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EFFECT OF FILLER ON STRENGTH DEVELOPMENT OF EPOXY GROUT

Lim Siong Kang[1], Mohd Warid Hussin[2*]

[1]*Department of Civil Engineering,*
Faculty of Engineering & Science, Universiti Tunku Abdul Rahman, Malaysia

[2]*Department of Structures and Materials,*
Faculty of Civil Engineering, Universiti Teknologi Malaysia

*Corresponding Author: *warid@utm.my*

Abstract: Epoxy grout is used for most structural repair works due to its high strength, adhesive and availability. This study uses epoxy resin and its hardener as binder, graded sand and ground granulated blast furnace slag (GGBFS) as filler to produce the epoxy grout. The objective is to produce a sufficient mix proportion for epoxy grout that has good workability and high strength properties, which can be used as structural repair material. The method used to obtain the mix proportion was by trial mix as determined by flowability and strength of the grout. Several batches of epoxy grouts with different epoxy: hardener: filler ratios were designed and tested for its flowability and compressive strength properties. Finally, the mix proportion with fresh properties, namely viscosity or flowability that fulfills the requirements of ASTM C 881 and has optimum strength development was selected. The optimum compressive strength obtained for epoxy grouts with 5:1:11 epoxy:hardener:filler ratio was above 70 MPa for air cured specimen, which can be considered as high strength repair material. The results for slag based epoxy grout showed that the replacement of slag up to 50% as filler to epoxy mix with proper mix proportion is suitable to be used in concrete structural repairs.

Keywords: *Slag, Epoxy, Viscosity, Compressive strength.*

1.0 Introduction

In Malaysia, there are few types of grout materials used in repairing concrete works. The application of this repair material depends on the type, situation and causes of concrete cracks. Some cementitious grouts that used for concrete cracks repair are not sufficient enough to bind due to their low adhesive and bonding strength to existing structures surface, higher drying shrinkage and lower resistant to chemical attack. Resin grouts are widely used to seal the structure cracks because of their superior properties as compared to cementitious grouts. This study concentrates mainly on the problem of producing a suitable mix proportion for resin grout, which is formed by resin-hardener/initiator system as binder, fine aggregate and ground granulated blast furnace slag (GGBFS) as filler.

Epoxy resins, also known as epoxide or ethoxyline resins, contain the epoxy group which is the chief centre of their reactivity. When manufactured, the resins are either liquids or solids, contain on average two epoxy groups per molecule. In this physical state, the resins are thermoplastic, that is, they can be repeatedly softened when heated and hardened by cooling. In fact, some epoxy resins are almost pure organic chemicals. However, the essential feature of epoxy resin technology is the conversion of the resin into a hard, infusible three-dimensional network in which the resin molecules are cross-linked together by means of strong covalent bonds. This conversion can be termed as polymerization, but is more commonly called curing or hardening of the resin. Curing is an irreversible change and once the resin has been cured it cannot be recovered again in its original form. Cure can be slowed down, stopped or speeded up, but it cannot be reversed. Hence epoxy resins fall into the category of thermosetting polymers, which, once polymerized, cannot be re-used by melting and reprocessing. Continued heating of a thermoset merely leads to softening and eventually degradation and breakdown of the material (Potter, 1975). The most common and widely used epoxy resins are made by allowing polycondensation involving epichlorohydrin and bisphenol A, or known as diglycidyl epichlorohydrin of bisphenol A (DGEBA) (Premamoy, 1996). The study was carried out using epoxy resin as mentioned above and its harderner as binder to produce epoxy grout.

2.0 Materials and Methods

The production of the epoxy grout was based on low viscosity DGEBA epoxy resin and its hardener as binder, graded sand and ground granulated blast furnace slag (GGBFS) as filler. GGBFS was used as micro-filler to investigate its effect on engineering properties of resin grout (Siong Kang et al., 2006). Monofunctional glycidyl ethers at type of monofunctional reactive diluents, were used at relatively low percentages to achieve lower viscosities and to form part of the polymer backbone of DGEBA resins, to impart a measure of flexibility without the possibility of migration. The low viscosity resin used complied with the requirement of Type I, Class A epoxy resin (ASTM D 1763, 1981). The chemical compositions of DGEBA resin are shown in Equation 1 and the common physical and mechanical properties of epoxy resin are tabulated in Table 2. Type of hardener used to cure low viscosity DGEBA resin was selected based on manufacturer's suggestion. It is in the form of reaction product of polyamine with fatty acids like linoleic acid, linolenic acid and arachidonic acid, each one has carboxyl function group (COOH) to produce amidopolyamines or amides provide the largest group of commercial hardeners for adhesive applications**.**

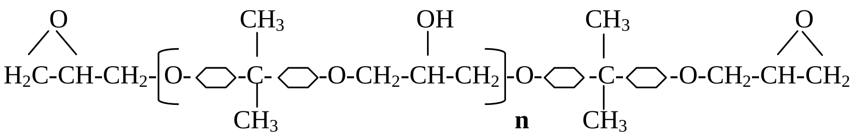

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Table 1: Typical properties of casted low viscosity epoxy resin with hardener manufacturer's specifications)

Resin : Hardener ratio (by volume)	4 : 1
Specific gravity	1.09
Viscosity (Brookfield) Spindle #3/ 20rpm, 20^0C	250cP
Tensile strength (N/mm^2) BS6319: Part 7 at 20^0C	20
Compressive strength (N/mm^2) BS 6319: Part 2 at 20^0C – 7 days	75
Flexural strength (N/mm^2) BS 6319 Part 3 at 20^0C	55
Tensile bond strength (N/mm^2) Dry concrete at 20^0C Wet concrete at 20^0C	Concrete failure in all cases
Modulus of elasticity (N/mm^2) in flexure	4500
Useable pot life at 20^0C	40-60 minutes

The mixing procedures of epoxy grout are described as follow. First, GGBFS and graded dry sand were weighed according to mix proportions and mixed in a clean, dry container until all the materials blended intimately and uniformly. Proposed amount of resin was weighed and its hardener was added to resin in another clean and dry container. The epoxy resin and hardener were thoroughly mixed. The blended filler was later added into epoxy-hardener system. The binder and filler were thoroughly mixed for three minutes to obtain a uniform mixture. Before casting, the mould (either steel or timber) shall be applied with special demoulding wax to ease the demoulding work. The dimension of cube samples was 50mm x 50mm x 50mm in accordance to ASTM C 579 (2001).

The mix proportions of the resin grout were derived from trial mixes based on results from viscosity test (ASTM D 2393, 1986) and compressive strength. With reference to ASTM C 881 (1990), the viscosity required for Type IV and V, Grade 1 and 2 bonding system shall fall within the recommended range of 1,000 to 100,000 centipoises (1 to 10 Pascal second or Pa.s). This study was carried out to obtain resin systems with viscosity in the range of 1500 to 2100 centipoises in tropical weather, which can provide consistent flow and pumpable characteristic, and at the same time high strength (Siong Kang et al, 2006)

The designed epoxy grout shall have consistent flow. Cubes have been cast for trial mixes to determine the compressive strength. Epoxy grout, which has the optimum binder to filler ratio and required strength was selected for further study. The slag in the range of 10 to 50 percent was added to replace the fine graded sand to investigate its effect on viscosity, working life and strength. The sand replaced by slag in epoxy can be added up to 50 percent without affecting the consistency of the flow and strength performance of the grout. The designation of epoxy grouts with difference binder to filler ratio is shown in Table 2. All specimens were subjected to air curing in the laboratory with an average temperature of 27^0C to 30^0C and 65% relative humidity.

Table 2. Designation of various type of epoxy grout

Series	Size of Sand Passing Sieve (μm)	Resin to Hardener Ratio	Binder to Filler Ratio	Sand to Slag Ratio (Filler)	Flowable/ Viscosity (centipoises)	Gel Time (minute)
EG-850-A1	850	3:1	1:1.5	100% sand	Consistent (1500-2000)	37-42
EG-850-B1	850	4:1	1:1.8	100% sand	Consistent (1500-2000)	38-43
EG-850-C1	850	5:1	1:1.83	100% sand	Consistent (1500-2000)	40-45
EG-C1 (Pure Resin)	N.A	5:1	-	-	Liquid (300-500)	10-15
EG-850-D1	850	6:1	1:1.86	100% sand	Consistent (1500-2000)	43-48
EG-850-C1S10	850	5:1	1:1.83	9:1	Consistent (1500-2000)	40-45
EG-850-C1S30	850	5:1	1:1.83	7:3	Consistent (1500-2000)	40-45
EG-850-C1S50	850	5:1	1:1.83	5:5	Consistent (1500-2000)	40-45

3.0 Results and Discussion

The mix proposition of epoxy grout was selected from trial mixes with various epoxy: hardener: filler ratios, shown in Table 2. Once the optimum mix proportion based on the results shown in Table 3 was decided, the slag was then incorporated into the design mix as part of filler to study its effect on the engineering properties of epoxy grout.

Table 3: Average compressive strength for epoxy grout at different ages

Series	Age (Days)	Binder to Filler Ratio	Resin to Hardener Ratio	Density (kg/m^3)	Compressive Strength (MPa)
EG-850-A1	1 7 28	1:1.5 (0.67)	3:1	1720	37.92 39.34 40.45
EG-850-B1	1 7 28	1:1.8 (0.56)	4:1	1720	61.46 67.04 68.22
EG-850-C1	1 7 28	1:1.83 (0.55)	5:1	1800	74.86 84.20 86.64
EG-C1 (Pure)	1 7 28	-	5:1	1119	51.66 71.25 70.92
EG-850-D1	1 7 28	1:1.86 (0.54)	6:1	1800	41.91 55.89 73.97
EG-850-C1S10	1 7 28	1:1.83 (0.55)	5:1	1800	74.79 83.44 84.29
EG-850-C1S30	1 7 28	1:1.83 (0.55)	5:1	1800	74.80 83.52 84.32
EG-850-C1S50	1 7 28	1:1.83 (0.55)	5:1	1800	74.60 82.96 84.16

Figure 1 shows the comparison for compressive strength of EG-C1 (without filler) and EG-850-C1CTR (with filler) grouts. The results has shown that epoxy grout with filler obtains higher compressive strength than pure epoxy resin which have the same resin to hardener ratio. The results also prove that the proper filler to binder ratio enhances the compressive strength of samples compared to the samples without filler. The high exothermic occurred during the gelatinous stage that caused the samples to expand. When samples were hardened and left to cold in ambient temperature, contraction of samples occurred, resulting in stress build up. This latter problem was due to the differences between the thermal expansion coefficients of the polymer matrix, thus induces major effect on the internal micro-stresses which was sufficient to produce micro-packing and cracks (Premamoy, 1996). The filler added into resin matrix decreased the reaction heat, and hence reduced the internal thermal stress of resin matrix to prevent the internal cracks of samples.

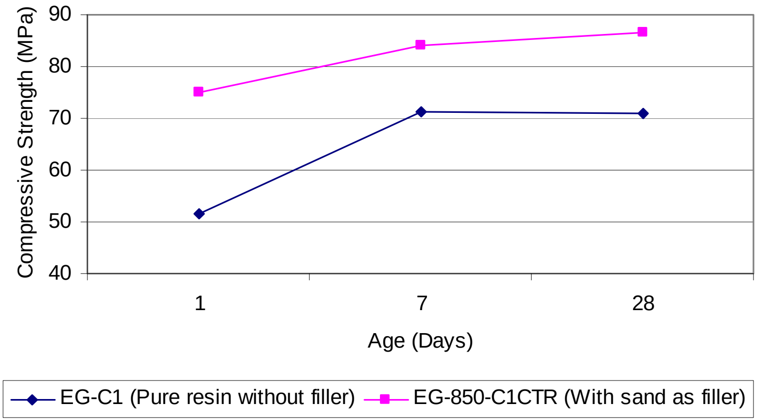

Figure 1: Compressive strength of epoxy cubes (without filler) and epoxy cubes (with filler) at various ages

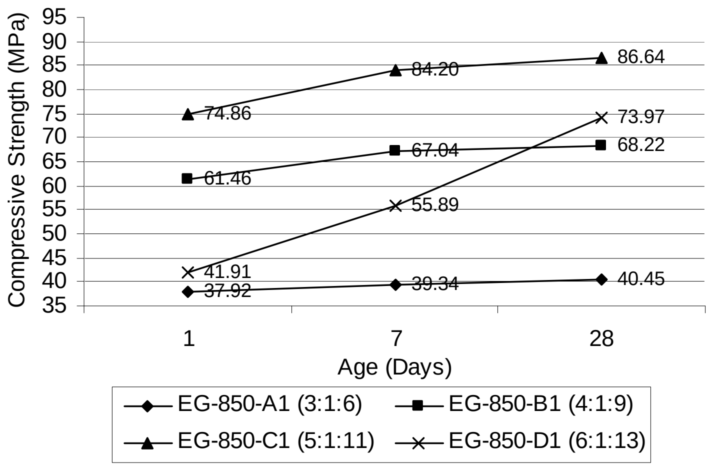

Figure 2: Compressive strength of epoxy grout with different epoxy: hardener: filler ratios at various ages

Figure 2 shows that various binders to sand ratio of epoxy grout which result in the varying compressive strengths at different ages. EG-850-A1 with the least epoxy content almost obtained the optimum compressive strength at 1st day and maintained its strength thereafter. The compressive strength of EG-850-A1 at 28th day was about 40 MPa. Although the graded sand added to EG-850-A1 was the lowest among the mixes, the epoxy to hardener ratio was not compatible. The hardener concentration was higher to cure the epoxy resin, hence accelerated the polymerization process and almost completed within 1 day. The percentage of cross-linked of epoxy matrix was not compatible to provide the optimum strength to the samples. EG-850-B1with higher epoxy content achieved the compressive strength above 60 MPa at 1st day and maintained its strength after 7th day in the range of 65 to 68 MPa. Although the binder to sand ratio of EG-850-B1 was lower than EG-850-A1, the compressive strength of the specimens was higher than the later. The hardener to epoxy ratio of EG-850-B1 was more compatible as compared to EG-850-A1. This enhanced the cross-linked of epoxy matrix and hence tightened the bonding between epoxy matrix and filler. An inclusion of filler to polymer matrix can reduce cost by increase the overall volume of mix as compared to pure epoxy mix. In addition, it also reduce high exothermic of the grout to prevent thermal contraction, and maintain dimension stability (Goulding, 1994). EG-850-C1 with higher filler content provided the highest compressive strength among the mixes. The binder to filler ratio of the mix was compatible and enabled the highest percentage of polymerization (cross-linked). It achieved a strength of 85 MPa at 28th day. EG-850-D1 which has the lowest binder to filler ratio among all the mixes achieved the strength about 75 MPa at 28 day. While the other mixes almost fully cured and achieved the optimum strength at 7th day, EG-850-D1 specimens still showing an increment in its strength after 7 days until 28 days. The strength has increased from 55 MPa at 7th day to 75 MPa at 28th day, an increment of 36% within the period. The lowest concentration of the hardener of EG-850-D1 specimens caused the curing process of epoxy matrix to decelerate, hence delayed its strength development. Based on the results obtained, EG-850-C1 showed the highest compressive strength as compared to other mixes. The epoxy resin in used is the most expensive material among the raw materials to produce resin grout which costing about RM 50 per liter. Undoubtedly, EG-850-C1 mix is more economical as compared to EG-850-D1 mix in which the usage of epoxy was lesser.

Figure 3 shows the replacement of slag within the range of 10 to 50% did not significantly affect the compressive strength of epoxy grout. The compressive strength of EG-850-C1 (Control Mix) at 28th day is 86.6 MPa. Epoxy grouts with 10 to 50% slag as part of filler generally achieved the compressive strengths around 84 MPa at 28th day. The compressive strength of epoxy grout with slag as filler reduced about 2 MPa as compared to control mix due to the particle size of slag which is finer than graded sand, hence enhances the elasticity of the casting sample. The increase of slag content up to 50% added into the epoxy matrix reduces the brittleness of the samples, which enhances the cohesiveness and durability, and also maintains the adhesiveness of the grout as observed from the mode of failure of epoxy grout samples compared to cement grout samples after test, Figure 4.

The micro fine GGBFS reduced the heat of reaction during polymerization of epoxy matrix, hence extended its curing time. Due to the particle size of GGBFS which was finer than graded sand, the elasticity of the casting samples was enhanced. The increase of slag content up to 50% reduced the brittleness of the samples.

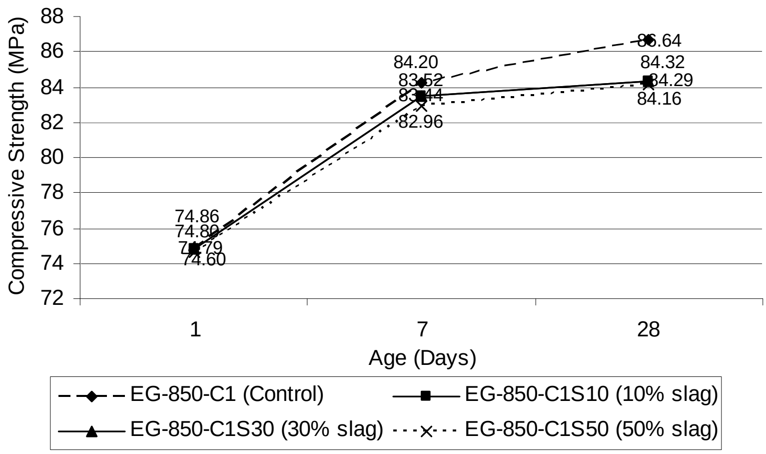

Figure 3: Compressive strength of epoxy grout with various replacement level of GGBFS as filler (epoxy:harderner:filler ratio 5:1:11)

Figure 4: Failure mode of epoxy grout compared to cement grout after compressive strength test

4. Conclusions

The proper resin to hardener ratio was determined to obtain the strength and working life required. The study found that the optimum epoxy to hardener ratio is 5 to 1 by weight. The binder to filler ratio was designed in order to obtain the strength required, and the desired working life and viscosity. The replacement of GGBFS within design proportion maintain the workability and pot life of epoxy grouts, reduced the settlement of sand and enhanced its homogenous and also increased the compressive stress at 28 days.

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