

EFFECT OF SLAG CONTENT TO CEMENT GROUT ON THE COMPRESSIVE STRENGTH DEVELOPMENT IN TROPICAL WEATHER ENVIRONMENT

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ABSTRACT: Cement based grout is one of the economical and an effective material that is usually used for repairing structural cracks. This paper investigated the compressive strength development under different curing regimes of the cement-based grouts produced by various replacement levels of slag (GGBFS) compared with the 100 percent OPC based grout in tropical weather. This paper covered the investigation of the compressive strength of the ordinary Portland cement grout and the slag cement based fluid grouts with the replacement of GGBFS in range of 30 percent to 60 percent slag. All specimens were cured under three different curing conditions to investigate effect of curing regimes to the development of compressive strength. The investigation proved that the slag cement based grout could stand the tropical weather and provided the suitable strength for normal concrete structural repairing works. The test results showed that 50 percent slag replacement specimens provide optimum long-term compressive strength among others under water curing condition. The optimum slag replacement can enhance the strength of cement mixes in long-term under water curing regime. This has indicated a good sign for further investigation of other engineering properties to produce a more effective repairing material using slag as a partial cement replacement.

Key words: Grout, slag, compressive strength, partial cement replacement

1. INTRODUCTION

Cracking of structure elements may cause by several factors such as design false, overloading, improper construction and curing, seasonal temperature variations and etc. Repair of cracks should be carried out to make sure the cracking structure could function as expected.

The cost and compatibility of the repairing materials are significant factor to be considered in repairing works. Grout is one of the materials that are usually used for repairing structural cracks. Grout has been used till nowadays since the grouting technique introduced. Grouting technique started 200 years ago by a French engineer, Charles Berrigny who inspired the idea to repair the structure damages of harbor of Dieppe by grouting using percussion pump invented by him in year 1802 [1,2]. Later, in England, Marc Isambard Brunel used Portland cement as cement grouting materials in 1838 during the construction of the first Thames tunnel at Wapping. Then, cement grouting becomes widely used in the early part of the last century [2]. For current practice, all types of grout are used including cement, cement and sand, clay-cement, slag-cement, resin gypsum-cement, clays asphalt, pulverized fuel ash and a large number of colloid and low viscosity chemicals etc. Nonveiller (1989), define grouting as a procedure of injecting the grout materials into the fissures, cracks in order to enhance their properties, reduce the deformations [1].

Ground granulated blast furnace slag (GGBFS) cement is hydraulic cement produced during the reduction of iron ore to iron in a blast furnace. Molten slag is tapped from a blast furnace, rapidly quenched with water (“granulated”), dried and ground to a fine powder. The rapid quenching “freezes” the molten slag in a glassy state, which gives the product its cementitious properties and become one of the most popular cementitious materials used in

concrete [3]. Slag cement has been around for a long time. Its history parallels that of Portland cement (which was patented by Aspdin in 1824). Earliest documented use of slag cement was in 1774, as a mortar in combination with slaked lime. Advances in slag removal and granulation processes resulted in the first commercial use of slag-lime cement in Germany in the 1860's. The Paris underground metro was built utilizing these cements, beginning in 1889 [4]. Blended Portland-slag cement first appeared in Germany in 1892, and subsequently in the United States in 1896. It was not until the 1950's, however, that slag cement was used as a separate product added at the concrete mixer with Portland cement and other ingredients [4].

2. BENEFITS OF USING SLAG CEMENT BASED CONCRETE

Currently, slag cement is used to produce blended cement that complies with ASTM C 595, Standard Specification for Blended Hydraulic Cements [5]. Slag cement can be used as a constituent in hydraulic cements produced under ASTM C 1157, Standard Performance Specification for Hydraulic Cement [6].

Blended cements can be produced to provide the benefits in performance that are also available when slag cement is used as a separate component of the concrete mix. By varying the proportion of the blend, attribute such as sulfate resistance, alkali silica reaction mitigation, lower permeability and bleeding, increase the final strength and durability and also produce mass concrete can be attained with blended cement. A blend designed for a specific project requirement can also be produced [7,8].

Production of slag cement creates a value-added product from a material — blast furnace slag — that otherwise might be destined for disposal. Not only does the making of slag cement lessen the burden on landfills, but it also reduces air emissions at steel plants through the granulation process (as compared to the traditional air cooling process). Use of slag cement in all concrete applications and also non-concrete applications such as soil-cement and hazardous waste solidification reduces the environmental impact of concrete by [9]:

- a) Reducing greenhouse gas emissions by eliminating approximately one ton of carbon dioxide for each ton of Portland cement replaced;
- b) Reducing energy consumption, since a ton of slag cement requires nearly 90-percent less energy to produce than a ton of Portland cement;
- c) Reducing the amount of virgin material extracted to make concrete; and
- d) Reducing the "urban heat island" effect by making concrete lighter in color thus reflecting more light and cooling structures and pavements with exposed concrete.

APPLICATION OF CEMENT- BASED GROUT

Cement-based grouts can self –compact under its own weight without segregation and easy to flow into place and have high filling ability. High fluidity of grout is a prime requirement of high cohesion or segregation resistance during flow to form uniform and homogeneous concrete [9]. As the fluid grout can be fully compact without vibration, the application of fluid grout can therefore reduce labour and machinery, improved compaction and hence enhanced durability of the critical cover zone of structural member [9].

An essential feature of all grout systems is that they must be sufficiently fluid to be injected into the void to be grouted and shall be set to a solid. Cementitious grouts may be used for a very wide range of applications including [10]:

- a) Structural applications such as grouting of tendons in pre-stressed concrete.
- b) Grouted connections and grouted repairs for various types of structures.
- c) Geotechnical grouting for ground water control and for soil strengthening.
- d) Compensation grouting and slab jacking for the control of settlement.

- e) Contact grouting behind tunnel linings during tunnel construction to fill the remaining voids and so improve the stress distribution on the lining and limit surface settlements.
- f) Grouting of conductor pipes in soil and gas wells to prevent loss of hydrocarbon product slurry trench cut-off walls for the containment of contaminants in the ground or the control of landfill gas migration.
- g) Encapsulation/ fixation of radioactive and toxic wastes and many other aspects of pollution control.
- h) *In-situ* stabilization of contaminants etc.

These applications involve many different engineering disciplines including structural, geotechnical, chemical and environmental engineering. Each application of cementitious grout has tended to develop its own form of specification and test procedures.

3. EXPERIMENTAL PROGRAM

4.1 INTRODUCTION

The use of slag as partial replacement in Portland cement to produce slag cement based fluid grout will enhance the engineering properties, as well as the durability of grout. The investigation on compressive strength development of cement grouts according to standard specification of ASTM C 937 - 02 [11] was carried out.

4.2 RAW MATERIALS SELECTION

The raw materials that used to produce slag cement based fluid grout shall comply with the standard ASTM C 938 – 02 [13]:

- a. **Cement** – Ordinary Portland Cement (OPC) was used to produce the slag cement based fluid grout. The OPC used complies with the Malaysian Standard MS 522: Part 1 (1989), which is equivalent to the British Standard BS 12: and Type I Portland cement as in ASTM C 150 – 02a [14,15]. Table 1 shows the chemical and physical properties of the OPC.
- b. **Ground Granulated Blast-Furnace Slag (GGBFS)** – The GGBFS was used as partial replacement of OPC in producing Portland blast-furnace slag cement. The GGBFS used complies with the requirements in ASTM C 989 – 89 [16] or as in BS 6699: 1992 [17]. The grade of GGBFS used is 100 based on the slag activity index (SAI), ASTM C 989 – 89.
- c. **Sand** – The type of sand used is standard washed sand according to ASTM C 778 – 91 [18]. Sand was oven dried at 105°C around 24 hours to mitigate moisture content inside it. The totally dried sand then sieved to remove litter/ rubbish and graded according to the requirements of ASTM C 637 – 90 [19].
- d. **Water** – Water was used for process of cement hydration and also provides workability for cement grout. Water should be clean, neutral and contains limited substances that no harmful to the process of cement hydration and durability of concrete. In general, tap water can be used in producing of cement grout.

4.3 PROPORTION

Table 1 presents the chemical analyses of the cementing materials. The mix designs for five different types of cementitious-based grouts (M-CTR to M-50) should be complied with the requirement of ASTM C 937 – 02 [11]. The GGBFS contents vary from 0 to 50 percent by total cementitious materials weight. The water content for design mixes was determined by flow cone method based on ASTM C 939 – 02 [12].

Table 1: Physical and chemical properties of OPC and GGBFS

Chemical Constituents	OPC (%)	GGBFS (%)
Silicon dioxide (SiO ₂)	20.1	28.2
Aluminium oxide (Al ₂ O ₃)	4.9	10.0
Ferric oxide (Fe ₂ O ₃)	2.5	1.8
Calcium oxide (CaO)	65.0	50.4
Magnesium oxide (MgO)	3.1	4.6
Sulphur oxide (SO ₃)	2.3	2.2
Sodium oxide (Na ₂ O)	0.2	0.1
Potassium oxide (K ₂ O)	0.4	0.6
Titanium oxide (TiO ₂)	0.2	-
Phosphorous oxide (P ₂ O ₂)	<0.9	-
Loss on ignition (LOI)	2.4	0.2
Carbon content (C)	-	-
Physical Properties		
Specific gravity	3.2	-
Fineness (% passing 45µm)	93.0	100

4.4 MIXING PROCEDURE

The mixing procedure of fluid grout is based on ASTM C 1107 – 91a [20] under section mixing. First, OPC, GGBFS and graded dry sand were weighed and mixed in a clean, dry concrete mixer around 3 minutes until they were blended intimately and uniformly. Then, the measured clean tap water was added into the dry mix. The grout was mixed for about 3 minutes until uniform in concrete mixer before can be tested with the flow cone to determine the workability for fluid grout. According to ASTM C 827 – 87 [21], to produce the fluid mixture using flow cone method, the time of efflux of the fluid grouts shall in the range of 10 seconds to 30 seconds. For this research, the time of efflux for fluid grouts were complied with standard of ASTM C 937 – 02 [11] which shall within 21 ± 2 seconds when tested by flow cone based on ASTM C 939 – 02 [12]. The freshly mixed fluid grout was filled into molds in the set halfway. Puddle each with a gloved finger five times to consolidate. Fill the mold and puddle again. When filling the mold, use sufficient material so that after the final consolidation the mold is slightly overfilled [20]. The final consolidation (the fluid grout stop to compact by its self-weight) of each fluid grouts in this research was after one hour. Bring the excess grout to the center and finish the surface by cutting off the excess with the straight edge of a trowel held vertically and drawn across the top of the mold with a sawing motion. The excess grout was clean out from surrounding molds by using cloth. Prior to demoulding of cube samples after 24 hours, the cubes were subjected to different curing conditions and tested for short term (ages 7, 14 and 28 days) and long term (3, 6 and 9 months) compressive strength.

4.5 CURING

The curing conditions adopted for the purpose of this investigation are described as below:

- i. Continuous water curing at 25 -26⁰C.
- ii. Air curing in laboratory. Average temperature at 30⁰C with 65% relative humidity.
- iii. Tropical climate outside laboratory. Temperature ranged from 26⁰C (raining) to 38⁰C (hot) with humidity range from 25% (hot and dry) to 90% (wet).

Figs 1 – 4 show the compressive test set-up and the curing regimes adopted in this study.



Fig. 1 Compressive test



Fig. 2 Air-cured samples



Fig. 3 Water-cured samples



Fig. 4 Natural weather-cured samples

5. DICCUSSION OF RESULTS

Compressive strength was determined according to BS 1881 : 1993 : Part 116 [22]. Three 70.6 x 70.6 x 70.6 mm cubes were weighed and tested for load at uniform rate 0.20kN/s until failed. Figs 5 to 7 presented the average compressive strength for each batch of grout under different curing conditions at 7, 14 and 28 days:

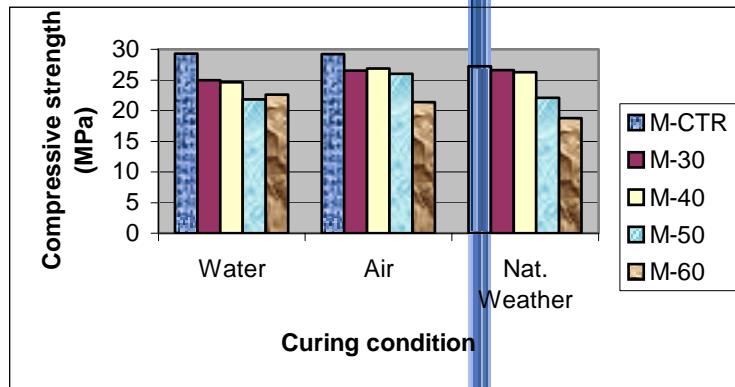


Fig 5. 7-days compressive strength of cement grout

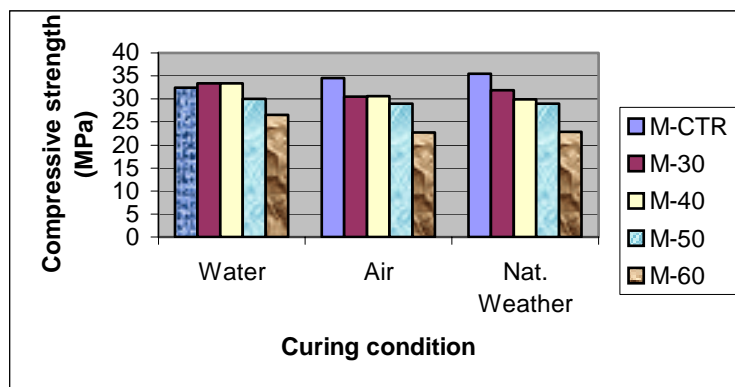


Fig 6. 14-days compressive strength of cement grout

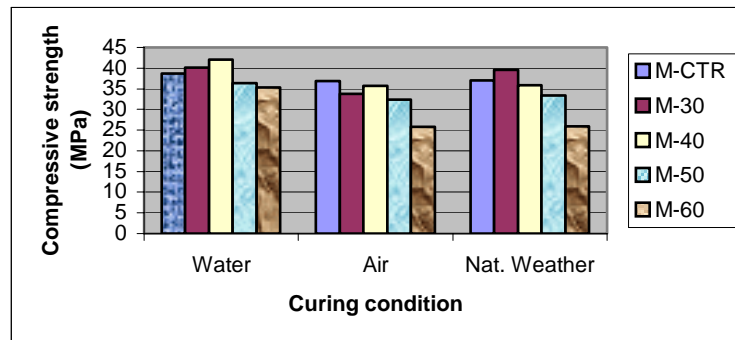


Fig 7. 28-days compressive strength of cement grout

From Figs 5 to 7, they showed that the 7-day initial strength of samples under air and natural weather curing condition were higher than the samples under water curing condition (except M-60 mix) because of the higher temperature had accelerated the hydration process at initial stage (7 days). When come to the 14 days and 28 days period, the water curing samples showed a higher compressive strength than other two curing conditions as the water curing samples have sufficient water for further hydration process at the mentioned ages compared with samples under air and natural weather that facing the evaporation due to the tropical weather causing insufficient water content for hydration process. According to Bungey [23], under dry condition, water will absorb to the sides of pore, once the pore walls have reached their absorption limit, water will diffuse across the pores and vapour. The evaporation faced by air cured samples can be noticed by it's lighten density compared with density of water

cured samples. The samples under natural weather may have higher or lower strength and density compared with the samples under air curing condition in laboratory within 7 to 14 days. When hot day with low humidity, it can cause the water inside samples facing higher evaporation through the diffusion mechanisms and weaken the samples. When raining day, the samples have good initial curing condition to maintain water content inside samples as the inlet and outlet of pores are restricted by water. Initial water curing is important to improve the strength of slag cement or cement-based grout. From Fig. 7, it showed that 30 to 50 percent slag replacement grouts achieved the strength above 30 MPa on 28 days under all curing condition. The M-60 mixes have achieved the strength above 30MPa on 28 days under water curing condition. Water curing can maintain the water content inside M-60 samples for continuous hydration process. 40 percent cement content in M-60 samples is insufficient to hold the water content inside it from evaporation under air and hot tropical weather, the hydration process of cement paste itself was incomplete causing the strength lower. The second factor that reduce the strength of M-60 is slag and cement proportion for M-60 only can produce little amount of extra C-S-H gel by reaction of calcium hydroxide (Ca(OH)₂), which was by-product of cement paste and silica from GGBFS within 28 days.

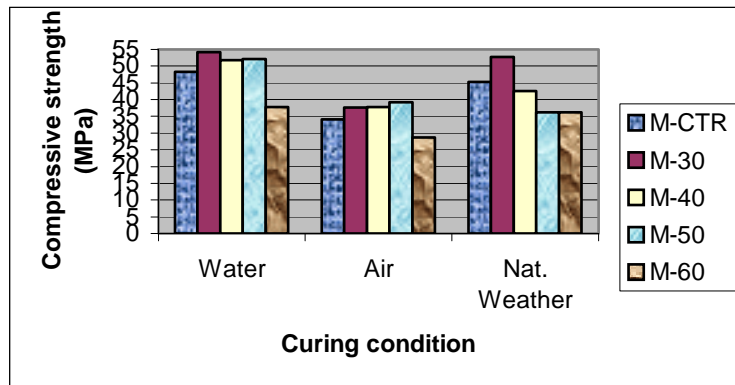


Fig 8. 90-days compressive strength of cement grout

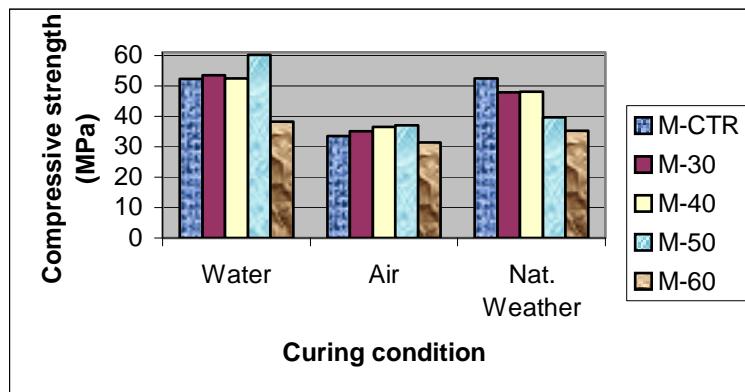


Fig 9. 180-days compressive strength of cement grout

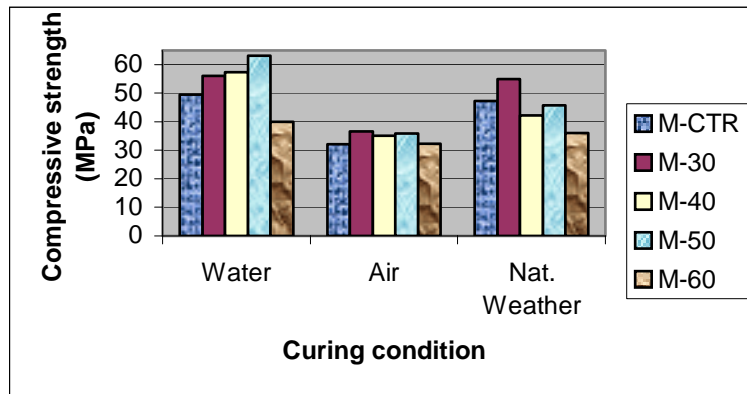


Fig 10. 270-days compressive strength of cement grout

Figs 8 to 10 showed the long-term strength development of cement-based grouts. Based on the results obtained, it proved that slag cement based grouts have consistent strength development up to 9 months under water curing regimes. This has proved that GGBFS (Grade 100) replacement to OPC in range of 30 to 50 percent can form more C-S-H gel in long-term period and have higher strength than 100 percent OPC mixes. The strength of cement grouts mostly decreased under air curing condition except M-60 grout due to evaporation of water inside samples but still can achieve the compressive strength above 30 MPa up to 9 months. The M-60 grouts can maintain small amount of water inside samples under open-air regime after 9 months. It was found that when the 9 months M-60 cubes were tested until crushed, there were obviously seen that a small part of moisture area exist inside samples. This phenomenon can explain why the M-60 samples under open air regime still have strength development up to 9 months. For natural weather curing samples, the results showed that the strength development up to 9 months were better than air-cured samples while lower than water-cured samples. The strength development of samples under tropical climate depends on the relative humidity and temperature that inconsistently changed. It seems like the samples cured under inconsistent wet-dry cycles, which is, consider as severe condition. The strength development of samples was good when they have sufficient moist-cured (raining) in the period, the rain water was absorbed into samples through capillary to compensate water loss via evaporation and maintain sufficient water inside samples for further hydration process. On the other hand, when there was no rain in the period, the weather was hot and humidity was low, the water inside samples changed to vapour and evaporated through capillary of samples. This phenomenon caused the strength of samples decreased. Based on the results obtained, the slag cement based grout still can achieve the strength more than 35 MPa up to 9 months and consider durable under tropical climate.

6. CONCLUSION

Based on the-above investigations, it can concluded that replacement of 30 to 60 percent slag as partial cementitious materials developed compressive strength of more than 35Mpa at 28 days under water curing condition. The 28-day compressive strength of cement grouts still can achieve more than 30MPa except M-60 under air and natural weather. The development of strength for all slag cement based specimens still increase after 3 to 6 months under water cured and natural weather but decreased under air curing condition. The results showed that 50 percent replacement of slag has performed optimum among all mixes after 9 months under water curing condition which its compressive strength achieved 60 MPa. The results proved that appropriate moist cured can provide better long-term strength development for all slag cement based grouts. The air-cured condition is not suitable after application of slag cement based grout, as the strength will decrease in long-term period. In order to maintain strength

development based on results obtained, it is encouraged to provide 90 percent relative humidity curing regime (cover by wet plastic sheet, nylon beg etc.) after repairing works using slag cement based grout.

7. ACKNOWLEDGEMENTS

This research was carried out in the Structure and Material Laboratory of Faculty of Civil Engineering, Universiti Teknologi Malaysia. Financial support from the Construction Industry Development Board of Malaysia (CIDB) is greatly appreciated.

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