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Effect of Penetron Admix on the Properties of Concrete

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Abstract

This research investigates the effects of the waterproofing admixture ***Penetron Admix*** on the fresh and hardened properties of structural concrete and assesses whether the product is suitable for use on construction projects in Mauritius. A grade 25 control mix (mix Y-0) and three mixes, each containing different percentages of admixture, were batched. The three mixes were labeled (Y-1), (Y-2) and (Y-3) and contained 0.8%, 2% and 3% admixture by weight cement respectively. The water/cement ratio was kept constant throughout the experiments. The properties of concrete which are considered most useful on site, like workability, setting time and strength were investigated. The results showed that Penetron Admix enhanced the properties of the concrete. With the standard dosage of 0.8%, the characteristic strength of concrete at 28 days was increased by 15%. The optimum percentage of Penetron Admix for maximum strength, which is the most important concrete property, was found to between 2%- 2.2% by weight of cement. The permeability decreased drastically with the use of the product, namely 80% decrease at the standard dosage of 0.8% dosage. No major change was observed for the hardened density. The admixture also increased the workability and setting time of the fresh mix, but these effects were significant only with mixes containing 2% and 3% dosage.

Keywords: waterproofing admixture, structural concrete, effects on concrete properties

1. INTRODUCTION

Nowadays, concrete is widely used worldwide, and will indeed remain the most common construction material for still a long time to go. This is due to the numerous beneficial aspects of concrete, including its excellent technical properties and competitive price on the market.

Sometimes, admixtures are added to the concrete at the time of batching to enhance its properties. Admixtures are ingredients other than water, aggregates, hydraulic cement, and fibers that are added to the concrete batch immediately before or during mixing (Collepardi-2001). The proper use of admixtures can confer same benefits as those of supplementary cementitious materials in reducing the emission of greenhouse gases and in increasing the life cycle of concrete structures, thus making concrete a sustainable construction material (Aitcin et al., 1999).

Nowadays, there are many different types of admixtures that exist, with each one having a specific function in the concrete. Since concrete is not an impermeable material and infiltration of water through slabs and beams is a common problem in many concrete buildings, a type of admixture has been created to remedy to these complications, namely permeability-reducing admixtures, also known as waterproofing admixtures.

A new type of waterproofing admixture namely, PENETRON ADMIX, has been introduced in Mauritius since 2010 by a local company, Colin Mayer Agencies (CMA). The product is produced by ICS Penetron Ltd, whose headquarters of the company is based in New York. The product provides complete integral waterproofing and the concrete becomes permanently sealed against the penetration of water and other liquids from any direction and is also protected from deterioration due to harsh environmental conditions (Technical data sheet, ICS/Penetron International Ltd). However, its effects on other properties of concrete and thus its suitability for use on local construction projects have not been assessed (personal communication with site engineer, Bagatelle Office Park, Aug 8, 2012). Moreover, the actual recommended percentage of Penetron

Admix in concrete is 0.8% by weight of cement, but 2% and 3% may be used in special cases. The effects of these higher percentages are also quite unknown. Since its introduction in 2010 in Mauritius, the application of Penetron Admix on local construction projects has increased.

Penetron Admix is added to the concrete at the time of batching. The concrete then becomes permanently sealed against the penetration of water or other liquids from any direction and is also protected from deterioration due to harsh environmental conditions. The Penetron Admix has been specially formulated to meet varying project and temperature conditions.

When added to concrete, the crystalline elements produce a chemical reaction that causes long, narrow crystals to form and fill the capillaries, pores and hairline cracks of the concrete mass. Crystals will continue to grow inside the concrete as long as moisture is still present. The crystalline chemicals will remain dormant once the concrete has cured and dried, until water enters it again (like through a new crack), this will cause the chemicals to react again and formation of crystals will take place again to stop the water. (Biparva and Yuers-Integral Crystalline Waterproofing Technology, page 50 & 51).

In other countries, Penetron Admix is mainly used for reservoirs, sewage and water treatment plants, subway and other tunnel systems, underground vaults, foundations, swimming pools. Some famous projects where it has been used include the Statue of Liberty and the Singapore Changi Airport Terminal 3. Some projects where the product has been used in Mauritius are New Sicom Tower at Port Louis, Voila Bagatelle Hotel, Bagatelle Office park, Le Meritt Ellipsis-Trianon and Element Bay Resort-Bain Boeuf.

The technical data sheet for Penetron Admix states that an increase in compressive strength is achieved with the use of the product. For the normal dosage of 0.8%, an increase of approximately 8.5% is obtained when compared to untreated specimen at 28 days. The product also decreases permeability and increases hardened density of the concrete. The use of Penetron Admix results in an increase in slump value of the concrete. As for setting time, it was stated that retardation of set may occur when using the product.

The aim of this research was thus to determine how PENETRON ADMIX up to 3% dosage affects the fresh and hardened properties of concrete, in addition to the purpose for which it is intended, that is, to waterproof concrete and to assess its suitability for use in local construction projects.

2. MATERIALS & METHODOLOGY

2.1 Standards used for the tests

Preliminary tests on aggregates, tests on fresh and hardened concrete, the making of test specimens and the curing of the specimens were done according to standards as given in table 1.

Table 1: Standards used for the tests

Test	**Relevant standard used**
Preliminary tests (Tests on aggregates)	
Methods for Sampling of Aggregates	**BS 812 Part 103:1985**
Water absorption	**BS 812-Part2-95**
Specific gravity	**BS 812-Part2-95**
Fresh Properties	
Slump test	**BS 1881-Part 102-83**
Compaction factor test	**BS 1881-Part 103-93**
Initial and final setting time test	**ASTM C 403**
Hardened Properties	
Cube compressive strength	**BS 1881-Part 116-83**
ISAT permeability test	**BS 1881-5-1983**

Figure 1: Washing of aggregates before preliminary testing

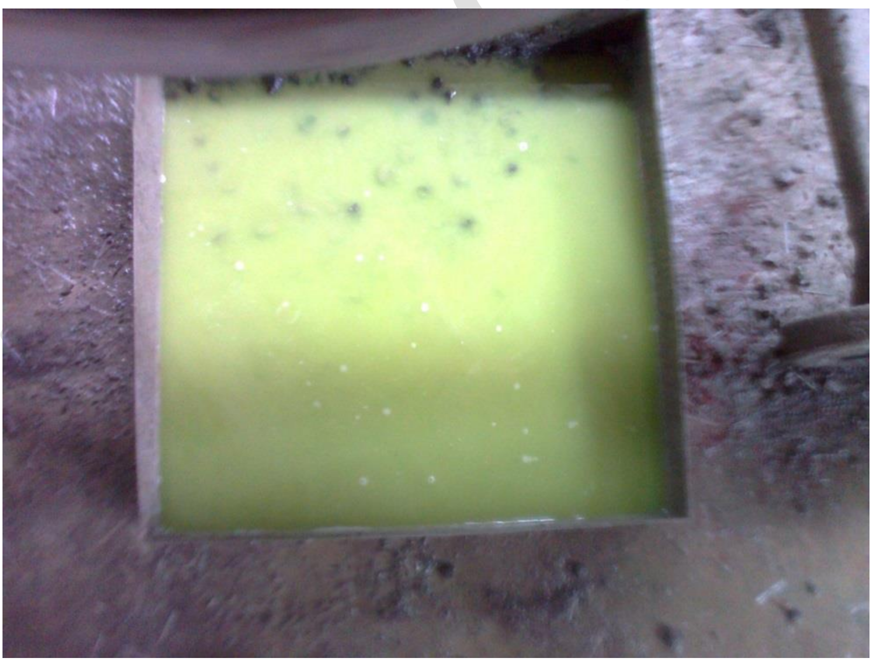

Figure 2: Green water due to tracer in the Penetron admix when added to concrete

Figure 3: Investigating Slump

Figure 4: Compaction factor test

Figure 5: Investigating setting time

Figure 6: Cube strength test

2.2 Materials

2.2.1 Cement

The cement was provided by a local hardware store
Brand: Baobab Portland cement

2.2.2 Coarse aggregates

The coarse aggregates, both 6/10 and 14/20 were purchased at Gamma Materials

2.2.3 Fine aggregates

The fine aggregates were also obtained from Gamma Materials

2.2.4 Water

Tap water obtained at the university laboratory was used during the experiments

2.2.5 Penetron Admix

The Penetron Admix was provided by Collin Mayer Agencies (CMA)

2.3 Program for casting and testing of specimens

Below is a table showing the test procedures that will be carried out in the lab, together with the quantity of samples required and the total amount of concrete for the samples.

Table 2: Program for casting and testing of specimens

Days	Test procedure	Quantity	Volume
0	Casting of concrete		
1	De-molding of cube specimens and curing		
7	**-**Compressive strength on 100 mm cubes -Measurement of hardened density	3	0.0030
28	**-**Compressive strength on 100 mm cubes -Measurement of hardened density	3	0.0030
29	Initial Surface Absorption Test (ISAT) on 150mm cube	2	0.0068
91	Compressive strength on 100 mm cubes	3	0.0030

2.4 Planning of Laboratory Works

The laboratory works consisted of:

1. Preliminary tests on aggregates as given in table 1.
2. Four set of mixes were designed and batched. Each mix was assigned a code for easy referencing. The mixes consisted of a control mix and 3 mixes with increasing proportion of Penetron Admix. The codes for the mixes are given in table 3 below.

Table 3: Reference codes for the different mixes

Mix	Percentage of Penetron Admix by weight of cement / %
Y-0	0
Y-1	0.8
Y-2	2
Y-3	3

The following properties and conditions were used to determine the mixture proportion of the mixes:

- Same strength of concrete (25 MPa)
- Same targeted slump (100 ± 10 mm)
- Same maximum aggregate size (20 mm)
- Same proportion of aggregates in all mixes

<u>Note</u>: 0.8% was used instead of 1% as it is the standard dosage used normally and the local supplier of the product wanted tests to be done on that percentage.

2.5 Mix Design

The British method was used (also known as the DoE method). It comprises of tables and charts from the British Research Establishment (BRE) which are used to obtain mix proportions on a 'kg/m^3 basis'

The properties below were used for the mix design:

- Design slump: 60-180 mm
- Target Strength: 25 MPa
- Maximum aggregate size: 20 mm
- Relative density of aggregate: 2.7
- Proportion of fine aggregates

Table 4: Mix proportions

Cement (kg/m^3)	Fine aggregates (kg/m^3)	Coarse aggregates (kg/m^3)		Free water content (L/m^3)	Absorbed water (L/m^3)	Total water required (L/m^3)	Free water to cement ratio
	0-4 mm	6-10 mm	14-20 mm				
375	860	385	580	225	42	267	0.60

3. RESULTS AND ANALYSIS

3.1 Preliminary Investigations on Aggregates

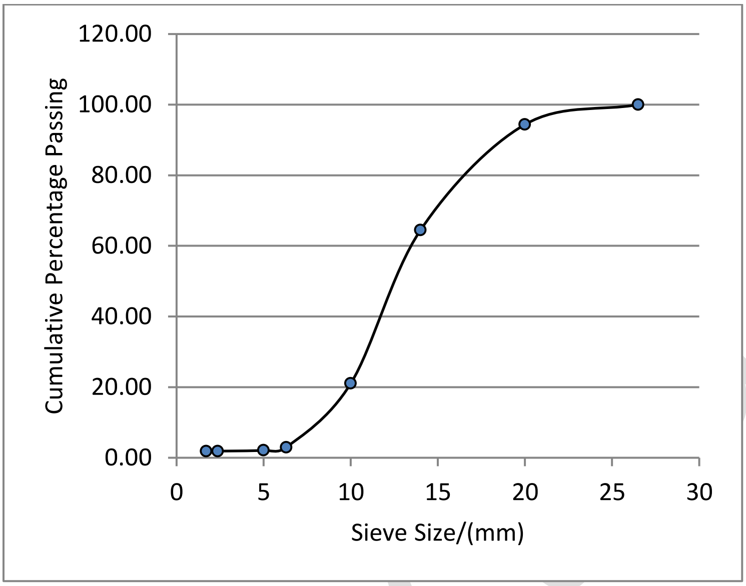

Figure 7: Grading curve for 14/20 coarse aggregates

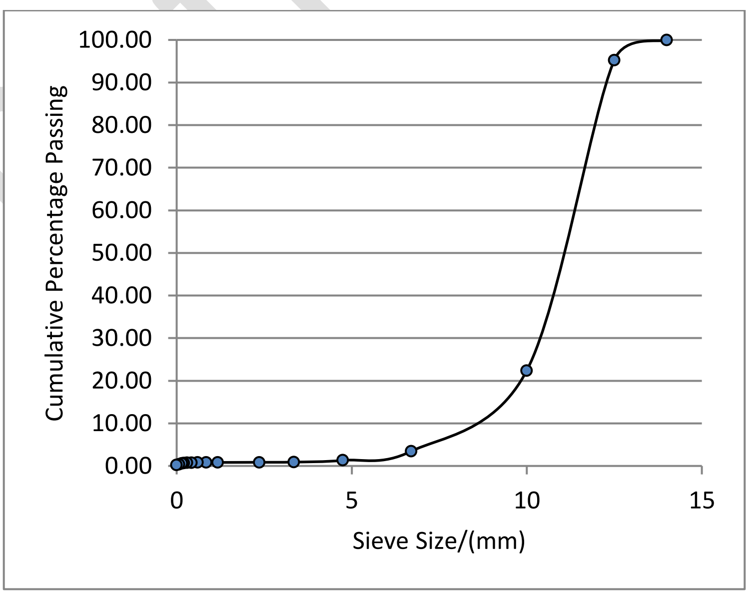

Figure 8: Grading curve for 6/10 coarse aggregates

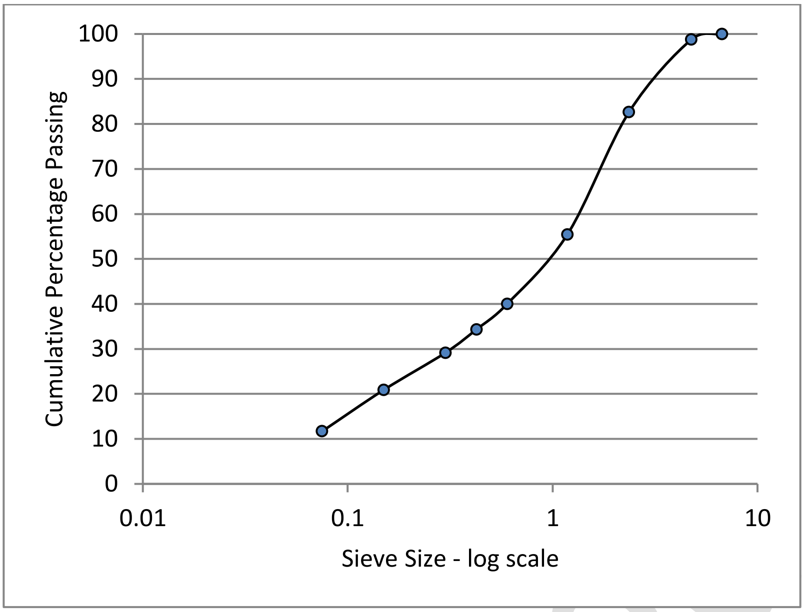

Figure 9: Grading curve for 0/4 fine aggregates

3.2 Relative Density and Water Absorption

The results for the relative densities of the aggregates and for the water absorption are given in table 5.

Table 5: Relative density and water absorption of aggregates

Aggregate Size (mm)	Relative Density on Oven Dried Basis	Relative Density on SSD Basis	Apparent Relative Density	Water Absorption (% of dry mass)
0-4	2.78	2.85	2.98	2.4
6-10	2.69	2.75	2.87	2.3
14-20	2.62	2.67	2.77	2.1

3.3 Results for Fresh Properties

3.3.1 Results of slump test

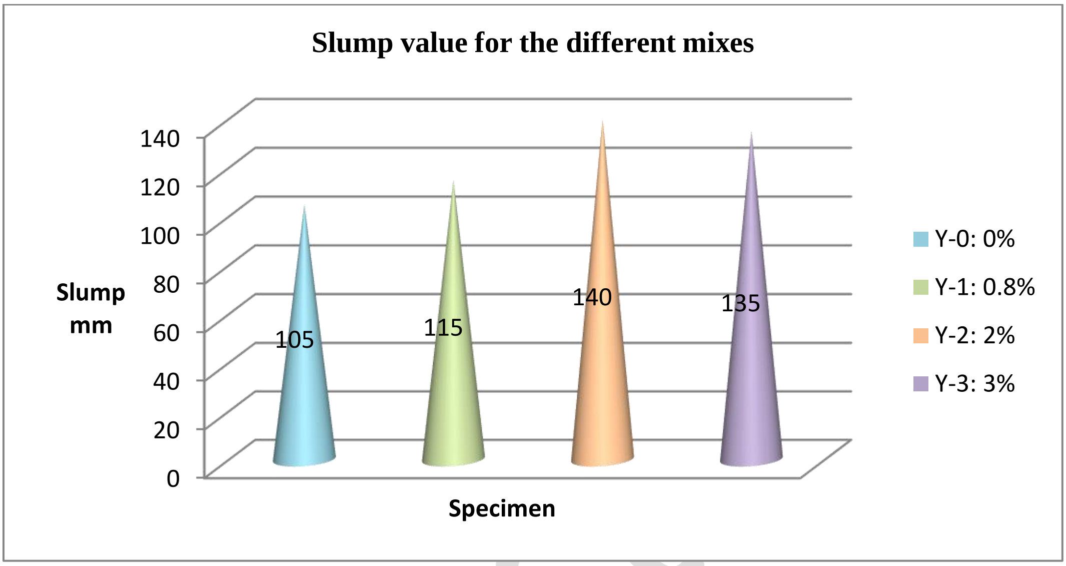

Figure 10: Slump value for the different mixes

Table 6: Comparing slump value of Y-1, Y-2 and Y-3 to Y-0

Concrete Mix	Slump Value (mm)	Ratio difference of slump to Y-0
Y-0	105	1.00
Y-1	115	1.10
Y-2	140	1.33
Y-3	135	1.29

3.3.1.1 Observations on slump test

1. The slump values of the different mix were seen to increase with addition of Penetron Admix.
2. Maximum slump value was obtained for Y-2 mix, with an increase of 33% with respect to Y-0.
3. For the standard percentage of 0.8% Admix, the slump was nearly the same as the control mix, with only an increase of 10%.
4. The slump for Y-3 mix was seen to be slightly lower than for Y-2 mix, but with a percentage increase of 29% over the control mix.

3.3.1.2 Discussions on slump test

1. Although Penetron Admix is quite similar to cement, slump did not decreased. On the contrary, an increase in slump was observed. This is due to the different chemicals present in the admixture, which may act as a water-reducer.
2. Since slump is increased, this means that Penetron Admix will reduce the water demand for a specified slump. In other words, if slump was kept constant in these experiments for all the 4 mixes, there would have been a decrease in water/cement ratio. This is positive, since the lower the water/cement ratio down to a threshold value increases the compressive strength.
3. The results confirmed the research present in the report of ICS Penetron International, where by an increase in slump was noted with use of Penetron Admix.

3.3.2 Results of initial and final setting time test

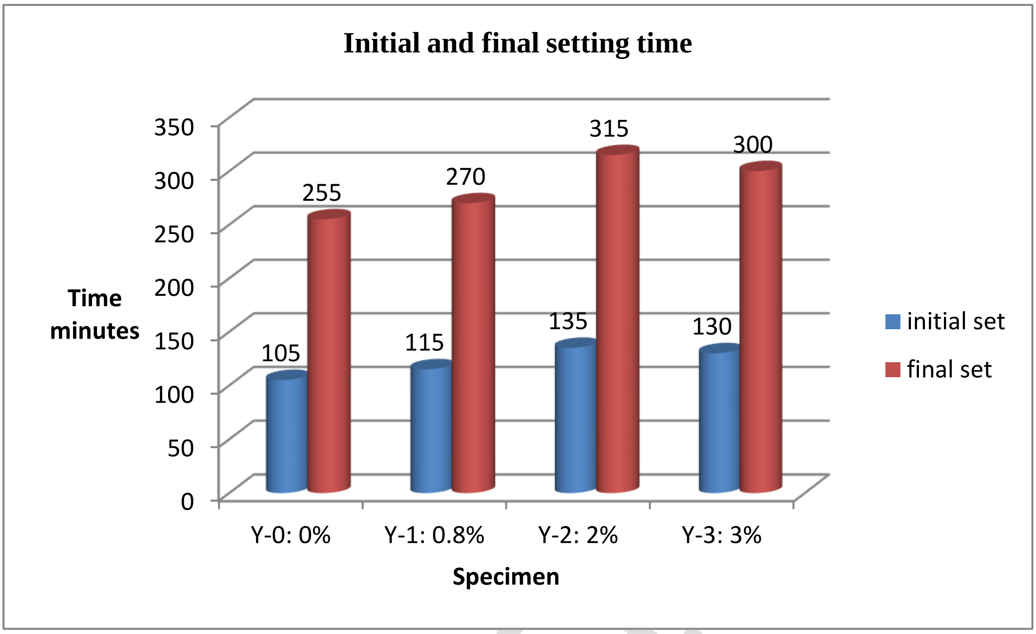

Figure 11: Setting time for the different mixes

Table 7: Comparing setting time of Y-1, Y-2 and Y-3 to Y-0

Concrete Mix	Initial Setting Time (minutes)	Ratio difference to Y-0	Final Setting Time (minutes)	Ratio difference to Y-0
Y-0	105	1.00	255	1.00
Y-1	115	1.10	270	1.06
Y-2	135	1.29	315	1.24
Y-3	130	1.24	300	1.18

3.3.2.1 Observations on setting time

1. An increase in initial setting time was noted with the use of Penetron Admix.
2. Mix Y-2 produced the highest initial setting time of 135 minutes, thus an increase of 29% with respect to the control mix.
3. Mix Y-2 and mix Y-3 produced nearly the same initial setting time.
4. An increase of 10% was noted for initial set of Y-1, whereas for Y-3, the increase was 24%.
5. For final setting time too, an increase was also noted when Penetron Admix was added.
6. Again, mix Y-2 produced the highest final set with an increase of 24% over the control mix.
7. Mix Y-1 produced an increase of only 6% whereas mix Y-3 produced an increase of 18%.

3.3.2.2 Discussions on setting time

1. Past studies from a private laboratory present in the 'Test Report' by ICS Penetron International (2004) suggested that the initial and final setting time of the mix decreased by 15 minutes and 30 minutes respectively when using 1.0% dosage of admix. However, results from this research shows that initial setting time and final setting time were delayed.
2. The increase in setting time may be due to the consumption of calcium hydroxide, a chemical present in the admixture, which has an effect on the hydration period of the mix.
3. Setting time is hardly affected when using the standard dosage of 0.8%. Only at higher concentrations will the setting time be noticeably affected.

3.3.3 Results of compaction factor test

Table 8: Comparing compaction factor of Y-1, Y-2 and Y-3 to Y-0

Concrete Mix	Compaction Factor(CF)	Ratio difference of CF to Y-0
Y-0	0.93	1.00
Y-1	0.93	1.00
Y-2	0.95	1.02
Y-3	0.95	1.02

3.3.3.1 Observations on compaction factor

1. With the use of Penetron Admix, no major difference was observed in the compaction factor of the different mixes with respect to the control mix.
2. Y-1 had nearly the same compaction factor as Y-0.
3. Only an increase of 2% was noted for the Y-2 and Y-3 over the control mix.

3.3.3.2 Discussions on compaction factor

1. The compaction factor for all the mixes were in the adequate range of 0.70-0.98 (Suresh, 1999).
2. The compaction factor did not change much because the workability of the mix was not adversely affected by the admixture. But an increase in slump value produced a small increase in compaction factor value.
3. Degree of workability of the mixes ranges from medium to high (Wilby, 1991).
4. The results of the compaction factor test can be correlated to slump value, even though the relationship is not linear.

3.4 Results for hardened properties

3.4.1 Results of compressive strength test

Table 9: Results of compressive strength of each mix

Concrete Mixes	Compressive Strength (N/mm^2)		
	7 Days	28 Days	91 Days
Y-0	18.8	25.5	32.1
Y-1	20.9	29.4	34.3
Y-2	21.5	31.9	37.1
Y-3	21.3	31.6	35.8

Table 10: Ratio difference of each mix w.r.t to mix Y-0

Concrete Mixes	Ratio difference w.r.t Y-0		
	7 Days	28 Days	91 Days
Y-0	1.00	1.00	1.00
Y-1	1.11	1.15	1.07
Y-2	1.14	1.21	1.16
Y-3	1.13	1.20	1.12

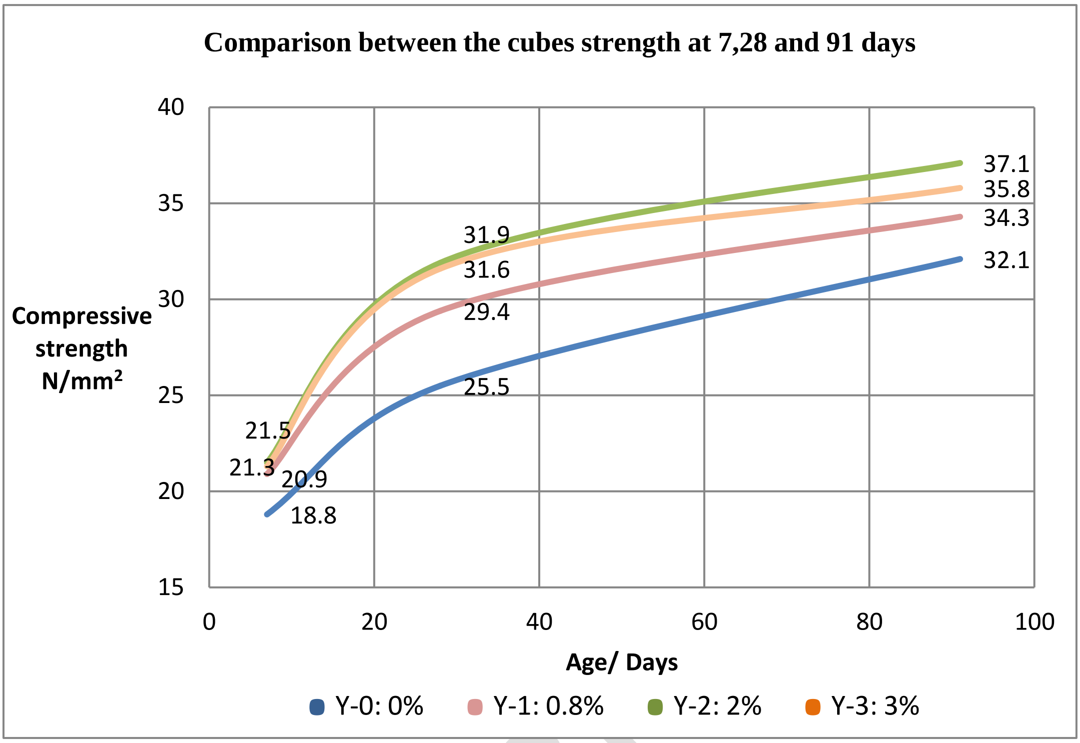

Figure 12: Comparison between the cubes strength at 7, 28 and 91 days

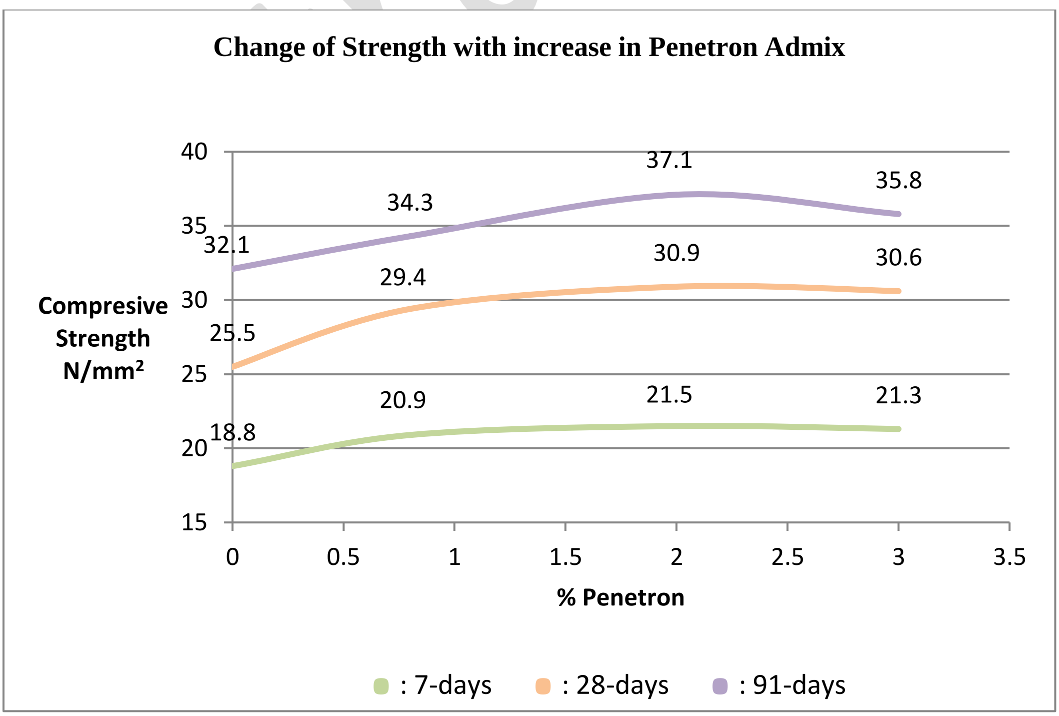

Figure 13: Change of strength with increase in Penetron Admix

3.1.4.1 Observations on compressive strength

1. The target strength of 25N/mm^2 was successfully reached for the control mix
2. A general increase in strength was noted for all the 3 mixes (Y-1, Y-2, Y-3), when compared to the control mix.
3. At 7 days, the increase was most marked at 2% Penetron dosage (Y-2), with an increase of 14% in strength with respect to the control mix. The increase for Y-1 and Y-3 were 11% and 13% respectively.
4. At 28 days, the highest increase in strength was also found to be at 2% dosage(Y-2). The percentage increase in strength was 20%. For Y-1 and Y-3, the percentage increase was 15% and 20% respectively.
5. At 91 days, the same trend was noticed whereby the highest strength was observed at Y-2 with an increase of 16%. Increase for Y-1 was 7% and for Y-3, it was 12%.
6. The development of strength during the 91 days is represented in table 11 below:

Table 11: Development of strength

Cube Mix	7-days strength as a % of 28-days strength	28-days strength as a % of 91-days strength
Y-0	74%	79%
Y-1	71%	86%
Y-2	67%	88%
Y-3	67%	86%

7. Till a percentage of 2% of Penetron Admix, a gradual increase was noticed in strength, but after 2%, the strength was seen to make a small decrease. This observation was made for 7-days, 28-days and 91-days strength.
8. The percentage of Penetron Admix which gave maximum strength was found to lie somewhere between 2.0% and 2.2%.

3.4.1.2 Discussions on compressive strength

1. The increase in strength with the use of Penetron Admix confirms information from the technical data sheet. However, strength decreases when percentage dosage of admixture is increased from 2% to 3%.
2. At 28 days, the concrete was behaving more like a grade 30 than a grade 25. This is a big advantage in terms of gain in strength.
3. From table 11, it is observed that, with addition of Penetron Admix, development of strength from 7 days to 28 days was faster, but development of strength from 28 days to 91 days was slower, which shows that the admix increased the rate of early strength development.
4. A comparison is made in table 12 below between the results of this project and the research made by the University of Cape Town from the paper: Chemical additive introduced to seal liquid holding concrete structures (2001) on a dosage of 0.8% of Admix.

Table 12: Comparing results with past research

	Research by University of Cape Town	**Actual Results**
7-days strength	12.5% increase	12% increase
28-days strength	15.9% increase	15% increase
91-days strength	N.A.	7% increase

5. The increase in strength may be explained by the formation of microcrystals in the capillary tracts of the concrete, thus blocking these voids and adding strength to the concrete.

3.4.2 Results of initial surface absorption test – ISAT (ml/m^2/s)

Table 13: Results of initial surface absorption test

Reference	**10 min**	**30 min**	**1 hour**	**2 hours**	**Total water absorbed**
Y-0	0.8400	0.5300	0.3500	0.1600	1.8800
Y-1	0.1800	0.1100	0.0650	0.0240	0.3970
Y-2	0.0980	0.0610	0.0408	0.0187	0.2185
Y-3	0.0420	0.0285	0.0180	0.0072	0.0957

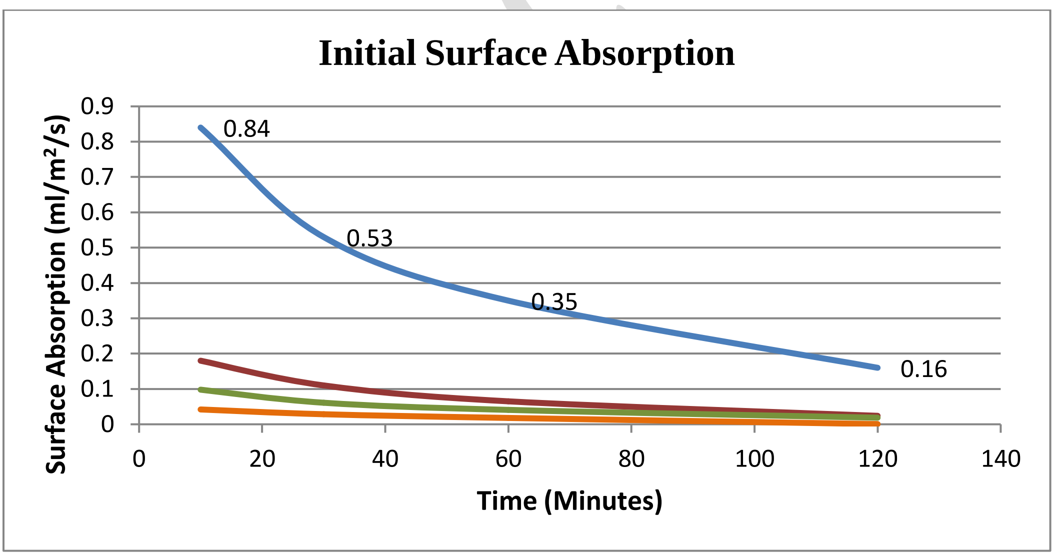

Figure 14: ISAT results (including control mix)

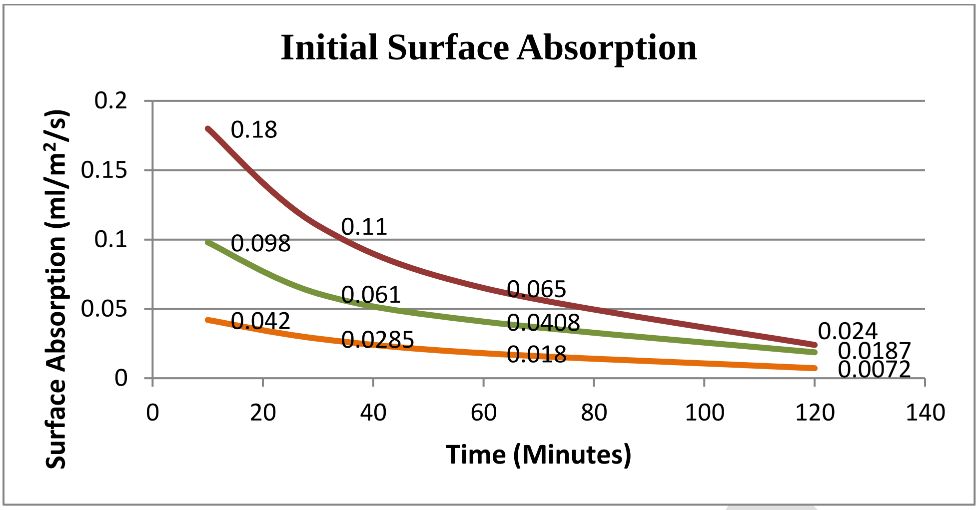

Figure 15: ISAT results (excluding control mix)

Y-0: 0% Y-1: 0.8% Y-2: 2% Y-3: 3%

3.4.2.1 Observations on ISAT

1. There was a drastic decrease in water absorption, even for the least percentage of Penetron Admix, that is, 0.8% (Y-1 mix)
2. The absorption of water decreased gradually with increasing percentage of Penetron.
3. The absorption was reduced by 79% for the initial reading of 10 minutes for the mix Y-1.
4. The total water absorbed for the different mix during the test was reduced by 79% for Y-1, 88% for Y-2 and 95% for Y-3.
5. The percentage reduction of water absorption for the different mix during the different intervals of time are shown in the table below:

Table 14: Percentage reduction of water absorption with respect to control mix

Reference	10 min	30 min	1 hour	2 hours	Total water absorbed
Y-0	0%	0%	0%	0%	0%
Y-1	79%	79%	81%	85%	79%
Y-2	88%	87%	88%	89%	88%
Y-3	95%	95%	94%	96%	95%

6. According to the results, when percentage of Penetron Admix is doubled, permeability of the sample is reduced by 40% to 60%.

3.4.2.2 Discussions on ISAT

1. The efficiency of the product against water absorption is unquestionable. Even a small dosage of the product has a significant effect on the permeability of the mix.
2. The permeability of the mix is reduced due to the formation of microcrystals inside the small capillary tracts of the concrete that completely seals this passage, thus preventing water from going through.
3. Since permeability is very low, the mix is also protected against aggressive liquids, chemicals and gases. The reinforcing steel bar will also be much better protected.
4. Since permeability is closely related to durability, a less permeable concrete will result in a much more durable concrete.
5. Large pores are reduced in size and number, and there is creation of tortuosity.

3.4.3 Results for hardened density

Table 15: Hardened density results

Concrete Mixes	Hardened Density (kg/m^3)		
	7 Days	28 Days	91 Days
Y-0	2463	2483	2513
Y-1	2468	2477	2518
Y-2	2486	2499	2540
Y-3	2486	2517	2560

3.4.3.1 Observations on hardened density

1. Generally, a small increase in density was observed with the use of Penetron Admix when compared to the control mix Y-0.
2. At 7 days, Y-2 and Y-3 had approximately the same density, with an increase of 0.9% over Y-0.
3. At 28 days, Y-3 produced the highest density, with an increase of 1.4% over Y-0.
4. For 91 days, an increase of 1.9% was observed for Y-3 over Y-0.

3.4.3.2 Discussions on hardened density

1. The results confirmed the research carried out by the University of Cape Town, which stated that an increase of density was observed with the use of Penetron Admix.
2. The increase may be due to the fact that the capillary voids present in the concrete are partly filled with the product, thus making it slightly denser.

4. CONCLUSION AND RECOMMENDATIONS

The research shows that Penetron Admix;

- **(i)** Is beneficial in terms of strength gain. Even the small percentage of 0.8% dosage produced an increase in strength of 15% for the characteristic 28-days strength. Higher dosage was even more beneficial for the strength, but with higher dosage, cost of the concrete will also increase.
- **(ii)** Increases the workability, the maximum increase being obtained at 2% dosage;
- **(iii)** Significantly increase the initial and final setting time of the mix when used above the standard dosage. Initial setting time was increased by up to 30 minutes with a dosage of 2% and final setting time was increased by up to 1 hour with the same dosage. Since a standard dosage of only 0.8% is usually used on construction sites, only when using higher percentage of this admixture should retardation of set be an issue.
- **(iv)** Increases compaction factor significantly only above the standard dosage of 0.8%. Moreover, the mixes produced were all in the suitable range of 0.92-0.98 for compaction factor value.
- **(v)** Significantly decreases permeability. The standard dosage of 0.8% produced a decrease of 79% in the permeability. The permeability was lowered even more with increasing percentage of the admixture, resulting in a more durable concrete.
- **(vi)** Does not have a significant impact on density.

It can be therefore concluded that Penetron Admix improves the strength and durability of concrete. The retardation of set that it also brings may be beneficial when concrete delivery is quite far from the construction site, and delay in delivery is susceptible to occur. Another advantage when using Penetron Admix is the higher early strength obtained, such that de-shuttering can be carried out earlier on fast track construction projects. Another important factor to be noted when using the product is that the workability increases. In other words, the required workability may be achieved by using a lower water/cement ratio that was used to design the mix.

In the light of the above coupled with the fact that Mauritius has a tropical climate and traffic congestion problems, Penetron admix is recommended for use in local construction projects.

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