GGBFS AS POTENTIAL FILLER IN POLYESTER GROUT: COMpressive STRENGTH DEVELOPMENT

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ABSTRACT

This paper examines the possibility of using ground granulated blast furnace slag (GGBFS) as a partial replacement of filler in polymer grout. In this study, river sand was replaced by GGBFS at the level of 0% (control), 10%, 20% and 30% by weight. The effects of five curing conditions on the compressive strength at the age of 7, 28, 90, 180 and 365 days were studied. Three specimens were used at each specific age and curing condition. Samples microstructure after 1 year cured under natural weather and sea water were studied using SEM. A comparison was also made on the development of compressive strength between polyester grout with and without GGBFS. From the results, it was observed that GGBFS used as filler to the polyester grout matrix resulted in a better long term compressive strength than that of the control resin. The positive effects of GGBFS on the compressive strength of polyester grout against the hostile environment of Malaysia make this material a feasible additive besides its environmental and economic advantages.

Key words: Polyester; GGBFS; compressive strength; curing condition

INTRODUCTION

Polymer or resin concrete serves as a unique concrete composite, particularly in the area of repair due to its easy application, quick setting characteristic, high mechanical strength, chemical resistance, wear resistance, controlled shrinkage and availability in differences viscosities\textsuperscript{1, 2}. Polymeric composite materials are relatively one of the youngest building materials and becoming more popular in the construction industry in developed countries. Since 1960s the use of various polymer compositions in the construction industry has grown from very small beginnings to significant tonnages due to its bond strength that is considerably greater than the cohesive strength of concrete\textsuperscript{3, 4}. The composites using polymer along with cement and aggregated are called polymer modified mortars (PMM), while the composites made with polymer and aggregates are called polymer mortars (PM) or polymer concrete (PC)\textsuperscript{1}.

Polymer mortars and resin grouts are produced by using dry aggregates, thermosetting resin (binder) and curing agents that undergo polymerization (hardening). Thermoset resins possess a networked (cross-linked) structure, with the restrictive structure preventing melting.

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behavior, but decompose irreversibly at high temperatures. Heating may form such a structure or via a chemical reaction. Due to the excellent thermal stability and rigidity\textsuperscript{5}, various thermoset resins have been used to prepare polymer concretes and mortars including epoxies, polyesters, phenol-formaldehyde (or phenolic) and furfural-acetone types. Such materials exist in various forms such as: liquid resins, dispersible powders, water-soluble photopolymers or copolymers and latexes\textsuperscript{6}. Since the polyester resins are cost effective, easy to handle and portable as compared to the epoxy resin, this resulted in polyester resins being the most used polymer in PC compositions\textsuperscript{7, 8}. However, the choice of polymer and the composition of polymer modified concrete are dictated based on their application and mechanical properties requirements\textsuperscript{9}.

**FILLER TYPES AFFECTING PERFORMANCE OF POLYESTER**

Fillers are the most important additives in a polymer formulation and serve to reduce the cost without drastically affecting the properties of the compound. Indeed, in many cases, the performance may enhance. Powder fillers normally are added to improve gap-filling property and abrasion resistance. It reduces shrinkage and increases viscosity and heat distortion temperature (HDT)\textsuperscript{10}.

Laboratory tests were investigated by researchers around the world to look at the possibility of using different type of fillers in polyester composites. Fly ash, rice husk ash, fine tailings, silica powder, and ground calcium carbonate are the alternative materials for partial replacement of filler in polyester composites. These materials are becoming more and more common as alternative materials filler due to the environmental, economic, or technical benefits. However, the kind of alternative material that is used often depends on the availability and on field of application.

Among these materials, fly ash is the most common filler being studied\textsuperscript{11-15}. Varughese and Chaturvedi\textsuperscript{11} found that there was a good capability between sand and fly ash in polyester concrete system when fly ash is used as a fine aggregate in polyester concrete. The existence of fly ash also improves the mechanical properties and resistance to water absorption. However, properties decline at the higher level of fly ash as the mix becomes unworkable. A great improvement of chemical resistance to acid was detected by Gorninski et al.\textsuperscript{12}, due to the positive contribution of the fly ash in the polyester-sand interface. They showed that fly ash displayed good mechanical properties for orthophthalic and disophtalic polyester.

According to Soh et al.\textsuperscript{13}, the maximum limit of fly ash or ground calcium carbonate (GCC) filler should be controlled at 60\% or less to make the most of the excellent strength of unsaturated polyester resin mortar. Comparing both fillers, fly ash exhibited a little higher strength than that of using GCC. Mun et al.\textsuperscript{14} investigated basic mechanical properties of polyester mortars containing GCC and fine tailing (FT) from an abandoned mine as a filler. They stated that flexural and compressive strength of polyester mortars containing GCC demonstrated a decreasing tendency along with an increase in the mixing filler-(filler + binder) ratio. In contrast, the polyester mortars with FT filler showed an increase in strength with an increase in the filler-(filler + binder) ratio from 30\% to 40\%.

In addition, studies about the possibilities of using quarry waste and rice husk as partial replacement of filler in unsaturated polyester composites are made\textsuperscript{15-16}. The practices that are state above stayed on a limited level, because of the clear reduction in strength properties as the percentage of fillers increased. However, for a given amount of filler and regardless of filler type, polyester resin composites with smaller filler size exhibited higher strength and impact properties than those with larger filler size\textsuperscript{15, 16}. This may be due to the irregularly shaped filler that is unable to distribute the stress efficiently especially as the percentage of filler increased.

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In the past decade, many research and developments were made on the topic of utilizing ground granulated blast furnace slag (GGBFS) in the production of mortar and concrete. The results showed that GGBFS is a potential hydraulic binder for Portland cement replacement. The physical properties of GGBFS increases the workability, reduces bleeding of fresh cement concrete. Inclusion of GGBFS in concrete matrix also found to be effective in reducing heat hydration, improves late strength, reduces permeability and alkali-silica reactivity (ASR) expansion and resistance for sulfate attack.

During the hardening of polymer grout, the settlement of filler particles primarily depends on the density, particle size, and the viscosity of the formulated product. Settlement can be reduced or eliminated by proper formulation. Fine particles fillers with relatively low specific gravity in high viscosity products will reduce settlement, especially if the product is at all thixotropic. GGBFS is generally glassy granular material that is formed when molten blast furnace slag is rapidly chilled by contact of water (“granulated”), dried and ground to a fine powder. The specific gravity of the slag is approximately 2.83 with its bulk density varying in the range of 1200-1300kg/m$. Due to the specific weight of sand which is relatively higher than most of the alternative fillers, this caused a settlement during the hardening and non-uniformity in the final product of the polymer resin grout. This led to the idea to apply GGBFS as micro-filler by replacing sand partially.

This study is aimed to study the potential use of GGBFS as partial replacement of filler in polymer grout. A series of tests was conducted to examine the compressive strength. The strength development up to age of one year of polymer grout containing 10 to 30% GGBFS as filler replacement were investigated in terms of five curing conditions, namely air, water, natural weather (ambient environment) wet-dry cycles and tidal zone (seawater). The scanning electronic microscopy (SEM) was used to evaluate the effects of selected curing conditions on the one year resin grout samples with and without GGBFS.

**MATERIALS**

**Polyester Resin**

An unsaturated polyester resin brand named P9728P isophtalic unsaturated polyester (IUPR) is used as principal binder during this study. Table 1 shows the typical properties of IUPR used. Unsaturated polyester resin (UPR) has two main components such as polyester and a reactive diluent. For most commercial resins, the diluent is styrene monomer, but it is possible to use other vinyl monomers such as methyl styrene and alkyl methacrylate monomers. These diluents serve two vital roles for the system. They reduce the viscosity, so the resins can be processed, and they cross-link with the double bonds in the polyester, without the evolution of any by-products. Polyesters are joined by ester linkages between carboxylic acid and alcohol groups; the macromolecule formed may be linear or cross-linked. From the bi-functional monomers terephthalic acid and ethylene glycol, linear polyester is obtained. Esterification occurs between the alcohol and acid group on both ends of both monomers, forming long chain macromolecules. When trifunctional acids or alcohol are used as monomers, cross-linked thermosetting polyesters are obtained. During this study IUPR is dissolved in styrene locally available in the market. Eq. 1 depicts the chemical structure (linear polymer chain) of IUPR used.
Table 1–Typical properties of ISO-Unsaturated polyester resin P9728P

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance</td>
<td>Pinkish Brown</td>
</tr>
<tr>
<td>Non-Volatile, %</td>
<td>52 - 56</td>
</tr>
<tr>
<td>Viscosity @ 25°C or 77°F, centipoises (Cp) - Brookfield, #3/60</td>
<td>450 – 650 (Low viscosity)</td>
</tr>
<tr>
<td>Elongation (%)</td>
<td>3.7</td>
</tr>
<tr>
<td>Heat Distortion Temperature (HDT), °C or °F</td>
<td>60 (140)</td>
</tr>
<tr>
<td>Thixotropic Index @ 25°C or 77°F - #3, 6 and 60 round per minute (rpm)</td>
<td>1.5 – 2.8</td>
</tr>
<tr>
<td>Gel time @ 25°C or 77°F, minute - 1% MEKP</td>
<td>24 - 30</td>
</tr>
<tr>
<td>Acid Value, mgKOH/g - Solid Resin</td>
<td>25</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.1</td>
</tr>
<tr>
<td>Volumetric Shrinkage, %</td>
<td>9</td>
</tr>
</tbody>
</table>

Note:

°C = (°F-32) × 5/9

1 centipoise (Cp) = 1 × 10⁻³ Pascal.second (Pa.s)

![Chemical structure of Maleic Anhydrid](image1)

![Chemical structure of Propylene Glycol](image2)

![Chemical structure of Iso-Phthalic Anhydride](image3)

**Curing agent**

According to BS 6319: Part 1, hardener or curing agent is defined as a material, which chemically combines with a synthetic resin to produce hardened product. Methyl ethyl ketone peroxide (MEKP) is widely used as a curing agent of unsaturated polymer resin to mold products. MEKP is normally produced in the phlegmatizer (dimethyl phthalate, DMP) with acid as a catalyst. In addition, the product with a concentration up to 10% active oxygen is neutralized, and then is brought to the desired concentration by further dilution with phthalate.

According to Xinrui Li and partners, MEKP is ordinarily a mixture of several isomers, all isomers contain the bivalent -O-O- linkage, and the molecules and their anions are powerful nucleophiles. For this study, MEKP in dimethyl phthalate was used to cure the UPR. MEKP is a clear and colorless liquid. It is organic peroxide. The chemical structure of MEKP is shown in Eq. 2:

![Chemical structure of MEKP](image4)

The curing or cross-linking of unsaturated polyester resin (UPR) is achieved at room temperature by adding a catalyst (or initiator) plus an accelerator (or promoter) and at elevated
temperatures just by adding a catalyst and heating. Eq. 3 shows the cross linked process of polyester by peroxide curing agent.

\[
\text{O} \quad \text{O} \\
\begin{array}{c}
\text{[O-CH2-CH2-O-C-HC=CH-C]}_n \\
\text{Linear polyester}
\end{array} + \text{H2C=HC-} \\
\begin{array}{c}
\text{Peroxide curing agent}
\end{array}
\]

(3)

\[
\text{O} \quad \text{O} \\
\begin{array}{c}
\text{O-CH2-CH2-O-C-HC-CH-C} \\
\rightarrow
\end{array} \\
\begin{array}{c}
\text{O} \quad \text{O} \\
\text{H} \\
\text{CH} \\
\text{O} \\
\text{CH2}
\end{array}
\]

\[
\begin{array}{c}
\text{O-CH2-CH2-O-C-HC-CH-C} \\
\rightarrow
\end{array} \\
\begin{array}{c}
\text{O} \quad \text{O} \\
\text{CH2} \\
\text{CH}
\end{array}
\]

**Filler**

Oven-dried fine river sand complied with the specifications of ASTM C 778\textsuperscript{36} was used as a primary filler in preparing polyester resin. The ground granulated blast furnace slag (GGBFS) which functions as a powder filler (macro-filler) was used as a partial replacement of primary filler. GGBFS used in this study is a by-product of the steel industry; Slag cement (Southern) Sdn. Bhd (YTL), Johor Malaysia. Table 2 shows the chemical compositions and physical properties of GGBFS.

**Preparation of Polyester Grout Compositions**

The design of the polyester grout composition in this study was based on the capability to pump, sufficient strength and working life (pot life >30 minutes)\textsuperscript{37}. The formulations of mixes are given in Table 3. GGBFS was added from 10 to 30% of total filler weight with an increment of 10%. The flowability of the polyester grouts tends to decrease with an increase in GGBFS filler content. The might be due to the inclusion of GGBFS filler increase in solubility and water absorption of polyester matrix, resulting in high shear rate. When the shear rate increases, the viscosity of the polyester grout mixes increased. The viscosity of polyester grout is suggested to be around 2000 centipoises or equivalent to 2 Pascal second (low viscosity) or below tested with Brookfield viscometer using spindle 3, 60rpm to ease the pumping or injection works\textsuperscript{37}. Therefore, during this study, flowability or rheology of all the polyester grout compositions was maintained by adjusting the viscosity within the limitations ranging between 1550 and 2050 centipoises at spindle 3, 60rpm, 30°C (86°F).
The gel time of the polyester grout mixture was mainly controlled by the hardener and accelerator. The viscosity and gel time of polyester grouts were measured in accordance to ASTM D 2471. Commonly the accelerator like cobalt is used to reduce the gel time of polyester mixture. However, cobalt accelerator was not selected because the final polyester grout product produced in this study was aimed to apply in structural repairing which required a longer and sufficient working time for pumping. Thus, the percentage of hardener used was determined based on the sufficient working time ranging between 30 and 37 minutes and without compromising the strength. Table 3 shows the details of compositions polyester grouts designed.

**Methods**
The compressive strength test was performed in accordance to ASTM C 579-01. Three cubes of standard size measuring 50mm x 50mm x 50mm (1.9685in x 1.9685in x 1.9685in) were tested and the result was the mean of individual results. In total, 300 cube specimens were casted and tested at 7 days, 28 days, 3 months, 6 months and 1 year of ages. Five different exposure conditions were adopted to assess the compressive strength development and resistance to aggressive environments exposure such as tropical climate and tidal zone (chloride in seawater and sulfate in muddy soil). The specimens were demoulded after 24 hours of casting, and immediately exposed to the respective condition until their testing age. The details of the exposure conditions are as follows:

i) Air curing in the laboratory. Average room temperature of 27°C (80.6°F) to 30°C (86°F) with 65% average humidity.
ii) Natural weathering outside the laboratory. Temperature ranged from 26°C (78.8°F) to 36°C (96.8°F) with relative humidity 65% to 90%.

iii) Continuous water curing at 26°C (78.8°F).

iv) Wet-dry cycles. The specimens were put into water tank for 1 week (wet cycle) and then drawn out from water to be exposed in open air condition for another 1 week (dry cycle), which would give one complete cycle for testing purpose.

v) Tidal zone. Flow-ebb of sea water.

<table>
<thead>
<tr>
<th>Table 3—Composition for polyester grouts designed and tested</th>
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<tbody>
<tr>
<td><strong>Mix Ingredients</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Binder : Filler Ratio</td>
</tr>
<tr>
<td>GGBFS Content (%)</td>
</tr>
<tr>
<td>MEKP (%)</td>
</tr>
<tr>
<td>Viscosity (cP) at 30°C Spindle #3/60rpm</td>
</tr>
<tr>
<td>Pot Life (minute)</td>
</tr>
</tbody>
</table>

1Percentage of GGBFS and methyl ethyl ketone peroxide (MEKP) is based on the weight of binder.
cP: centipoise; rpm: round per minute.
1000 centipoise (cP) = 1 Pascal second (Pa.s).
Low viscosity < 2000cP: Consistent flow.
2000cP < Medium viscosity < 10000cP: Gelatinous form.
High viscosity > 10000cP.

**RESULTS AND DISCUSSIONS**

Figs. 1-5 show the results of compressive strength of polyester grouts with and without GGBFS under various curing conditions and cured ages. High compressive strength exhibited by all the mixes of grouts is evident from the figures. This is probably related to the good degradation of the resin-filler interface. The compressive strength at 28 days varies from 106 MPa (15374psi) to 124.88 MPa (18112.31psi). This achieved the strength requirement anticipated for polymer concrete and grouts i.e., ≥75MPa (10877.83psi). It is important to note that the lowest value of compressive strength about 93MPa (13488.51psi) was obtained in case of IP-30 at the age of 7 days, exposed to wet-dry cycles. This deduces the high strength gain by the polyester grouts at the early ages also. At the early strength of polyester grouts with 10 to 30% GGBFS are lower than the control grout strength up to 28 days. It can be seen that the strength of polyester grout with GGBFS beyond 90 days was found to be higher than the control grouts except for the samples cured under tidal zone. This can be explained that...
Fig. 1a–Compressive strength of grouts at 7 days of age (in unit MPa)

Fig. 1b–Compressive strength of grouts at 7 days of age (in unit psi)
Fig. 2a–Compressive strength of grouts at 28 days of age (in unit MPa)

Fig. 2b–Compressive strength of grouts at 28 days of age (in unit psi)
Fig. 3a–Compressive strength of grouts at 3 months of age (in unit MPa)

Fig. 3b–Compressive strength of grouts at 3 months of age (in unit psi)
Fig. 4a–Compressive strength of grouts at 6 months of age (in unit MPa)

Fig. 4b–Compressive strength of grouts at 6 months of age (in unit psi)
Fig. 5a–Compressive strength of grouts at 1 year of age (in unit MPa)

Fig. 5b–Compressive strength of grouts at 1 year of age (in unit psi)

GGBFS reduced the reaction heat by resin and its initiator during cross-linking process and thus decelerated or deferred the polymerization at the early ages. Another possible reason for this observation concluded by Shariq et al., may be due to the slow rate hydration at early ages for incorporating GGBFS.
Table 4 presents the percentage difference of compressive strength at various ages as compared to 28-day compressive strength when being subjected to different curing conditions. It is worth noting that the strength gain was independent of exposure condition at the age of 7 days and almost all the polyester grouts achieved 80% of 28-day compressive strength, respectively. This may conclude that the application of GGBFS as filler in polyester grouts may behave differently as compared to the water based cement concretes or mortars in terms of early age strength gain. Shariq et al.\textsuperscript{24} found that 7-day compressive strength of cement mortars incorporating GGBFS at 20%, 40% and 60% only gained about 60% of 28-day strength.

At the ages of 7 and 28 days, the polyester grouts with GGBFS exhibited comparatively smaller strength gain than that of the control grout. However, this effect was diminished with time. This could be attributed to the slow process of polymerization of resin matrix to bind the filler due to the presence of GGBFS. The compressive strength of grouts containing GGBFS as filler consistently increased up to the age of 1 year and was more pronounced as the percentage of filler increased. This may be due to the increased surface area as the sand is replaced by smaller particle size of GGBFS filler. The increase in surface area may result in better formation of physical and chemical bond between polymer micro-molecules and micro fillers\textsuperscript{16}. This infers the suitability of GGBFS as filler in polyester grouts in terms of consistency and long term gain in compressive strength. On the other hand, the control grouts showed a decrement in the strength beyond 3 months of age where the compressive strength was smaller than that of the 28 days. In fact, the 28-day compressive strength is commonly considered as the design strength and supposed to be optimum and presumed to be increased later on but the control grout could not accomplish this phenomenon. Nevertheless, the polyester grouts at 30% replacement level of GGBFS reached excellent compressive strength and are similar to those reported in literature. Mum et al.\textsuperscript{14} examined the properties of polyester mortars using fine tailing (FT) and ground calcium carbonate (GCC) as a filler. From the view point of percentage, the compressive strength of polyester mortars reaches maximum at a replacement of 30%, regardless of the type of filler. A study by Soh et al.\textsuperscript{13} was found that fly ash contents about 50% is most suitable for attaining maximum increase in strength of unsaturated polyester resin mortar.

In terms of curing condition, the polyester grouts exposed to the air and natural weather environments show identical and higher strength than those of the grouts exposed to other environments particular in water conditions, and this effect is more significant with time. This phenomenon, however, are contradicts for GGBFS applied in cement concrete. Atis and Bilim\textsuperscript{20} and Cakir and Aköz\textsuperscript{22} stated that water cured of GGBFS concrete indicated marked positive effect on compressive strength as compared to those dry cured condition. This explained why the water curing is important for hydration of cement as perceived. Since Malaysia’s environment is tropical and cyclic in nature with rain and scorching sunshine alternatively, it is believed that the cross-linking network forming process was accelerated during the sunshine, causing heat, resulting in higher strength gain in ambient environment. As Barbara\textsuperscript{5} stated, thermoset resin forms its long chain cross-linked structure (solidify) by heating or via a chemical reaction. On the contrary, the polyester grouts exposed to water and tidal zone showed lower compressive strength and could be attributed to the lowered temperature which slowed down the polymerization process, thereby decelerated the compressive strength development. The ingress of liquids into samples after long-term immersion also degraded the interfacial bonding between resin matrix and filler, thus deteriorated the strength. Nevertheless, the grout IP-30 with 30% GGBFS exhibited higher long-term compressive strength than the other grouts even when it is immersed in seawater due to GGBFS which possess a good inert mass ability as well as pozzlanic characteristic in preventing the ingress of liquids. Therefore, it can be concluded that incorporating GGBFS provides a positive effect on the strength and durability of the polyester resin grouts. Also there

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was neither weight loss, nor apparent deterioration observed in polyester grout samples exposed to all exposure environments including flow-ebb of seawater.

Table 4–Strength development of grouts expressed as percentage of 28-day compressive strength subjected to different exposing conditions

<table>
<thead>
<tr>
<th>Age</th>
<th>Grout</th>
<th>Strength development as percentage of 28 days strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Air</td>
</tr>
<tr>
<td>7 days</td>
<td>IPG-CTR</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>IPG-10</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>IPG-20</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>IPG-30</td>
<td>82</td>
</tr>
<tr>
<td>28 days</td>
<td>IPG-CTR</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>IPG-10</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>IPG-20</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>IPG-30</td>
<td>100</td>
</tr>
<tr>
<td>3 months</td>
<td>IPG-CTR</td>
<td>103</td>
</tr>
<tr>
<td></td>
<td>IPG-10</td>
<td>108</td>
</tr>
<tr>
<td></td>
<td>IPG-20</td>
<td>108</td>
</tr>
<tr>
<td></td>
<td>IPG-30</td>
<td>103</td>
</tr>
<tr>
<td>6 months</td>
<td>IPG-CTR</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>IPG-10</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>IPG-20</td>
<td>112</td>
</tr>
<tr>
<td></td>
<td>IPG-30</td>
<td>111</td>
</tr>
<tr>
<td>1 year</td>
<td>IPG-CTR</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>IPG-10</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td>IPG-20</td>
<td>111</td>
</tr>
<tr>
<td></td>
<td>IPG-30</td>
<td>113</td>
</tr>
</tbody>
</table>

Figs. 6-9 show the microstructure images of the control and polyester grout with 30% GGBFS. From the observation of the factures surfaces, grouts with 30% GGBFS are denser and uniform, and less porous than the control grouts. Fig. 6 and 8 show the control grouts are almost caused by the failure of sand particles for both natural weather (ambient environment) and sea water (immersed in sea facing flow-ebb) exposure conditions, respectively. In Fig. 7 and 9, it can be seen that 30% of very fine GGBFS efficiently fill the micro-pores and are covered within the grout mass. Furthermore, GGBFS also possess cementitious properties which might enhance the adherence between the particles and the other constituents of the grout. It is evident that with more cohesive and high strength in final product, durable against the hostile environments and the flow-ebb of the seawater is developed. Therefore, it is suggested that polyester grouts with 30% GGBFS replacement of sand as powder/micro-filler has better resistance to aggressive and hostile environments and is durable in tropical countries.
Fig. 6–Microstructure image of IP-CTR (control) after 1 year exposed to natural weather (1000X magnification)

Fig. 7–Microstructure image of IP-30 (30% GGBFS) after 1 year exposed to natural weather (1000X magnification)
Fig. 8–Microstructure image of IP-CTR (control) after 1 year exposed to sea water (immersed) (1000X magnification)

Fig. 9–Microstructure image of IP-30 (30% GGBFS) after 1 year exposed to sea water (immersed) (1000X magnification)
CONCLUSIONS

Grouting is required to fill the joints, fissures, cracks and voids leakage by curtain grouting irrespective of any construction of the structures. The site engineers suffer a lot of problematic situation depending upon water spring, shear zones and water table falls etc below the rock foundation, so for foundation treatments the polyester resins and GGBS are very useful and other materials parallel like rice husk ash/ sawdust/spongy materials along with sodium silicate as accelerators with grout mix of cement and water are also useful to plug the leakage/consolidate the cavities/spring zone situations.

The results of this study reveal that the replacement of GGBFS up to 30% by filler mass as powder/micro-filler in polyester grouts performs better than the polyester grouts without GGBFS. Although the early strength of GGBFS polyester grouts was less than the control grouts, however, beyond 28 days their compressive strength kept improving and was higher than that of the control grouts. The natural weather of Malaysia with rain and scorching sunshine alternatively shows a positive effect on the long-term compressive strength gain of GGBFS polyester grouts. The polyester grouts with GGBFS were dense, uniform and less porous structure which not only exhibit high compressive strength but also efficiently sustain the aggressive environment in sea water and the flow-ebb of seawater. Thus, on the basis of the results and the discussions made herein, it can be concluded that GGBFS is a potential material to be used as powder/micro-filler in the polyester grouts for concrete. The overall performance of the polyester grouts with GGBFS was alike the epoxy resins and can serve as a cost effective material for concrete repair work.

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