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POLYESTER GROUT INCORPORATING FLY ASH AS POTENTIAL INFILL MATERIAL FOR GROUTED CONNECTIONS

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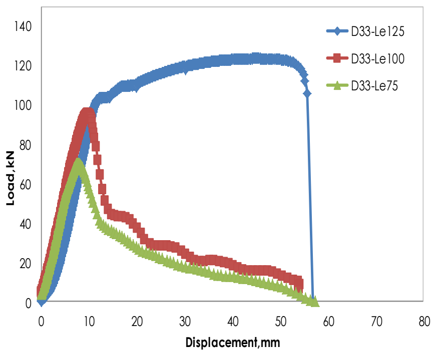
Graphical abstract



Abstract

This paper presents the mechanical properties and performance of polyester grout as infill material for grouted connection in precast concrete. The mix proportions of polyester grout was properly designed and manufactured. The polymer binder with polymer additive was added together with filing materials of sand and fly ash. The binder to filler ratio was 0.43. Properties such as flowing ability and compression strength were studied by varying the level of fly ash in the mixtures. Also, to assess the efficacy of polyester grouted connections, three grouted connections were tested in direct tension. The test results show that, polyester resin grout with binder to filler ratio 0.43% and 16% fly ash perform satisfactorily. The polyester grout is suitable for use in the steel pipe splice connections.

Keywords: Polyester grout, fly ash, compressive strength, flowing ability, grouted connection

1.0 INTRODUCTION

Research on innovative grout, which is able to provide higher compressive strength and faster development of strength compared with conventional grout, is particularly essential for grouted connections between precast concrete structural elements. Many types of connection, such as beam splice, column splice and beam to column connection depends on grouted connections for their structural integrity and stability [1]. The performance of grouted connections is influenced by the quality of the grout, significantly. The grout utilized as infill material to splice reinforcement bars and to ensure continuity during the load transfer. The strength of the grout would affect the capacity of the splice grouted connection [2-3]. High strength grout is specified to increase the bond between grout and bar and to ensure that the forces in the bars can be transferred to the surrounding material accordingly.

Alavi-Fard and Marzouk [4] presented the results of bar pullout tests on a series of high strength concrete block specimen. The objective of the study was to study the effect of the concrete compression strength on the bond strength. It was shown that an increase in the compressive strength of the concrete could increase the bond strength.

Cement grouts, which are usually used in construction for grouted connections have experienced a number of limitations including long curing times, gradual development of strength, and lower compressive strength. Polymer mortar (PM) is an example of a relatively new composite material that can be used as bonding material. This material has high compression strength and cures much faster than the cement grout. Typically, polymer grout takes a few hours to cure, whereas cement grout cures in days or weeks [5], which is an important advantage in many of its construction applications. Polymer mortar or grout formed from a resin binder and fine inorganic aggregates such as sand and fly ash [6-7]. Fillers are used in the production of PM not only to reduce the cost of the material but to improve gap-filling property and abrasion resistance. It increases viscosity and reduces shrinkage [8].

Although, polymer grout is fast setting and rapid strength development, however, the use of polymer mortar in grouted connection is still limited because of the lack of information and familiarity with the product by practitioners. Therefore, the objective of this paper is to study mechanical properties and performance of polyester grout incorporating fly ash that can be used as infill material for grouted connections.

2.0 EXPERIMENTAL PROGRAM

2.1 Materials

Polyester grout (PG) in this study was produced solely using polymer binder, dry filling material of aggregate and fly ash. The PG was cured totally without any cement and water and through polymerization process after polymer additive was added.

2.1.1 Polymer Binder

Unsaturated polyester resin in this study become a polymer binder and was utilized as the main material in producing polymer mortar. The choice of this resin is due to their low cost as compared to others thermoset resin. Additionally, unsaturated resin has excellence mechanical properties and readily available in market. The properties of unsaturated polyester resin used in this study are presented in Table 1. Polymer additives of initiator of Methyl ethyl ketone peroxide (MEKP) and cobalt naphthanate (CoNp) were added with 1% and 0.5% by weight of polyester resin, respectively. The polymer additives in this study were formulated into the polymer binder based on results of previous study by [9].

Table 1 Properties of unsaturated polyester resin

Properties	**Unsaturated polyester resin**
Styrene monomer content (%)	39-44
Viscosity-Brookfield at 20 °C	400-600
Density (g/cm3)	1.1
Gel time (min)	15
Tensile strength (MPa)	7
Barcol hardness	47

2.1.2 Filler

Filling materials of sand (density; 1.6 g/cm^3) and fly ash (2.5 g/cm^3) were used in polyester grout (PG). Both materials were oven dried for 24 hours at the temperature of 105°C. The moisture content was limited between 0 to 0.5% before producing polymer mortar. The sand as inert materials was sieved through 600 μm purposely to standardize the particle size and to establish consistency during sample preparations. Untreated fly ash was used directly after it undergoes an oven drying process. The choice of fly ash in this study is due to excellent compatibility between fly ash and polyester resin as reported by [10].

2.2 Mix Proportions

A total of eleven different polyester grout mixes were prepared in this study. A laboratory trial test was performed to investigate the effectiveness of using fly ash as a micro-filler over the flowing ability and compressive strength of the polyester grouts. The proportion of binder to filler used in this study is 0.43. Fly ash was added from 12 to 32% of the total filler volume with an increment of 2%. The choice of this range is in accordance with finding of Soh *et al*. [11], that the maximum limit of ground calcium carbonate (GCC) filler or fly ash should be controlled at 60% or less to make the most of the excellent strength of unsaturated polyester resin grout. The mixture proportions of trial mixes are given in Table 2. The binder and filler were mixed thoroughly in a clean and dry container for 5 to 10 min until a uniform, fresh grout was obtained. The fresh polyester grouts were used to conduct flowing ability test and compression test.

Table 2 Mixture proportions for trial mixes

Mix	Binder content (Polyester resin) (%)	Filler Content (Sand and fly ash) (%)	Binder/Filler ratio	Fly ash content (%)	Sand content (%)
PG-12-30				12	58
PG-14-30				14	56
PG-16-30				16	54
PG-18-30				18	52
PG-20-30				20	50
PG-22-30	30	70	0.43	22	48
PG-24-30				24	46
PG-26-30				26	44
PG-28-30				28	42
PG-30-30				30	40
PG-32-30				32	38

2.3 Testing Methods

2.3.1 Flowability

The flowability of the fresh mixed polyester grout (PG) was determined using mortar flow spread test to examine the flowing ability with respect to flow spread diameter. The standard flow mould conforming to ASTM C 230/C 230M [12] was used to determine the flow spread of mortars as shown in Figure 1. The upper and lower diameters of the mould cone are 100 mm and 50 mm, respectively, with a height of 70 mm. A plate of glass was used as flow base. Polymer binder with filling material was poured into the cone without any compaction. Then, the mould was lifted vertically so that the PG can flow over the glass plate. The flow spread diameter of PG was measured after the grout had completely stopped flowing.

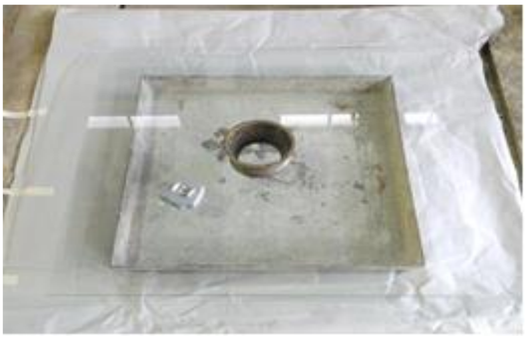


Figure 1 Test setup for flowability test

2.3.2 Compressive Strength

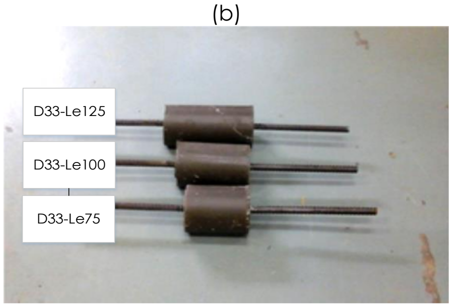
Grout compressive strength test was conducted using a universal compression test machine in accordance with ASTM C 109/C, 2005 [13]. The cubic specimens were prepared for compression test using cubic moulds of size 50 x 50 x 50 mm. The specimens were tested after 1 day without being subjected to any curing process. For each mix proportion average values of three specimens were taken.

2.3.3 Tensile Test of Polyester Grouted Connections

Three polyester grouted connections were made with steel spiral reinforcing bar and welded reinforcement bar of constant diameter of 33 mm but with varying embedded length of 75 mm, 100 mm and 125 mm to join high strength deformed bars of 16 mm diameter. Figure 2 shows the preparation of test specimen .Wooden plywood were prepared to position the samples. Spiral was aligned symmetrically and centrally in a 110 mm diameter PVC pipe which is used as a mould. The two ends of the spliced bars butting against each other at the centre of PVC pipe, and fix to the plywood by steel wire. Then the PG-16-30 mix was poured into the connection as a bonding material. Then, the grouted connections were left to cure for 3 hours at room temperature. After the curing period is elapsed it was removed from the plywood and demoulded. Steel strain gauges of type FLK-6-11-3L with length of 6 mm was installed on the spliced bars at a distance of 16 mm extruding from the grouted spiral connections. The PG grouted connections were tested under increment tensile load using Dartec Hydraulic Actuator of 250 kN capacity. Figure 3 shows the test setup of the tensile test. The polyester grouted connections were tested to failure and the modes of failure were observed. The data obtained from testing included the applied load, bar displacement and strain in steel bar.

(a)

(b)



(c)

Figure 2 Preparation of specimens

Figure 3 Experimental setup of tensile load test

3.0 RESULTS AND DISCUSSION

3.1 Flowability

The results of the flowing ability test of polyester grouts with various level of fly ash are illustrated in Figure 4. The effect of the fly ash content on the flowing ability (flow spread) of the polymer resin grouts is evident from this Figure. In general, the flow spread of grouts decrease with the increase in the fly ash content. This is attributed to the increase in surface area of the filler in the presence of fly ash. These results were useful for selecting the proper fly ash contents to be used in polyester grout mixtures as infill material. The fly ash content greater than 16% was not effective for a good flowing ability of polymer resin grout. In addition, handling and mixing difficulties encountered in the polyester grout with fly ash content of 32%. Therefore, PG-32-30 mix is impossible to be use as infill material for lack of its flowability. It was understood based on the mortar flowability results that a fly ash contents greater than 16% should not be used for polyester grout as infill material for grouted connection. Because the flowability of this polyester grout will use as bonding material is limited by the practicalities of pouring the polyester grout mix in the grouted connection.

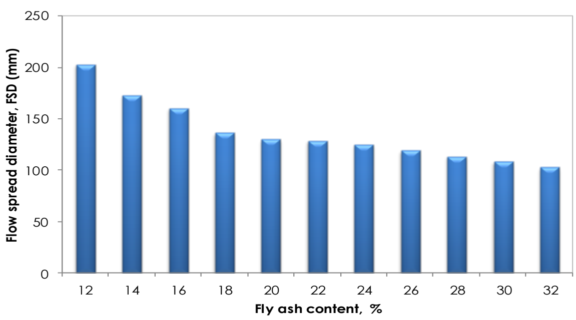


Figure 4 Flow spread of polyester grouts with various fly ash contents.

3.2 Compressive Strength

Figure 5 presents the results of the effect of fly ash content on the compressive strength at the age of 1 day of polyester grouts with binder to filler ratio of 0.43 and total filler content of 70%. The change in compressive strength of PG mixes with fly ash content is nearly the same up to 22%. However, beyond 22%, it increases with filler content. The highest value of the compression strength of 65.48 MPa was obtained for mix PG-32-30 with 32% of fly ash of the total mix volume.

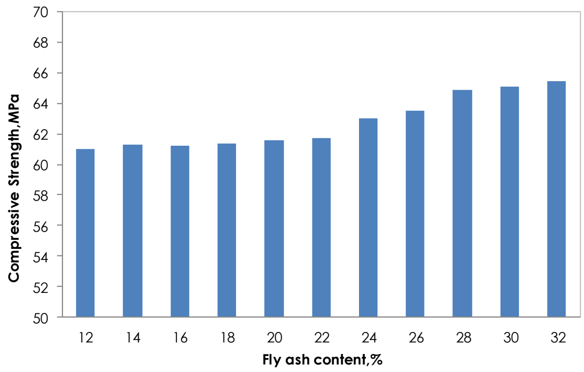


Figure 5 Compressive strength of polymer resin grout versus proportion of fly ash

3.3 Tensile Performance of Polyester Grouted Connections

The load- displacements curve, stresses-strain curve and the mode of failure for tested polyester grouted connections are shown in Figures 6, 7 and 8. The ultimate load, stress and strain for all connections are presented in Table 3. From Figures 6 and 8, it can be noticed that, two types of behaviour were observed. Firstly, specimens D33-Le100 and D33-Le75 provide inadequate bond and failed in brittle manner due to bar slippage out of the sleeve before the spliced bars yielded. Secondly, specimen D33-Le125 with bar embedded length of 125 mm provide adequate bond and failed in spliced bar fractured outside in ductile manner. The spliced bars in the sleeve was yielded and elongated before fracture outside of the sleeve. Referring to Figure 7 and Table 3 , the specimens that failed by bar pull out D33-Le100 and D33-Le75 with the bar embedded length are 100 mm and 75 mm respectively had the ultimate tensile stresses in the spliced bar below the specified yield stress of 500 N/mm^2. The spliced bar didn't yield at the strain less than 2300x10^{-6} mm/mm, indicating that the spliced bars remained elastic throughout the test. On the other hand, the maximum stress reached in the bar of specimen D33-Le125 was 612.06 N/mm^2 this value is beyond the specified yield stresses of the deformed bar of 500 N/mm^2. Also in view of the maximum strain of 3550x10^{-6} mm/mm reached in the bar is substantially greater than the yield strain of 2300x10^{-6} mm/mm. In the case of D33-Le125 (see Figure 7), the spliced bars behaved elastically before yielding, and then, behaved in-elastically after yielding and experienced a sudden increment of strain. This could be due to the tensile fracture of the spliced bars. Similar behavior of the spliced bars were also discovered by previous researcher such as those reported by [2]. This indicates that, the specimen D33-Le125 was able to provide full tensile strength of the connected steel bars.

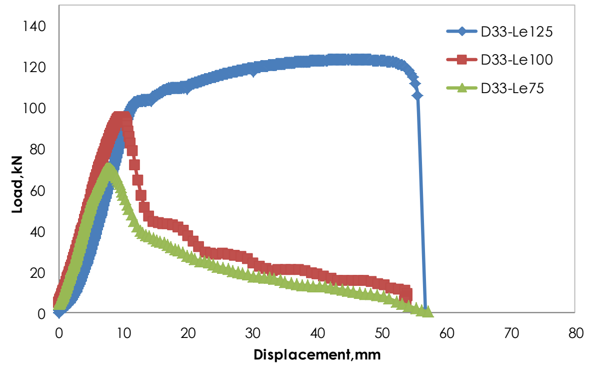


Figure 6 Load- displacement curve for the tested connections up to failure

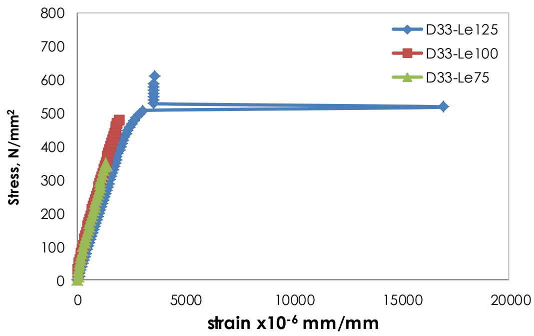


Figure 7 Stress-strain curve of splice steel bar for tested connections

Table 3 Results of tensile load test

Specimen	Ultimate tensile load (kN)	Ultimate stress (N /mm^2)	Ultimate strain (mm/mm)	Failure modes
D33-Le75	70.31	337.96	1253*10^{-6}	Bar slip
D33-Le100	95.44	477.12	1930*10^{-6}	Bar slip
D33-Le125	123.50	612.06	3550*10^{-6}	Bar fractured

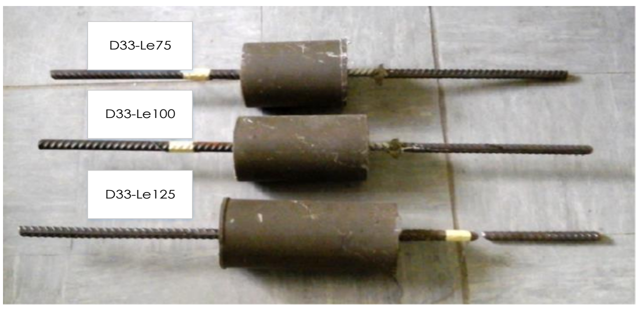


Figure 8 Mode of failure for tested specimens

4.0 CONCLUSION

The influence of various amount of fly ash on mechanical properties for polyester resin grout was investigated in this study. Also, three polyester grouted connections were tested in direct tension. The experimental results indicate that, the compression strength of polyester grouts were enhanced by increasing the fly ash content in polyester grouts mix. Specimen PG-32-30 with the binder to filler ratio of 0.43 and the optimum fly ash content of 32% provided the maximum compression strength of 65.48 MPa at 1 day. However, the flowability for this grout decreases with the increase in fly ash content. A good flowing ability (flow spread) can be achieved in the polyester grouts using 16% of fly ash content. PG-16-30 with 16% fly ash content is a potential material to be used as bonding material in grouted connection because it shows a good performance and acceptable workability. Also, by taking the advantages of high strength of polyester grout and confinement of spiral, the required development length in splice reinforcement bar can be as short as eight times the bar diameter, which is approximately 22.3 % of the anchorage length recommended by BS8110 [14]. The anchorage length recommended by BS 8110 is 35 times diameter of bar, which is 560 mm.

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