Plastic Concrete Reuse Using Extended Set-Retarding Admixtures

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Synopsis: This paper reports a preliminary experimental study on the effect of extended set-retarding admixture or 'stabiliser' on the plastic and hardened properties of grouts and concretes containing general purpose Portland cement, blended cement and low heat cement.

The effect of stabiliser on efflux time or 'flow time' of GP cement grout was studied and the dosage required to achieve an efflux time of 35 seconds was estimated. The results showed a linear relationship with increasing stabiliser dosage extending the holding time of the grout.

The effect of stabiliser on the timing and measure of peak hydration temperature was then assessed and the results showed that for GP cement and GB cementitious grouts, peak temperatures were lower after adding stabiliser, and for all three grouts the time to peak hydration was significantly increased.

Finally, the effect of stabiliser on the plastic and hardened properties of fresh concrete, stabilised concrete, and a blend of fresh and stabilised concrete was assessed. The results showed that the initial one hour slumps and the final slumps of the blended concretes were all within tolerance.

The results also showed that adding stabiliser to the concretes did not a significantly reduce compressive strength when compared to the original, non-stabilised concretes.

Keywords: Ready mix concrete, extended set-retarder, stabiliser, returned plastic concrete, flow cone, peak temperature rise, recycling, type of cement, cementitious material, environment.

1. Introduction

The annual global production of concrete is approximately five billion cubic yards (3.8 billion cubic metres) and therefore twice as much concrete is used in construction as in all other building materials including wood, steel, plastic and aluminium (1). Returned plastic concrete, surplus production, rejected concrete and trial batches will typically comprise one to three per cent of concrete production and this significant waste stream must be recycled or disposed of (2). Plastic concrete can be recycled by washing and reusing reclaimed aggregate and waste water in low grade concrete, and hardened concrete can be recycled after crushing. However, cement and supplementary cementitious materials cannot be recycled.

A survey by National Ready Mixed Concrete Association (NRMCA) found that a majority of concrete producers used a system of settling basins to remove suspended solid from wastewater, which was treated and discharged into a drainage system or reused in the plant as batch water in concrete (3).

The use of waste water and reclaimed aggregate in concrete is problematic, because complications including flash setting, shrinkage cracking and reduced durability, can occur. The energy needed to crush hardened concrete liberates carbon dioxide derived from fossil fuel along with dust, which is also problematic. Where recycling is not possible or practical, hardened waste concrete, sufficiently drained solid sludge, and treated waste water, must be disposed to landfill or into a drainage system in accordance with environmental regulations. The increased regulation of the quality of solid and liquid waste entering the industrial waste stream has significantly increased the cost of the disposal of waste concrete, and this is a significant issue for the ready mix concrete industry (4).

Recent advances in concrete technology have introduced a chemical admixture that can be used to reduce or possibly eliminate the need for the disposal of waste water and returned concrete (5, 6). This is possible because an extended set-retarding admixture or 'stabiliser' can suspend the hydration reaction of cement and thus allow the holding of plastic concrete for several hours. Extending the setting time of returned concrete using a stabiliser, allows it to be added to fresh concrete in limited proportions without adversely affecting the properties of the fresh concrete (7).

This paper reports a preliminary experimental study on the effect of stabiliser on the properties of plastic and hardened concretes, with a view to the potential use of stabilisers to facilitate the re-use of returned plastic concrete.

2. Experimental Plan

The experiment was conducted in three phases:

1. Phase 1 assessed the effect of stabiliser dosage on holding time (stabilised duration) on General Purpose (GP) cement grout.
2. Phase 2 assessed the effect of stabiliser dosage on temperature rise during hydration of GP, GP plus fly ash (FA), and low heat GP and Ground Granulated Blast Furnace Slag (GGBS) cement grouts.
3. Phase 3 determined the effect of stabiliser dosage on the physical properties of plastic and hardened concretes, including concretes containing 10 and 25 per cent stabilised, re-used plastic cement.

2.1 Constant Factors

The following factors were held constant during the experiment:

1. The content of cementitious used in all grout and concrete mixes was 340kg/m^3.
2. The water/cement ratio in all grout and concrete mixes was 0.55.
3. The mix proportions of all concrete batches were the same in every trial.
4. To avoid experimental difficulties associated with holding grout for extended periods, a16 second efflux time was used.
5. In Phases 2 and 3, stabiliser was added to the control concrete and grout at one hourly interval.
6. In Phase 3 the concrete temperature was maintained at 21 ± 2 degrees Celsius,
7. The dosage of water reducer added to all grout and concrete mixes was 300ml/100kg of cement.
8. Stabilised concrete for all types of cement and cementitious materials was replaced with 10 per cent and 25 per cent of fresh concrete.

2.2 Variable Factors

The following factors were varied in the experiment:

1. Stabiliser dosage.
2. Cement types used in Phase 2 and Phase 3.
   a) General purpose Portland cement (GP cement).
   b) Low heat cement (35% GP cement + 65% Ground Granulated Blast Furnace Slag (GGBS)).
   c) Blended cement (75% GP cement + 25% fly ash (FA)).

2.3 Response Variable

The response variables evaluated in this study were:

1. Holding time required to achieve an efflux time (flow time) of 16 seconds for cement grout (which was extrapolated to estimate the 35 second efflux holding time).
2. Temperature rise during hydration of cementitious grout.
3. Initial and final setting times of concrete, tested in accordance with AS 1012.18-1996 (8).
4. Compressive strength of concrete at 7 days, 28 days, and 56 days, tested in accordance with AS 1012.09-1999 (9).
5. Slump values of concrete, tested in accordance with AS 1012.09-1999 (10).

3. Experimental Procedure

3.1 Materials

Table 1 shows the chemical constituents of the three cement types used. The coarse and fine aggregates used were natural granite and river sand, respectively, in accordance with AS 2758.1. The aggregates were batched in the Saturated Surface Dried (SSD) condition. The amount of added water was adjusted for the aggregate moisture content. The stabiliser and water reducer used were both commercially available.

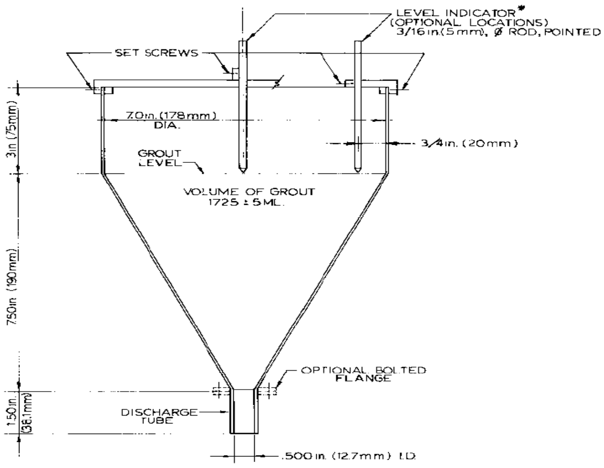
Table 1. Chemical constituents of GP cement and FA and GGBS cementitious materials

Chemical Constituents	GP Cement (%)	FA Cementitious Material (%)	GGBS Cementitious Material (%)
SiO_2	20.1	51.80	40.00
$Al2O_3$	4.9	26.40	13.60
$Fe2O_3$	2.7	13.20	1.40
CaO	63.3	1.61	39.20
MgO	2.2	1.17	5.60
SO_3	2.3	0.21	0.70

3.2 Phase 1 - Effect of Stabiliser on Efflux Time with Increased Holding Times

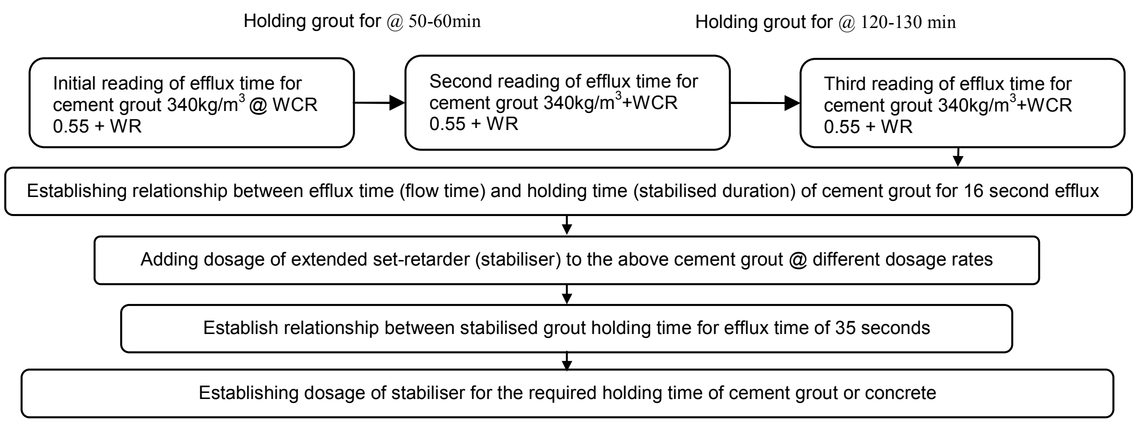
In order to predict the dosage of stabiliser required to be able to hold the concrete without hardening, the dosages were determined by measuring the holding time of the cement grout at efflux time of 35 seconds in accordance to ASTM C 939 (11). The flow cone test was used to measure the flow properties of the different cement and cementitious grouts. To perform the test, the grouts were poured into a flow cone of the type shown in Figure 1.

Figure 1. Cross section of Flow Cone (11)



The level indicator was used to ensure that the standard volume of grout was used for each test. The opening valve at the bottom of the cone was opened and the time for the grout to flow out of the cone (the efflux time) was recorded. In order to be able to determine the 16 second efflux time, the process was repeated at approximately one hour intervals using the same grout. The test was abandoned when the grout clogged in the cone and did not flow continuously through the opening. The process flow chart is shown in Figure 2.

Figure2. Process flow to determine the dosage of stabiliser for required holding time

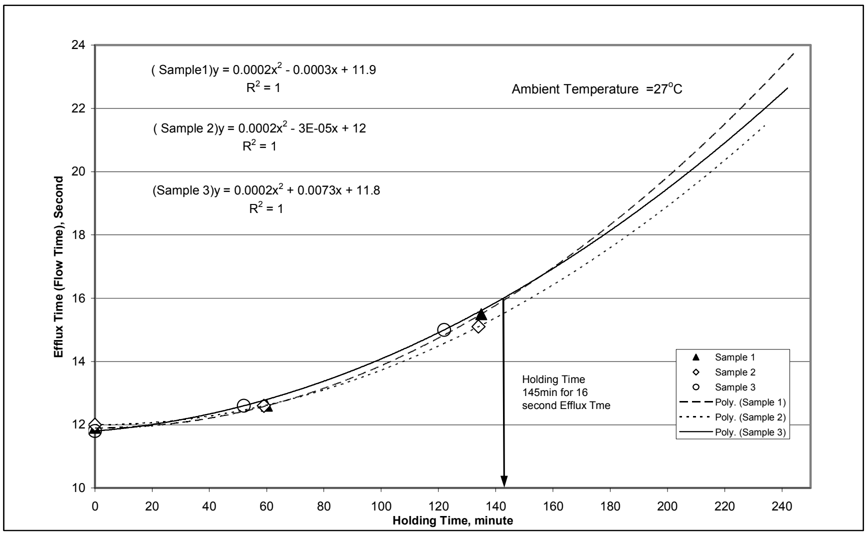


On adding the water and water reducing admixture to the cement, it was mixed until no cement lumps remained. Within a minute of completing the mixing, the grout was poured into the flow cone up to the level required. The opening valve at the bottom of the cone was then opened and the efflux time was noted. The second reading of the efflux time was taken after holding the grout for 50-60 minutes and the third reading of the efflux time was taken after holding the same grout for 120-130 minutes.

To avoid the experimental difficulties associated with holding grout for extended periods, a 16 second efflux time was used. This is one half of the time specified in ASTM C 939 (11) to estimate maximum permissible holding times.

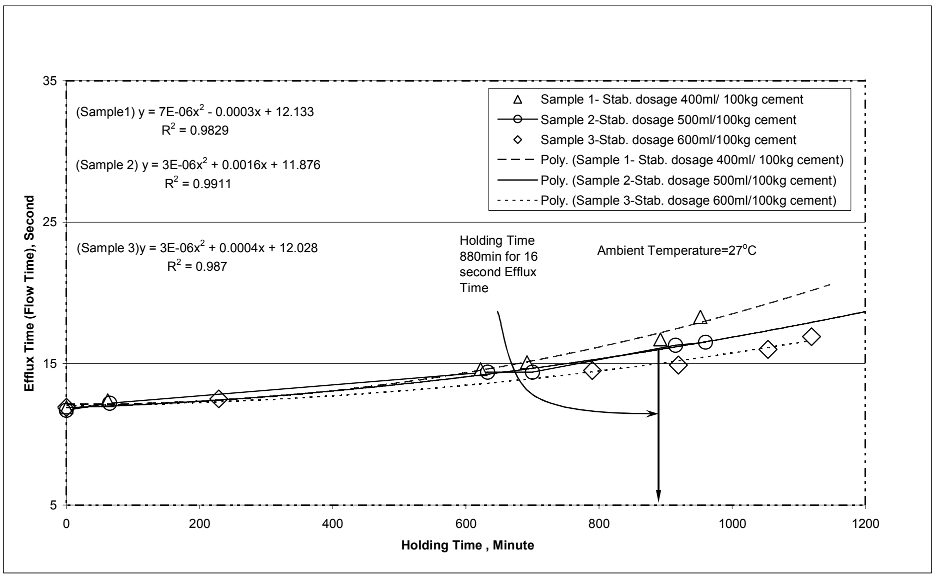
Graphs of Efflux Time vs Holding Time were plotted for the three samples and a trend line was fitted using a polynomial equation. The holding time required to achieve a 16 second efflux time was then calculated using the equation for the polynomial trend line. The estimated average holding time of the cement grouts for three samples was 145 minutes as shown in Figure 3.

Figure 3. Average holding time of 145 minutes for efflux Time of sixteen seconds



In the second trial, stabiliser was added to three grout samples after 145 minutes (the estimated 16 second efflux time). The dosage of stabiliser added to the cement grout for Sample 1 was 400ml/100kg, for Sample 2 was 500ml/100kg and for Sample 3 was 600ml/100kg. For each sample, the efflux time was recorded immediately after the stabiliser was added to the grout. The process was then repeated for various holding times. A polynomial equation was fitted to determine the curves of best fit for the Efflux Time vs. Holding Time curves shown in Figure 4, and the equations were used to extrapolate the holding times for a 35 second efflux time.

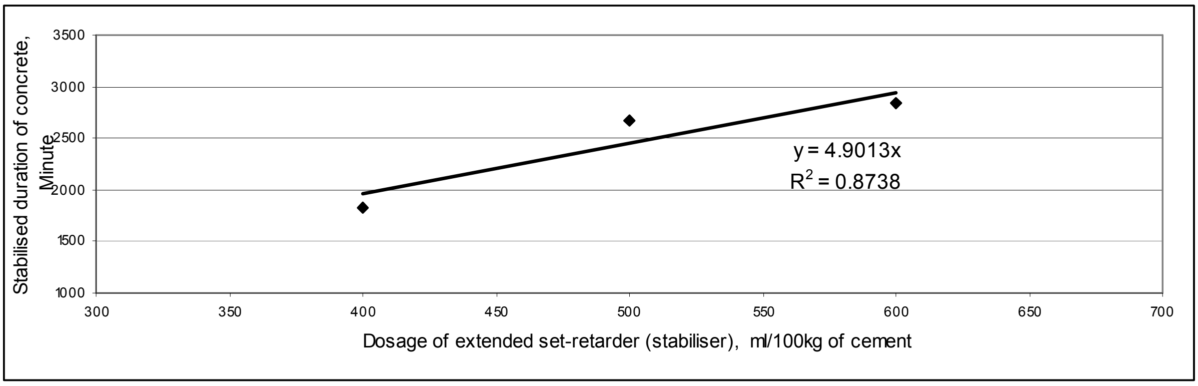
Figure 4. Estimated holding times required to achieve 35 second efflux times



The estimated holding time for the 35 second efflux time for Sample 1 was 1,975 minutes (ie, 145+1,830 minutes) for Sample 2 was 2,670 minutes (ie, 145+2,525 minutes) and for sample 3 was 2,845 minutes (ie, 145+2,700 minutes). From these data it was evident that the holding time of the cement grouts was positively correlated with stabiliser dosage.

The Holding Time vs Stabiliser Dosage data for a 35 second efflux time are graphed in Figure 5. A linear equation was used to predict the holding time of cement grout or concrete for a given dosage of stabiliser.

Figure 5. Holding time vs stabiliser dosage for a 35 second efflux time



For example, at a dosage of 600ml of stabiliser per 100kg of cement grout or concrete, a holding time of 2,940 minutes (49 hours) can be estimated using Figure 5.

3.3 Phase 2 - The effect of Stabiliser on Temperature Rise during Hydration

The effect of stabiliser on temperature rise during hydration (and therefore holding time) was assessed to establish a holding time vs temperature profile by measuring the temperature of three cement and supplementary cementitious materials grout samples over an extended period.

Figure 6. Effect of stabiliser and on temperature rise during hydration of GP cement grout

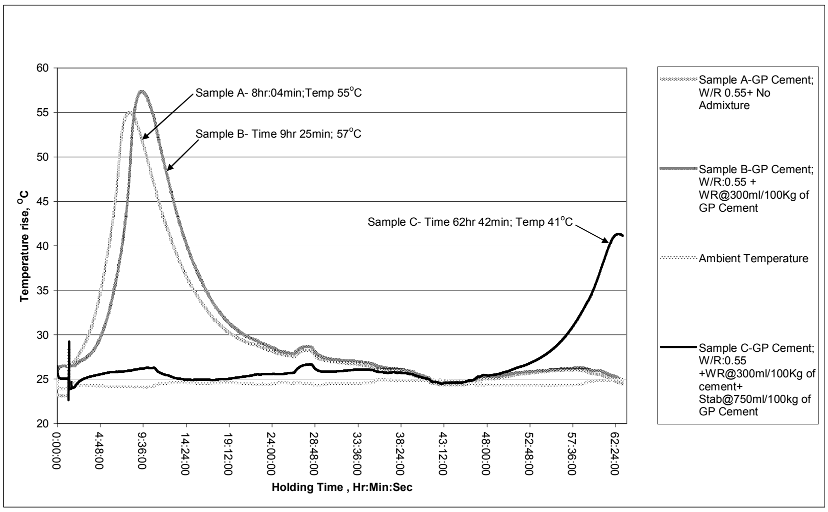


Figure 6 shows the effect of stabiliser on temperature rise during the hydration of three GP cement grout samples. Sample A was GP cement grout, Sample B was GP cement grout plus 300ml/100kg of water reducer and Sample C was prepared by adding 750ml/100 kg of stabiliser to Sample B after one hour. The peak temperature rise during hydration of GP cement grout (Sample A) was 55 degrees Celsius at 8 hours and 4 minutes. The addition of water reducer in Sample B increased the peak temperature to 57 degrees Celsius and extended the onset of hydration from 8 hours and four minutes to 9 hours and 25 minutes, and the further addition of stabiliser to Sample C reduced the peak temperature to 41 degrees Celsius and extended the onset of hydration to 62 hours and 42 minutes.

Figure 7. Effect of stabiliser on temperature rise during hydration of GB cement grout

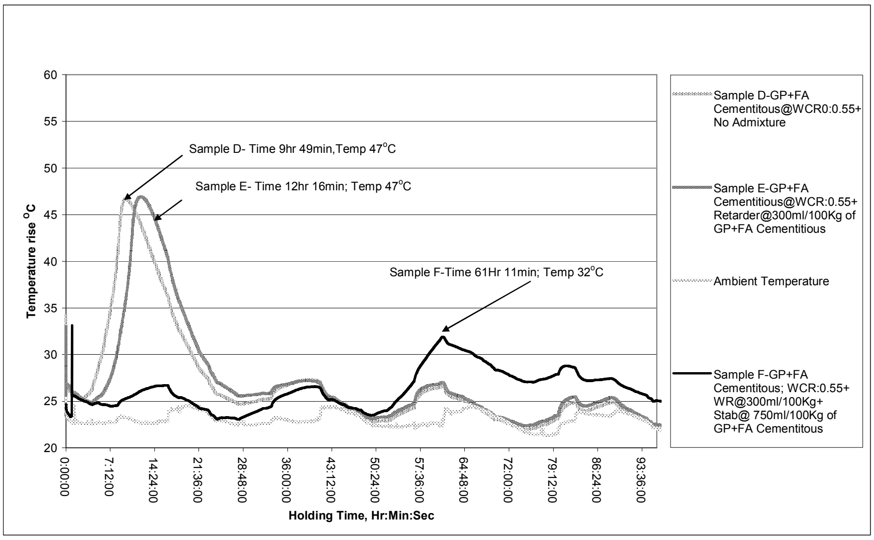


Figure 7 shows the effect of water reducer and stabiliser on temperature rise during the hydration of three GB cement grout samples. Sample D was GB cement grout, Sample E was GB cement grout plus 300ml/100kg of water reducer and Sample F was prepared by adding 750ml/100kg of stabiliser to Sample E after one hour. The peak temperature rise during hydration of the GB cement grout (Sample D) was 47 degrees Celsius at 9 hours and 49 minutes. The addition of water reducer in Sample E increased the peak temperature to 47 degrees Celsius and extended the onset of hydration from 9 hours fourty nine minutes to 12 hours 16 minutes, and the further addition of stabiliser to Sample F reduced peak temperature to 32 degrees Celsius and the extended the onset of hydration to 61 hours and 32 minutes.

Figure 8. Effect of stabiliser on temperature rise during hydration of LH cement paste

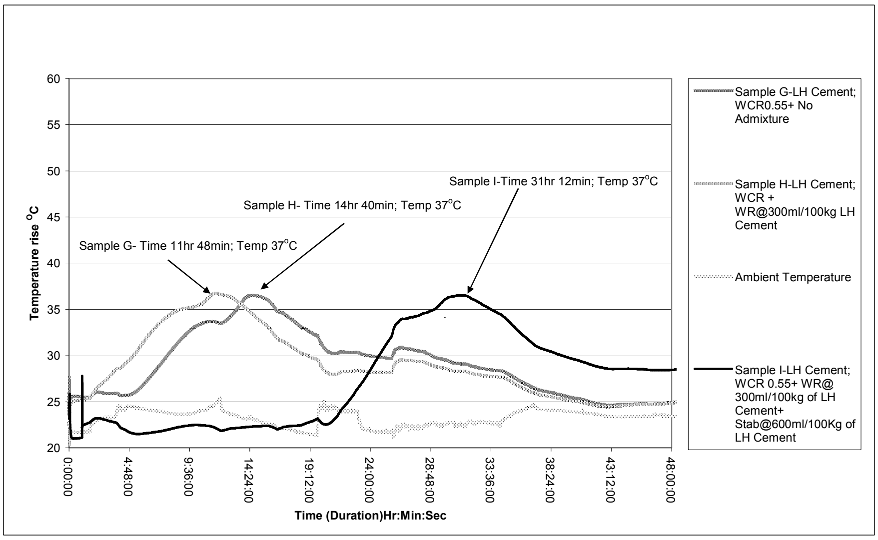


Figure 8 shows the effect of water reducer and stabiliser on the temperature rise during the hydration of three samples of LH cement grout. Sample G was LH cement grout. Sample H was LH cement grout plus 300ml/100kg or water reducer and Sample J was prepared by adding 600ml/100kg stabiliser to Sample H after one hour. The peak temp rise during hydration of the LH cement grout was 37 degrees Celsius at 11hours and 48 minutes. The addition of water reducer in Sample H increased the peak temperature to 37 degrees Celsius and extended the onset of hydration from 1 hour and 40 minutes to 14 hours and 40 minutes, and the further addition of stabiliser to Sample I caused no significant change in rise of temperature or onset of hydration.

Figure 9. Rate of heat evolution during hydration of a typical Portland cement (1)

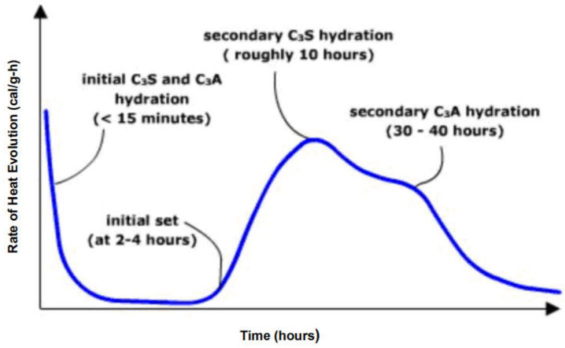
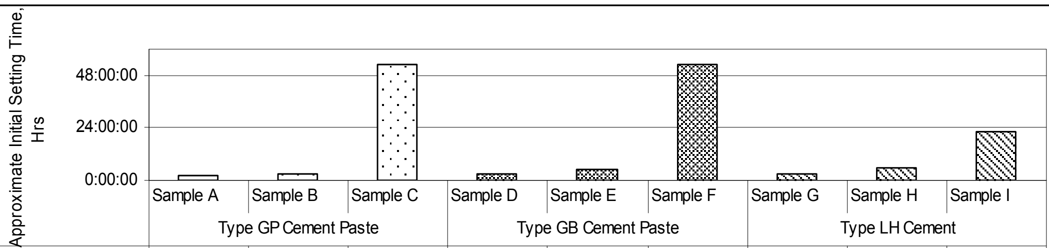


Figure 9 shows rates of heat evolution of a typical Portland cement and gives an approximation of the initial set and hydration times (1). Considering the initial start time of temperature rise (and hydration), the approximate initial setting time of all types of cement grout are shown in Table 10.

Figure 10. Approximate initial setting time for all types of cement



	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F	Sample G	Sample H	Sample I
	Type GP Cement Paste			Type GB Cement Paste			Type LH Cement		
Approx. Initial Setting Time, Hrs	2:00:00	3:00:00	52:48:00	3:00:00	5:00:00	52:58:00	3:00:00	6:00:00	22:00:00

The data show for GP and GB cement grouts that the peak temperature rise is lower after adding water reducers and stabiliser, whereas for LH cement grout, the peak temperature rise is same as the peak temperature rise for the control grout with added water reducer (12).

The action of stabiliser is quite different to the conventional water reducers. The stabiliser is capable of retarding the hydration of all clinker minerals and lowering the rate of calcium sulphate mineral solution. The stabiliser is a surface active agent designed to prevent surface nucleation of calcium ion rich hydrates. When nuclei have already formed, stabiliser retards their growth and alters the external morphology of subsequently formed hydrates. The ability of the stabiliser to stop formation of primary CSH hydrates and its moderate slowing of C_3A suggests that in Portland cement the extended set-retarder prevents epitactic growth of primary CSH on C_3S, while only slightly slowing the precipitation of C_3A hydrates (1).

3.4 Phase 3 - Effect of Stabiliser on Plastic and Mechanical Properties of Concrete

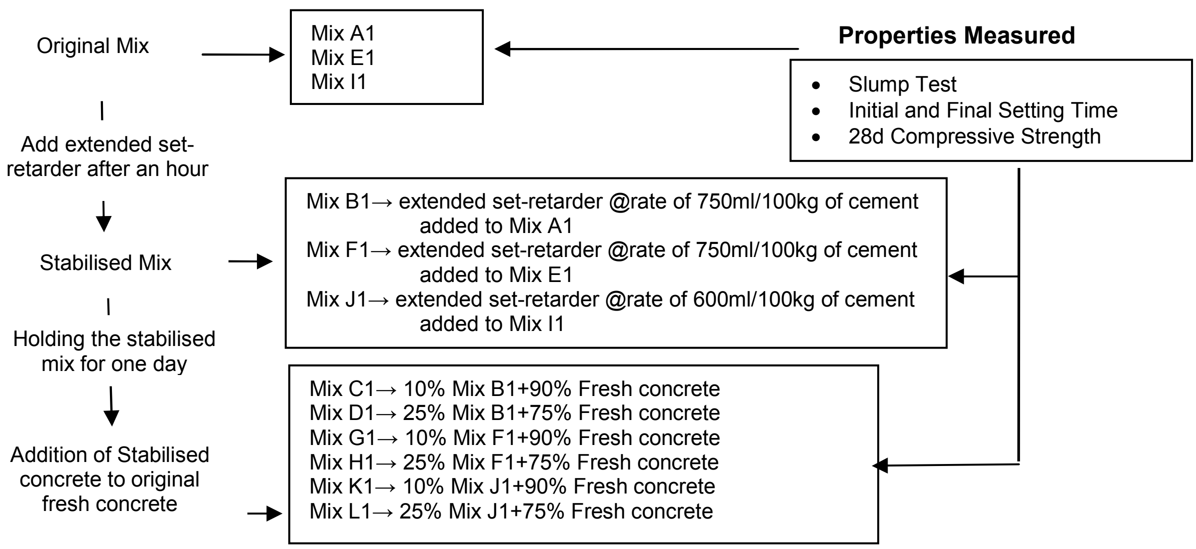
The following trials were carried out to measure the plastic and mechanical properties of control concrete and stabilised concretes. The mix proportions used for the trials of all the three types of cement and cementitous materials are as shown in the Table 2.

Table 2. Mix proportions of cement and cementitous materials for Phase 3 trials

	Mix A1 Control Mix	Mix E1 Control Mix	Mix I1 Control Mix
	GP Cement	GP+FA	GP+GGBS Cement
Total Cementitous	340	340	340
Cement (Type GP), Kg/m^3	340	255	-
Cement (Type LH), Kg/m^3	-	-	340
Collie Fly ash, Kg/m^3	-	85	-
Water to Cement Ratio	0.55	0.55	0.55
CCL Type GP Cement, Kg/m^3	340	255	0
Cement (Type LH), Kg/m^3	0	0	340
Collie Fly ash, Kg/m^3	0	85	0
20 mm, Kg/m^3	458	458	458
14 mm, Kg/m^3	313	313	313
10mm, Kg/m^3	255	255	255
River Sand , Kg/m^3	781	781	781
Free Water + Added Water, l/m^3	187	187	187
Water Reducer (WR), ml/m^3	1020	1020	1020

Two replicate batches were made for each type of concrete. Both batches were sampled to determine the initial and one hour slumps. After one hour holding time, stabiliser was added to one batch and then both batches were sampled to determine compressive strength and initial and final setting times.

Figure 11. Flow diagram of the phase 3 experiment



Key concrete performance properties are shown in Table 3. The slumps were well within tolerance, except they increased initially after adding stabiliser. The initial and finial setting times of the stabiliser compared to the control concrete were of longer duration. The fresh concrete incorporating 25 per cent and 10 per cent recycled concrete did not have any significant effect on the setting times shown in Figure 12. The compressive strength of all the concretes did not vary significantly in comparison to control concretes shown in Figure 13.

Table 3. Key concrete performance properties

	GP Cement				GB Cement (GP+FA cementitous)				LH Cement (GP+GBBS)			
	Mix A1	Mix B1	Mix C1	Mix D1	Mix E1	Mix F1	Mix G1	Mix H1	Mix I1	Mix J1	Mix K1	Mix L1
Initial Min Slump, mm	85	100	NR	NR	100	110	NR	NR	80	95	NR	NR
Hour Slump, mm	80	90	NR	NR	80	80	NR	NR	70	70	NR	NR
After adding Stabiliser Slump, mm	NR	140	NR	NR	NR	150	NR	NR	NR	140	NR	NR
Next day slump of Stab. concrete, mm	NR	NR	80	80	NR	NR	100	100	NR	NR	90	90
Initial slump Stab. Con.+ Fresh Con., mm	NR	NR	100	100	NR	NR	95	120	NR	NR	95	85
Hour slump Stab. Con. + Fresh Con., mm	NR	NR	70	80	NR	NR	75	100	NR	NR	85	70
Compressive Strength, MPa												
7 day Comp. Strength, MPa	39.0	36.5	38.0	36.5	30.0	35.0	36.5	33.5	30.5	29.5	25.0	22.0
28 day Comp. Strength, MPa	49.0	51.5	48.5	42.5	42.3	51.0	44.3	43.5	38.5	41.0	41.5	40.0
Initial Setting Time hr: min	7hr 30min	25hr 52min	7hr 25min	6hr 50min	6hr 38min	33hr 35min	7hr 05min	8hr 26min	8hr 38min	26hr 35min	8hr 0min	7hr 32min
Final Setting Time hr: min	10hr 0min	27hr 40min	9hr 05min	8hr 30min	7hr 45min	39hr 20min	9hr 30min	9hr 33min	11hr 20min	29hr 45min	10hr 12min	9hr 20min

Note : NR- Not Required,

Figure 12. Setting time of concrete (mins)

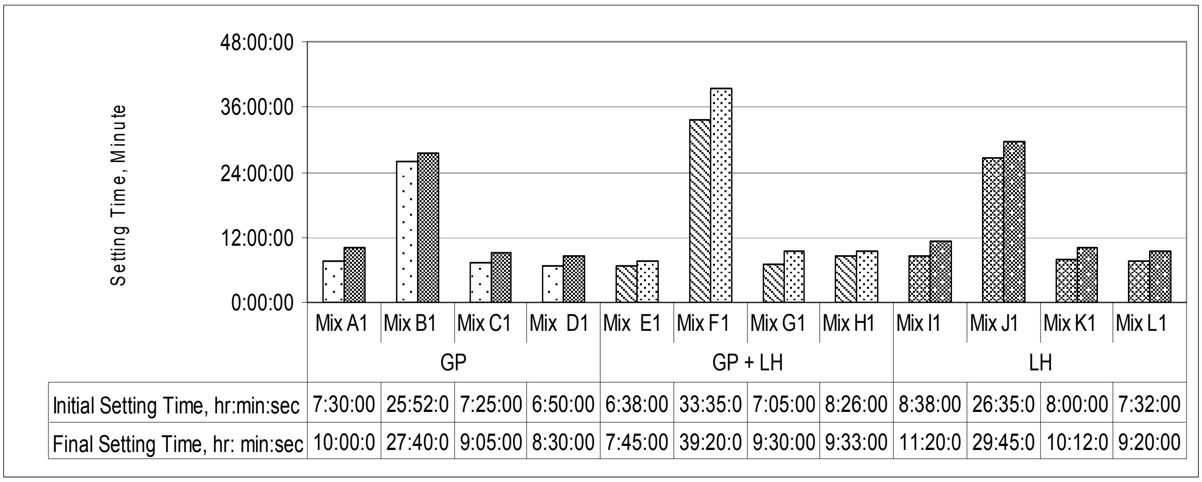
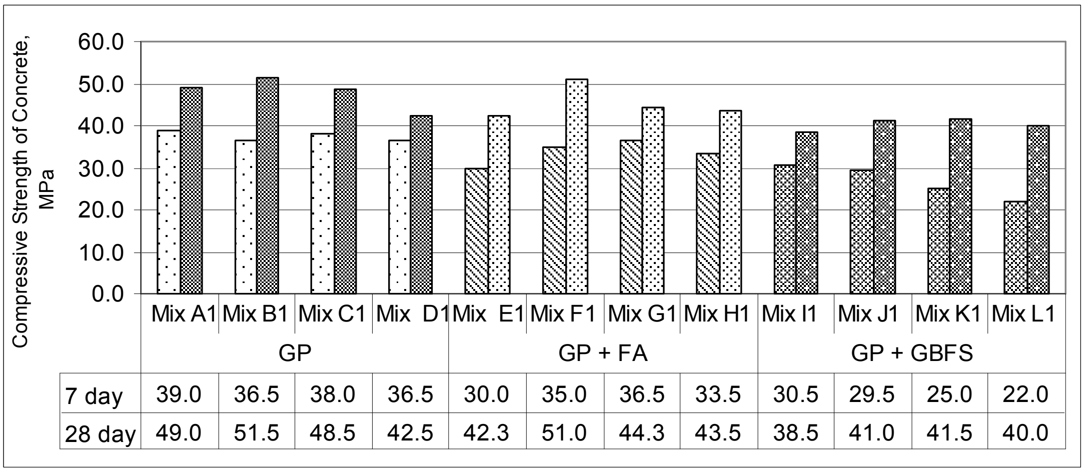


Figure 13. Compressive strength of concrete (MPa)



4 Conclusions

The effect of stabiliser on efflux time of GP cement grout was studied and the dosage required to achieve an efflux time of 35 seconds was estimated. The results showed a linear relationship with increasing stabiliser dosage extending the holding time of the grout.

The effect of stabiliser on the timing and measure of peak hydration temperature was then assessed and the results showed that for GP cement and GB cementitious grouts, peak temperatures were lower after adding stabiliser, and for all three grouts the time to peak hydration (setting time) was significantly increased.

Finally, the effect of stabiliser on the plastic and hardened properties of fresh concrete, stabilised concrete, and a blend of fresh and stabilised concrete was assessed. The results showed that the initial one hour slumps and the final slumps of the blended concretes were all within tolerance, and also showed that adding stabiliser to the concretes did not a significantly reduce compressive strength when compared to the original, non-stabilised concretes.

This preliminary study has indicated that the addition of stabiliser to returned concrete within 60 minutes of the addition of water will extend its setting time enough permit incorporation into a fresh mix, within certain limits, without significantly affecting the plastic or hardened properties of the final concrete.

Additional studies are required to elucidate an acceptable range of mix proportions for stabilised and fresh concrete, assess the suitability of a range of cement and cementitious materials, determine the design properties of recycled mixes including durability, drying shrinkage, setting time, and the like.

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