Al₂O₃) is about 10%, Si-(SiO₂) is about 25%, C-(CaCO₃) is about 65% are available.
Inference of Figure 11.1: SEM analysis of Variation – 4, with 30% Epoxy on its weight it reveals us that how closely quarry dust particles are linked and bonded with epoxy to forming a massive structure and also observed the different shapes and sizes of quarry dust particles. From above figure 11.1 (b), it reveals that some micro cracks of size 0.99, 1.04 and 1.088, micron meter length and micro voids are observed at the stage of microstructural investigation at 10, micron scale view which causes the lesser strength for mix variation–4, compare to mix variation–5.

Figure 11.2. EDS report of (Variation–4) with 30% epoxy

Inference of Figure 11.2: EDS analysis report of variation-4 which reveals us that the sample having the following chemical compositions like Al-(Al₂O₃) is about 10%, Si-(SiO₂) is about 20%, C-(CaCO₃) is about 60%, and Potassium(K) is about 10% are available.

4. CONCLUSIONS

From the above study the following conclusions are drawn.
1. According to Indian standards from figures 4 & 7, variations 2, 3, 4, and 5 with 20% of epoxy are shows relatively same strength with quarry dust and fly ash.
2. From figure 5, 6, and 8, 9, variations 4, and 5 with 25 and 30% of epoxy are shows more strength compare to all mixes.
3. From figures 4 to 9 in all variations fly ash with 30% of epoxy (variation-5) is shows more compressive strength i.e. 94.2 and 92.9 N/mm².
4. According to ASTM standards from Table 6 and 7 in variation-5, fly ash with 30% of epoxy is shows more compressive strength i.e. more than 100 N/mm².
5. SEM analysis also reveals that, Variation-5 means fly ash with 30% epoxy is shows more massive (with no micro cracks and voids) structure that supports more compressive and tough materials.
6. EDS reports reveals that Variation 1, 2, 3, and 4 combination of quarry dust shows less strength compare to Variation-5, due to presence Potassium(K).

5. REFERENCES

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