# Comparative assessment of polymer concrete with different types of resin

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**Abstract**: Polymer concrete is gaining increased popularity as a new construction material due to its high compressive, tensile and flexural strengths, short curing time, impact resistance, chemical resistance and freeze-thaw durability. It can be used to repair concrete structures, build slabs and beams of small cross sections and sleepers. There is a great potential of using this material in other structural applications as well. Research work in polymer concrete originated from well over couple of decades. In all of these research programs, either polymer concrete or mortar was made using different types and percentages of resin combined with sand, fly ash and coarse aggregate. The samples thus made were tested for the compressive strength, stress-strain relationships, tensile strength, modulus of elasticity and flexural strength. However, there is no common agreement among the research community about the effect of fly ash on these mechanical properties of polymer concrete.

Therefore, this paper investigates the available literature and the experimental results from authors' experimental programs in order to generalize the effect of fly ash on the mechanical properties of polymer concrete. The addition of fly ash as filler material, results in a reduction in the amount of resin, and an increment in the compressive strengths and an increase in the modulus of elasticity. Split tensile strength and flexural strength exhibits a decreasing trend with the increasing fly ash content.

**Keywords**: Polymer concrete, fly ash, mechanical properties.

## 1. Introduction

Polymer concrete is becoming increasingly popular due to many advantages that it possesses. It is very strong, durable and cures very rapidly, an important factor in most of the civil engineering applications such as transportation, utility, marine and building components [1, 2]. It has superior physical and chemical properties such as a short curing time, impact resistance, chemical resistance, electrical insulation, waterproofness, and freeze–thaw durability [3-5]. It is reported to have used in a range of civil and structural engineering applications such as bridge decking, concrete crack repair, pavement overlays, hazardous waste containers, waste water pipes and decorative construction panels [5-7]. The research work related to PC has started several decades ago [7-9]. Snell et. al. [10] argued that at that time polymer concrete was not the same material that is referred to today. Polymer concrete was either made by impregnating an already cured specimen of Portland cement concrete with a monomer solution, or by the method that is more familiar, by mixing the monomer with the Portland cement paste while concrete mixing. Either method at this early time for polymer concrete did not utilize a chemical method of polymerization and instead used thermal heating or exposure to radiation to initialize the polymerization reaction. These methods of polymerization increased the strength of the Portland cement that they were impregnated with substantially [10]. The formation of polymer concrete has changed significantly since impregnation into existing concrete and polymerization using radiation, notably in the direction of pre-mixing polymer concretes and not further including Portland cement in the mixture. Polymer concrete at this stage utilizes the strength of the polymer bond separately, which renders the inclusion of Portland cement unnecessary, along with this, changes in the formation of a polymer bond no longer require the use of radiation or extreme thermal energies to initiate the polymerization, but only a chemical reaction.

A polymer bond is formed from a monomer solution and a catalyst, the catalyst causes the monomer solution to form links of the monomers into a chain formation, after this there is branches formed from the linear chain and then finally the formation of crosslinks between the existing chains. The reaction that occurs is an exothermic chemical reaction which causes heat to be produced [11]. Polymer concrete uses the polymer resins as a binding material to develop polymer based concrete. The concrete that is created in this way is based on the same principle as Ordinary Portland Cement, with a binding material (in this case the polymer) and the aggregates, generally fine aggregate (sand) and coarse aggregate (gravel).

With the superior mechanical properties of polymer concrete also comes the high cost that is associated with this, though the use of recycled polyethylene terephthalate (PET) plastic wastes as the resin for polymer concrete [5, 6, 12] gives a promising alternative. The recycled polymer shows acceptable mechanical properties when compared to those of other polymer resins. Incorporating these recycled wastes into the polymer concrete is a sustainable and cheap way of making polymer concrete as well as being a way to sequester this waste into permanent infrastructure for a sustainable and environmentally enhanced future. The polymer concrete made out of recycled PET waste, together with fly ash and silica fume will ultimately be an environmentally friendly construction material.

There has been research into the mechanical properties of polymer concretes which used a single type of resin and differing fillers [13] such as fly ash and silica fume. These researchers concluded that including fly ash resulted in better properties than those for the polymer concrete (PC) with silica fume. The properties of PC are dependent on the type of polymer used and the gradation of aggregates used, with attributes obtainable for specific uses. A study into the use of PC reinforced with glass fibers as an overlay by Nossoni and Harichandran [14] proved that the use of PC as an overlay gave the structure a much better resistance to corrosion as well as having greater bonding with the existing concrete substrate. Research undertaken by Suh and Lee [15] into the feasibility of using a polymer concrete bed for a milling machine also showed that it has advantages with this specific application, as PC was proved to have a greater vibration dampening effect than Ordinary Portland Cement because polymer concrete has a higher tensile strength. The specific uses that polymer concrete can accommodate because of its superior mechanical properties and greater resistances are very broad; giving polymer concretes a considerable ability to be used where other materials are not suitable. Since polymer concrete has very low absorption, its use as a chemical waste container would not contaminate the PC itself and as such does not merit being treated as a hazardous material after its life cycle, giving polymer concrete a lower cost than OPC as a result for this case. Further research by Fattah and El-Hawary [9] recognised that PC is used very efficiently in precast components for buildings, bridge panels, hazardous waste containers, machine bases, and in various utility and transportation components. As PC generally has a very short working time to be positioned, using in precast members is the ideal use of PC, as this can be done very efficiently. Although these cases are of specialist types of polymer concretes being used for specific applications, polymer concrete has superior mechanical properties compared to ordinary Portland cement and is in general an improvement upon OPC. However there is no agreement among the research community about the variation in its properties if the amount of filler is changed. This research is based on investigating the mechanical properties of PC to confirm the effect of fly ash on it.

## 2. Experimental program

A testing program was developed to observe the behavior of epoxy, vinylester and polymer based polymer concrete. It was decided to carry out the investigation on polymer concrete cylindrical mortar samples to observe its mechanical properties.

### *2.1 Materials*

Epoxy resin, vinylester and polyester were used to prepare polymer concrete. Thixotropic epoxy resin used in this study was formulated to use with proper hardener to cure at room temperature. The selected vinylester had good toughness and broad corrosion resistance. Medium reactivity, rigid orthophthalic polyester resin was used. Compared to other polyester families, orthophthalic polyester has good chemical resistance and process ability. Properties of resin are shown in Table 1.

**Table 1: Properties of resin.**

| Property | Polyester | Vinylester | Epoxy |
|---|---|---|---|
| Type | Orthophthalic | Bisphenol | Thixotropic |
| Liquid state | | | |
| Viscosity (mPas @25$^0$C) | 1500-1900 | 420-580 | 900-1100 |
| Gel time (minutes)<br>Activator | 40-45<br>MEKP Interox NR20 | 35-45<br>Norox MEKP 925H | 40<br>Kinetix H160 hardener |
| Density (g/cm$^{-3}$) | 1.10 | 1.29 | 1.37 |

Fine dry sand used in the investigation had a bulk density of 1494 kg/m$^3$, water absorption of 8% and particle size smaller than 425 µm. In this laboratory testing, fine sand was dried in the oven to a constant mass at a temperature of 110°C for 24 hours as per ASTM: C128 [16]. It was then allowed to cool to comfortable handling temperature (approximately 30°C). This dry sand was used to prepare specimens.

Low calcium fly ash with 1100kg/m$^3$ bulk density was used in the investigation and the chemical composition is shown in Table 2.

**Table 2: Chemical composition of fly ash (by mass%).**

| Element | $SiO_2$ | $A1_2O_3$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | $SO_3$ |
|---|---|---|---|---|---|---|---|---|
| Percentage | 51.8 | 24.4 | 9.62 | 4.37 | 1.5 | 0.34 | 1.41 | 0.26 |

## *2.2 Mix design*

Mix design of the polymer concrete mortar was based on the void ratio method the authors used before [17] and the mix proportions by volume are shown in Table 3. These proportions were converted to the percentages by weight using the densities for the materials and are shown in Table 4. The notation used in these tables to identify samples are based on the percentage of resin and fly ash by volume. For example, S60R30F10 had 60% sand, 30% resin and 10% fly ash (volume percentages).

**Table 3: Mixing proportions by volume percentage.**

| Sample | Sand | Resin + Initiator | Fly ash |
|---|---|---|---|
| S60R40 | 60 | 40 | 0 |
| S60R30F10 | 60 | 30 | 10 |
| S60R20F20 | 60 | 20 | 20 |

**Table 4: Mixing proportions by weight percentage.**

| | Polyester | | | Vinylester | | | Epoxy | | |
|---|---|---|---|---|---|---|---|---|---|
| Sample | Sand | Resin | Flyash | Sand | Resin | Flyash | Sand | Resin | Flyash |
| S60R40 | 67.1 | 32.9 | 0 | 63.6 | 36.4 | 0 | 62.0 | 38.0 | 0 |
| S60R30F10 | 67.1 | 24.6 | 8.2 | 64.4 | 27.7 | 7.9 | 63.2 | 29.0 | 7.8 |
| S60R20F20 | 67.1 | 16.4 | 16.4 | 65.3 | 18.7 | 16.0 | 64.5 | 19.7 | 15.8 |

## *2.3 Sample preparation*

Resin was the main binding material for the polymer concrete and was required to be mixed with a catalyst. The purpose of incorporating the catalyst was to chemically start the curing process of the resin and hence harden the mix. Resin and catalyst proportions were selected based on the supplier recommendations. For epoxy polymer concrete, the proportions used were 25 parts of hardener to 100 parts of resin by weight. For vinylester polymer concrete, a volume percentage of 1.73% (1.73:100 parts) catalyst to resin was used. 2.5% volume percentage of initiator was used in the polyester resin. It was important that the catalyst and resin were fully mixed together to ensure that the molecular structure of the mixture was uniform. Dry materials (sand and fly ash) were mixed together separately. Finally, the resin catalyst mix was combined with the dry materials and mixed properly to gain a uniform mortar.

Cylinders with 50 mm in diameter and 100 mm in height were cast and allowed to cure in a temperature controlled room of 24$^0$C for 7 days until the testing were performed. Both ends of the samples were made smooth using a sanding machine.

## *2.4 Testing*

The tests were performed using a Sans compression testing machine with 1500 kN loading capacity at a constant cross head speed of 1.25 mm/min and 0.5 mm/min for compression and tensile testing respectively. Compression testing was performed as per ASTM: D695 [18]. Axial strains were measured using platen to platen method. Three failed samples from each category are shown in Figure 1. Split tensile testing was conducted using the same machine as per ASTM: D3967 [19] (Figure 2). All the tests were repeated for three samples.

(a). Epoxy (b). Vinylester (c). Polyester

**Figure 1. Samples tested for compression.**

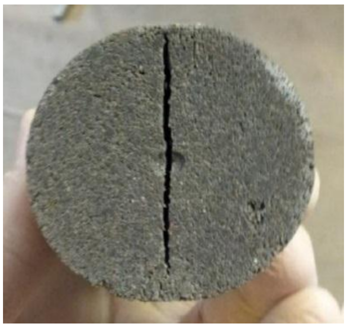


**Figure 2. Sample tested for tension.**

#### *2.4.1 Failure patterns*

Figure 1 (a) shows a typical failure pattern of a epoxy based polymer concrete sample in compression. This failure mode is a diagonal fracture that does not have cracking at either ends of the specimen. For most of the vinylester based polymer concrete samples, the cracks went from top to bottom of the samples as shown in Figure 1 (b). For polyester based polymer concrete, larger failure paths cannot be seen but there were multiple cracks specifically around the mid height of the specimen (Figure 1 (c)).

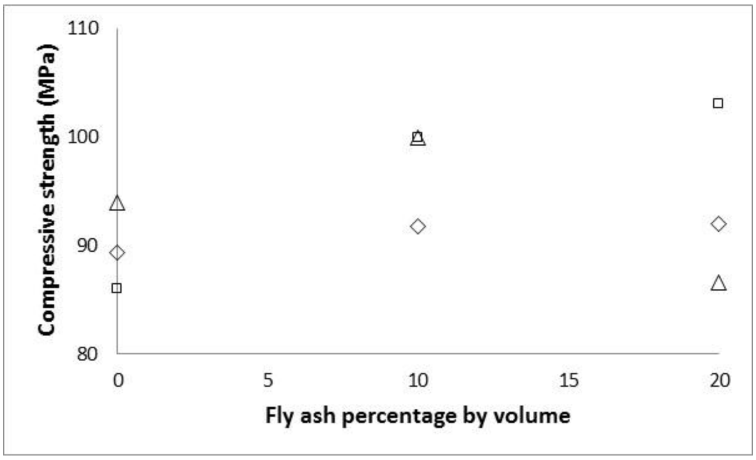
A typical failure pattern observed for all the types of polymer concrete failed in tension is shown in Figure 2. There is a clear and concise fracture plane that runs the length of the specimen and does not stop at one end of the specimen. It is a clean split down the centre of the specimen which has failed due to the tensile force only.

## 3. Experimental results and discussion

Samples were tested for the compressive strength and modulus of elasticity. In the compressive strength testing, loads and deformations were recorded and anlysed. For the tensile strength testing the failure load of each sample was recorded and the tensile strength was calculated.

### *3.1 Compressive strength*

Figure 3 shows how the compressive strength varies with the increasing percentage of fly ash for epoxy, polyester and vinylester based polymer concrete.




□ Polyester ◇ Vinylester Δ Epoxy

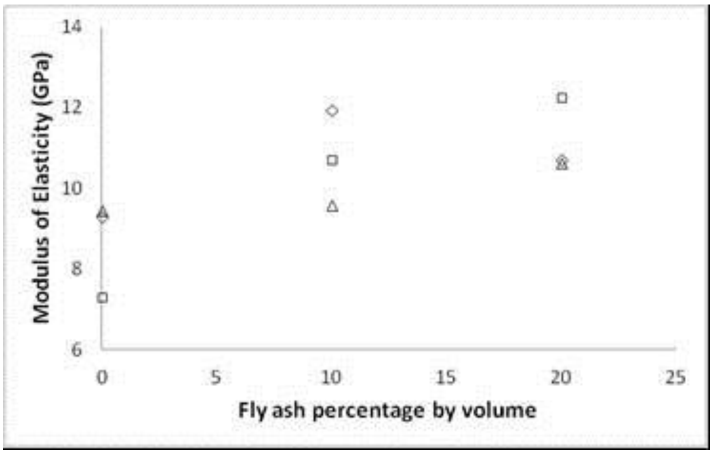
**Figure 3. Variation of compressive strength with fly ash.**

It can be observed from Figure 3 that for polyester based polymer concrete the compressive strength increases with increasing fly ash content which is a desirable property. Gorninski et al. [20] also reported a similar behavior for polymer concrete made out of orthophtalic and isophtalic polyester resin. Increasing fly ash content reduces the voids and increases the compressive strength for polyester based polymer concrete.

However for epoxy and vinylester resins, compressive strength increases with increasing fly ash content upto a certain level and then it starts decreasing. When Barbuta et al. [13] experimental results for epoxy resin mortar with fly ash are analysed by the authors, it can be seen that for increasing fly ash and decreasing resin the compressive strength increases and then decreases. They further reported that for 10% of fly ash is the optimum value to get the maximum compressive strength. In this experimental program, compressive strength of epoxy resin based polymer concrete is at an optimum point when the fly-ash content is approximately 10% taking into consideration the large steps in fly-ash content it is possible that an increase is achievable with a slightly higher or lower fly-ash content, this applies to all of the results. However past researchers reported fly ash percentages from 6% to 20% [1, 13, 20]. Gorninski et al. [20] argued that the strength level of the resin itself will contribute to the overall compressive strength of polymer concrete.

The compressive strength of standard ordinary Portland cement concrete mortar is much less than all of the results for the polymer concrete mortar, the compressive strength of the resins being on average almost twice as strong as the Portland cement. The strength of blended Portland cement can be much higher, but this strength comes at the cost of being much less workable and the strength achieved does not far exceed the strength achieved with polymer concretes.

### *3.2 Modulus of elasticity*




□ Polyester ◇ Vinylester Δ Epoxy

**Figure 4. Variation of modulus of elasticity with fly ash.**

The modulus of elasticity for all the specimens were calculated based on the recorded stress-strain relationships and using the linear regression analysis and shown in Figure 4.

Irrespective of the resin type, modulus of elasticity increases with increasing fly ash content. This trend is consistent with the previously published results for polyester based polymer concrete [1]. Modulus of elasticity ranges between 7-13 GPa for all the types of PC. As argued by Gorninski et al [1], this behavior must be related to the increase in the stiffness due to high concentration of fly ash.

### *3.3 Tensile strength*

Three specimens from each batch were tested in order to get the split tensile strength and the average results are plotted in Figure 5.

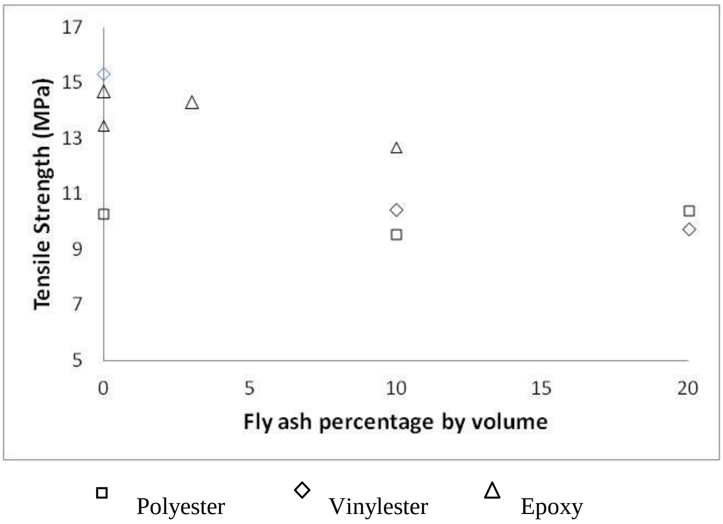



**Figure 5. Variation of tensile strength with fly ash.**

When the fly ash content is more, the bond between the resin and fly ash must be lower and hence the tensile strength is lower. It is worth noting that the split tensile strength of vinylester and epoxy polymer concrete paste was found to be much higher than that for polyester based polymer concrete.

## 4. Conclusions

From the results, it can be concluded that the addition of fly ash into the polymer concrete mix will increase the strength of the concrete in compression and also the modulus of elasticity. When fly ash is further increased, there is a point where there is excess fly ash and the resin will no longer properly bound with the aggregates. An optimum content of fly ash can be concluded for each resin. Polyester has an optimum at 10% or above, the trend increasing as the content of fly-ash increases. Vinylester also shows an optimum content of 10% fly ash, though this is only indicatively based on a wider range of fly ash content, an increase is possible on either side of the percentage that is optimum from these tests. From the results of the epoxy resin based polymer concrete, it is possible to draw the conclusion that compressive strength is increasing even for 20% of fly ash content. Modulus of elasticity is increasing and tensile strength is decreasing with increasing fly ash content. Between the compressive strength, tensile strength and modulus of elasticity there is no significantly superior type of resin evident, though polyester resin shows the highest compressive strength with the correct content of fly ash and resin.

## 5. Acknowledgement

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