CHAPTER 4

RESULTS AND DISCUSSIONS

4.1. Overview of Chapter.

The main objective of this chapter is to present the analysis and discussion on the experimental with respect to the influencing factors, trends and shortcomings. The overall discussion is divided into 3 parts; Quality Control that included the performance tests on constituent materials such as the results of sieve analysis of sand, XRF and XRD of powder material. The second and third parts contained the hardened concrete results and efficiency analysis respectively.

4.2. Quality Control.

4.2.1 Sieve Analysis of Sand.

The sieve analysis was conducted in accordance to the British Standard (BS) for the fine aggregates (sand) and coarse aggregates (stones, max. 20mm). The purpose of this test was to obtain well graded fine and coarse aggregates that offered maximum packing, hence, the hardened properties were improved. Table-4.1 shows the mix-proportion from various sieve sizes of the designed-graded sand and Table-4.2 shows the sieve analysis of the as-supplied sand. The results are plotted in the Figures 4.3 and 4.4 respectively. The designed-graded sand was selected from the previous research by N. Shafiq (1999) that was aimed to achieve the maximum packing and the minimum porosity of the concrete.

Table 4.1: Sieve analysis of 'Designed' graded aggregate

AGGREGATES	MAXIMUM ZONE (BS822)		TEST ANALYSIS		MINIMUM ZONE (BS822)	
	sieve size (mm)	% passing	sieve size (mm)	% passing	sieve size (mm)	% passing
FINE (SAND)	0.15	10	0.15	4	0.15	0
	0.30	15	0.30	8	0.30	2
	0.60	80	0.60	40	0.60	20
	1.18	90	1.18	72	1.18	50
	2.36	95	2.36	87	2.36	70
	5.00	98	5.00	92	5.00	90
	10.00	100	10.00	100	10	100
COARSE (STONES) (MAX. 20MM)	sieve size (mm)	% passing	sieve size (mm)	% passing	sieve size (mm)	% passing
	pan	0	pan	0	pan	0
	2.36	0	2.36	0	2.36	0
	3.35	3	3.35	3	3.35	0
	5.00	30	5.00	30	5.00	0
	10	80	10	80	10	30
	14	90	14	90	14	70
	20	100	20	100	20	90

Table 4.2: Sieve analysis of 'As-supplied' aggregates

AGGREGATES	MAXIMUM ZONE (BS822)		TEST ANALYSIS		MINIMUM ZONE (BS822)	
	sieve size (mm)	% passing	sieve size (mm)	% passing	sieve size (mm)	% passing
FINE (SAND)	0.15	10	0.15	0	0.15	0
	0.30	15	0.30	2	0.30	2
	0.60	80	0.60	20	0.60	20
	1.18	90	1.18	62	1.18	50
	2.36	95	2.36	87	2.36	70
	5.00	98	5.00	92	5.00	90
	10.00	100	10.00	100	10	100
COARSE (STONES) (MAX. 20MM)	sieve size (mm)	% passing	sieve size (mm)	% passing	sieve size (mm)	% passing
	pan	0	pan	0	pan	0
	2.36	0	2.36	0	2.36	0
	3.35	3	3.35	3	3.35	0
	5.00	30	5.00	30	5.00	0
	10	80	10	80	10	30
	14	90	14	90	14	70
	20	100	20	100	20	90

4.2.1.1. 'Designed' aggregate mixes

'Designed' grading was obtained from aggregates that were taken from three different parts of the main aggregate source. These mixes included the fine and coarse aggregates. The aggregate sizes and proportions were designed to suit the right measurements of the mix series designs and were used directly without any alterations during concrete mixing. The results displayed fulfilled the British Standard specifications as illustrated in Figure 4.1 and Figure 4.2.

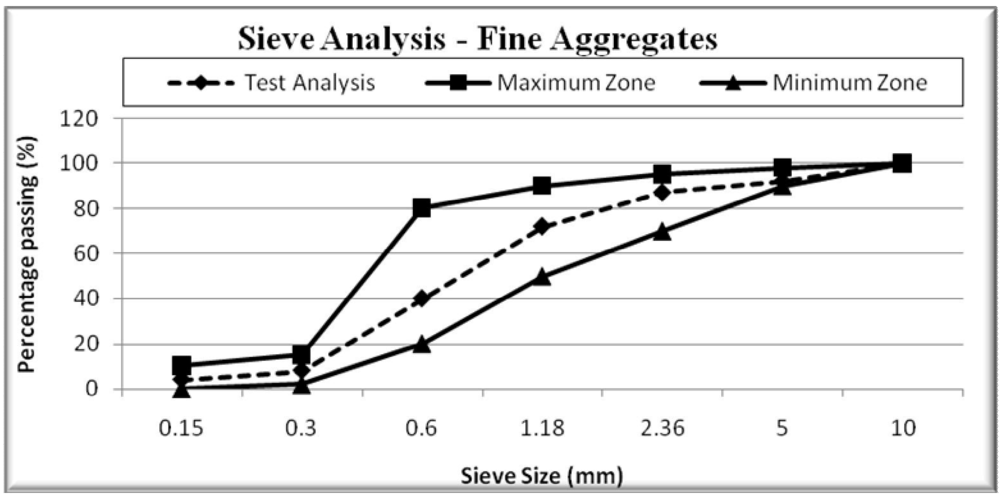

Figure 4.1: Sieve Analysis Test – Fine Aggregates – 'Designed' mixes

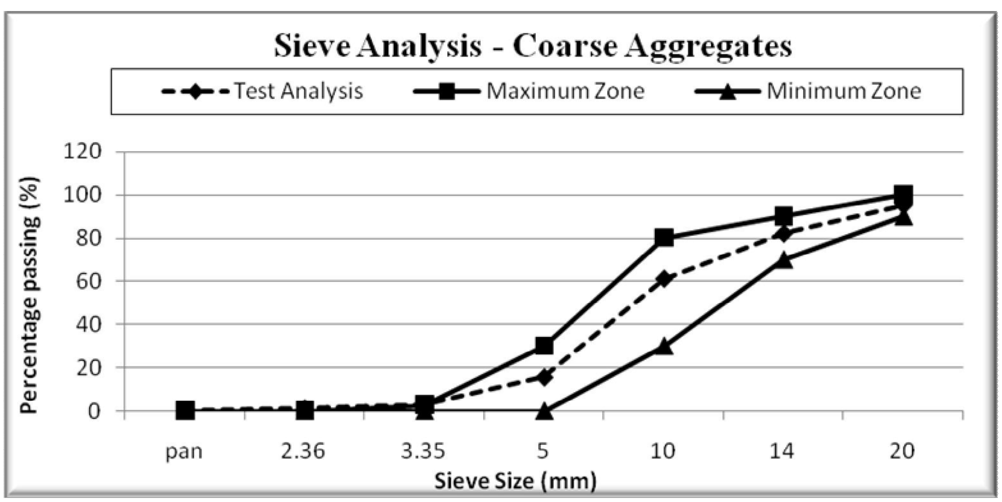

Figure 4.2: Sieve Analysis Test – Coarse Aggregates – 'Designed' mixes

Aggregates obtained and used from these mixes were well graded and finely distributed. The aggregates were good in quality, well packed and managed to reduce the risk of segregation. Less segregation of aggregates will increase the strength of concrete thus enhancing its durability (K.P. Mehta, 1999). This was so as the test analysis curve was designed to be in between the maximum zone curves and minimum zone curves.

4.2.1.2. 'As-supplied' aggregate mixes.

'As-supplied' aggregates were also obtained from three parts of the main aggregate source. The mixes also included fine and coarse aggregates. The mix proportions were designed to suit the right weight measurement but not designed with specification to the BS Standard where the test analysis curve was plotted according to results obtained from the sieve analysis test. This can be observed in Figure 4.3 and Figure 4.4.

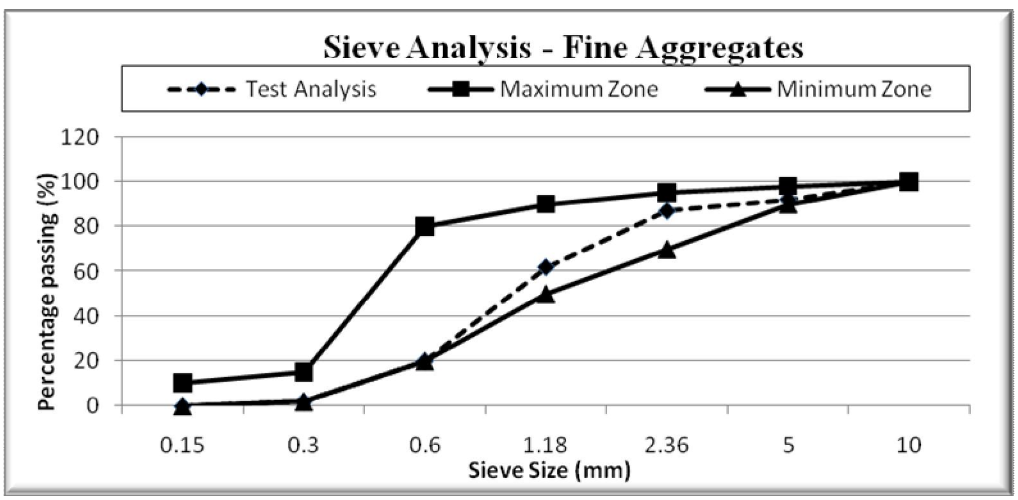

Figure 4.3 Sieve Analysis Test – Fine Aggregates – 'As-supplied' mixes

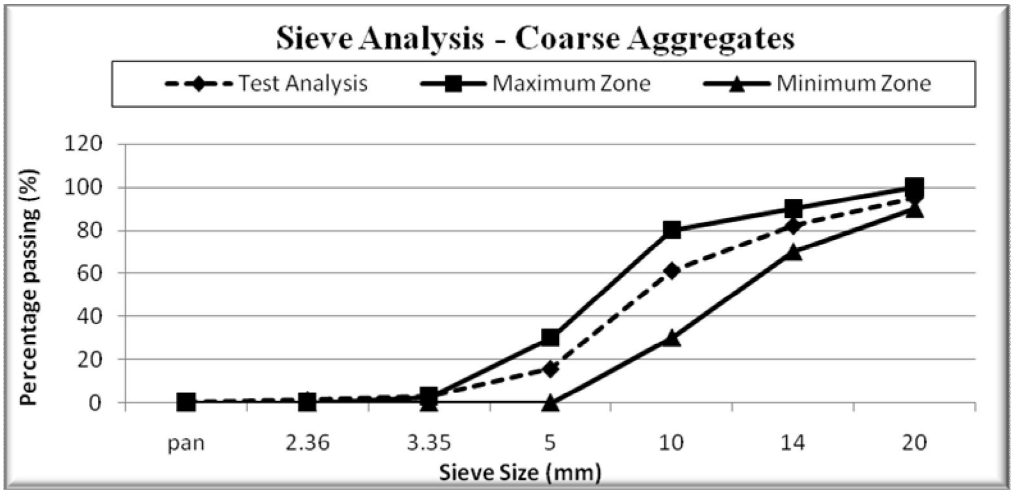

Figure 4.4 Sieve Analysis Test – Coarse Aggregates – ‘As-supplied’ mixes

It was found that the addition as much as 4% of sand size 0.15 mm, 6% of sand size 0.3 mm, 20% of sand size 0.6 mm and 10% of sand size 1.18mm were required to create the ideal mix design proportions. No alterations were involved for the gravels as gravels obtained were of the ideal sizes required which were of maximum 20 mm in diameter.

The test analysis curve for the coarse aggregate was within the minimum zone and maximum zone as specified by the British Standard. With alterations in fine aggregates, the main objective of the research of well graded and finely distributed aggregates in mix proportion was fulfilled. In plotted graphs shown later in the sub-sections for results discussions, the mixes were labelled as ‘UD’ which meant ‘Undesigned’.

4.2.2. XRF Results.

XRF test was conducted on the supplied cement and silica fume to determine their chemical composition. The XRF Test was conducted and the chemical composition of Ordinary Portland Cement (OPC) Type 1 and Silica Fume (SF) is as shown in Table 4.3.

Table 4.3 Chemical composition of OPC and SF

CHEMICAL COMPOSITION	(OPC) (%)	(SF) (%)
SiO_2	21.98	91.7
Al_2O_3	4.65	1.00
Fe_2O_3	2.27	0.90
CaO	61.55	1.68
MgO	4.27	1.80
SO_3	2.19	0.87
K_2O	1.04	-
Na_2O	0.11	0.10

The pozzolanic reactivity of SF depends on the amorphous state of SF particles and the high SiO_2 content inside. XRF test is proficient in analyzing the material contents inside SF, hence the amount of SiO_2 can be observed. The oxide content of SiO_2 and K_2O are able to lower the heat evolution in concrete hydration process (C.H. Hwang, 1996). The oxide content of SF that was used for this research was the optimum composition that could give significant improvement to the concrete properties.

Wonderful characteristics were shown by SF in concrete produced from this research where with the addition of SF, very high early strength was achieved compared to normal control mix concrete (CM). This can be observed in the following sub-sections.

4.2.3. XRD Test.

The XRD Test was used to analyze the crystalline properties of a material. Graph patterns of the test shows whether the material is in amorphous, partially crystalline or in crystalline conditions. Figure 4.5 describes the properties of SF.

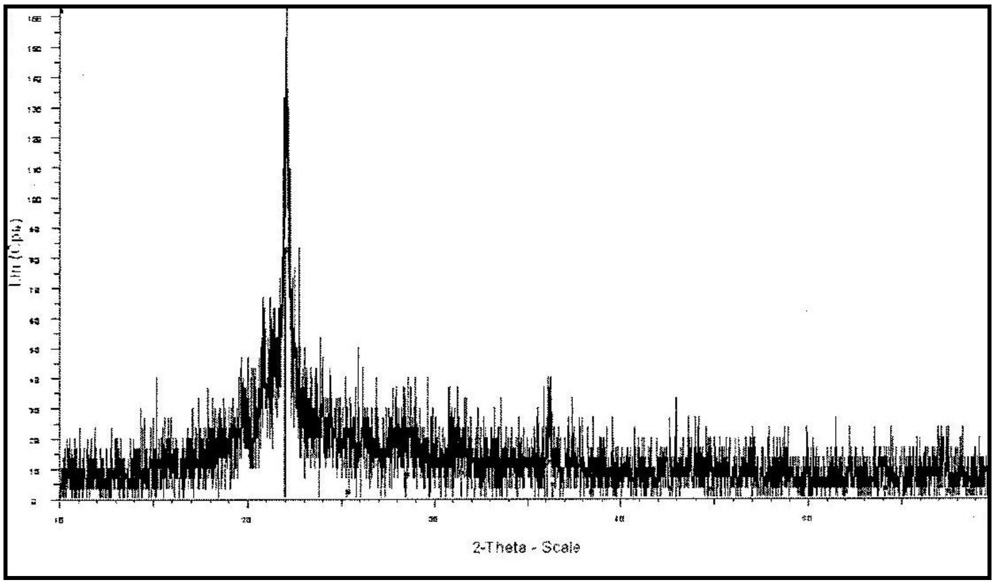

Figure 4.5: XRD Graph of SF

From Figure 4.5, the graph peaks, which appeared at the 2θ scale of 22˚ and 36˚, indicated the presence of SiO_2 cristobalite inside SF sample. The gradual dense scatter from the XRD graph is used to indicate the amorphous state of a material. For this research the SF sample shows a sharp intensity of dense scatter where SF can be categorized as partially crystalline sample. The fully amorphous material is indicated with a smooth gradual scatter, while the fully crystalline material is indicated with a flat and sharp peak of graph scatter.

4.3. Properties of Concrete.

Concrete properties were investigated in its fresh and hardened state. Fresh properties slump test was used to determine the desired workability. Whereas, hardened properties were obtained to determine the performance of concrete under different course of action.

4.3.1. Properties of Fresh Concrete using Slump Test

The properties of fresh concrete were measured based on its workability characteristics. Superplasticizer or also known as high water reducing admixture was used and was added into the concrete mix proportion to get the desired workability of 60 ± 10mm. The control mix was made of 0.5 w/c ratio, which was kept constant in other mixes. Measured slump for all concrete mixes is given in Table 4.4 and 4.5.

Table 4.4 Measured Slump of Concrete (Designed graded aggregate)

Mix Series ('Designed')	OPC (kg/m³)	FA (kg/m³)	CA (kg/m³)	W/C Ratio	SF (%)	SP (%)	Slump (mm)
250CM	250	860	1290	0.5	0	3	52
250SF5	250	860	1290	0.5	5	3	58
250SF10	250	860	1290	0.5	10	3	64
275CM	275	850	1275	0.5	0	3	53
275SF5	275	850	1275	0.5	5	3	60
275SF10	275	850	1275	0.5	10	3	66
350CM	350	840	1260	0.5	0	3	55
350SF5	350	840	1260	0.5	5	3	62
350SF10	350	840	1260	0.5	10	3	67
400CM	400	830	1245	0.5	0	3	58
400SF5	400	830	1245	0.5	5	3	66
400SF10	400	830	1245	0.5	10	3	69

Table 4.5 Measured Slump of Concrete (As-supplied aggregates)

Mix Series ('As-supplied')	**OPC (kg/m³)**	**FA (kg/m³)**	**CA (kg/m³)**	**W/C Ratio**	**SF (%)**	**SP (%)**	**Slump (mm)**
250CM	250	860	1290	0.5	0	3	50
250SF5	250	860	1290	0.5	5	3	54
250SF10	250	860	1290	0.5	10	3	58
275CM	275	850	1275	0.5	0	3	52
275SF5	275	850	1275	0.5	5	3	57
275SF10	275	850	1275	0.5	10	3	61
350CM	350	840	1260	0.5	0	3	54
350SF5	350	840	1260	0.5	5	3	58
350SF10	350	840	1260	0.5	10	3	63
400CM	400	830	1245	0.5	0	3	56
400SF5	400	830	1245	0.5	5	3	63
400SF10	400	830	1245	0.5	10	3	66

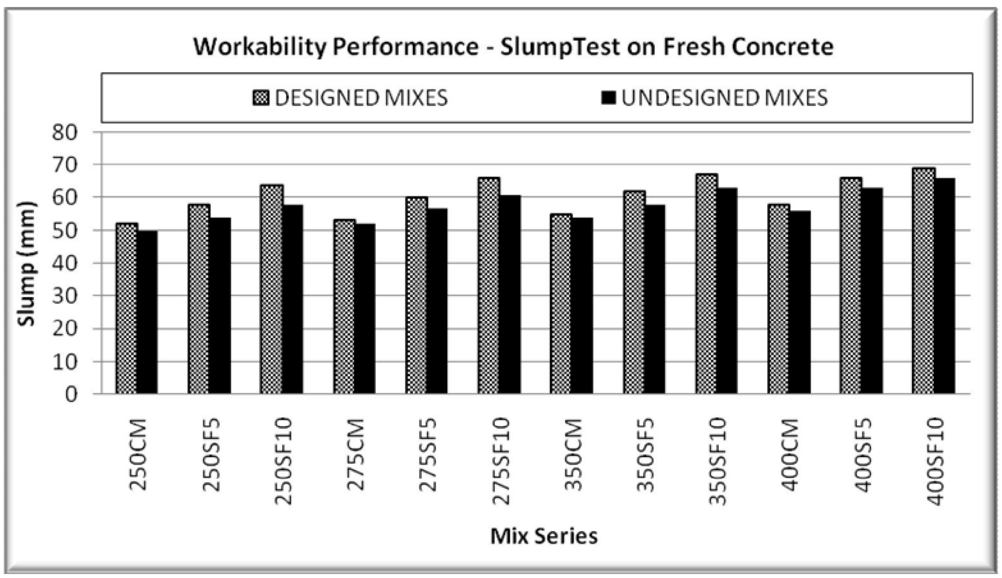

Figure 4.6 Workability Performances – Slump Test on Fresh Concrete

From Figure 4.6, the addition of SF into the concrete mixture has increased the concrete workability. Besides that, the increased amount of OPC used in mix series has also increased the workability of the concrete. This was mainly due to the segregation in aggregates caused by uneven size distribution in the 'As-supplied' mixes. The absorptive characteristic of SF cellular particles, thus concrete which contains higher amount of SF has greater ability to absorb water where it has reduced the tendency of bleeding. Thus the ‘As-supplied’ mixes required more water to achieve the required stability and workability. This has weakened the concrete’s performance in terms of strength performance and durability.

However for results obtained from ‘Designed’ mixes, the workability of the concrete is higher and better than the ‘As-supplied’ mixes. The amount of OPC has also increased the workability of the concrete mix. This has indirectly proved that good aggregate gradings contributed to the high workability performance of the concrete. OPC is not the only main consideration in improving concrete’s workability and strength.

The slump for this research was controlled within the range of 50 mm – 70 mm in HPC (Silica Fume Association, 2008). The designed slump was purposed to evaluate the workability of the concrete in terms of the effects of aggregates distribution and the addition effects of OPC and SF. As proven the workability of ‘Designed’ mixes was better than the ‘As-supplied’ mixes. ‘Designed’ mixes required less water during mixing and achieved ideal slump values.

4.3.2. Hardened Concrete Properties

4.3.2.1 Compressive Strength Test

The test was conducted to analyze the impact of OPC and SF addition into the concrete mix proportion. The results were arranged in Table 4.6 ('Designed' mixes) and Table 4.7 ('As-supplied' mixes);

Table 4.6 Compressive Strength Developments – 'Designed' Mixes

Mix Series ('Designed')	Age (Days)			
	3	7	28	120
	Compressive Strength (MPa)			
250CM	14.65	18.22	62.07	77.01
250SF5	38.18	43.12	62.20	78.95
250SF10	37.13	43.62	62.30	79.15
275CM	19.10	40.14	62.42	72.59
275SF5	46.70	50.50	68.42	85.40
275SF10	46.75	51.08	63.70	92.70
350CM	22.30	43.44	64.57	80.50
350SF5	41.83	49.67	67.50	102.30
350SF10	50.95	55.33	70.70	113.34
400CM	26.67	44.98	63.28	89.67
400SF5	45.55	49.95	69.34	117.21
400SF10	55.48	60.72	85.95	136.80

Table 4.7 Compressive Strength Developments – ‘As-supplied’ Mixes

Mix Series ('As-supplied')	Age (Days)			
	3	7	28	120
	Compressive Strength (MPa)			
250CM	9.65	12.21	42.26	57.20
250SF5	27.18	33.42	52.40	70.59
250SF10	30.13	40.21	58.65	72.65
275CM	12.23	36.91	53.24	59.65
275SF5	32.80	45.28	60.23	74.20
275SF10	35.89	48.82	62.95	83.91
350CM	20.21	38.54	59.75	65.50
350SF5	32.95	46.31	65.33	88.37
350SF10	35.92	50.35	66.32	105.64
400CM	22.58	40.13	63.28	72.54
400SF5	33.81	48.90	69.34	98.21
400SF10	42.95	52.27	85.95	128.46

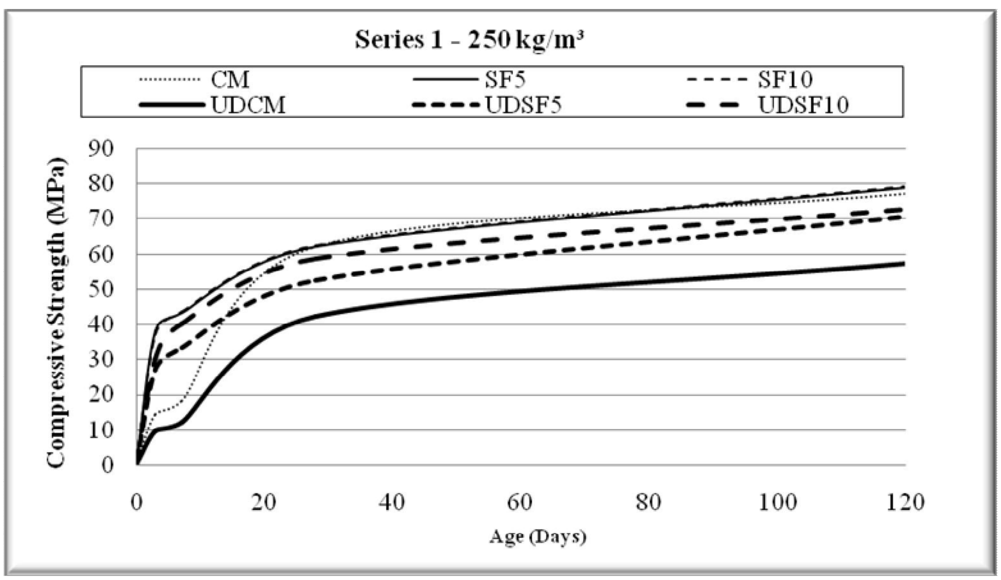

Figure 4.7 Compressive Strength Development of Series 1 (250 kg/m³)

From Figure 4.7, at the age of 28 days, the compressive strengths achieved between the 'Designed' and 'As-supplied' mixes for the control mixes (CM) with 100% OPC was 10%, addition of 5% SF (SF5) was 5% and addition of 10% SF (SF10) was 8% . The compressive strength changed after 28 days age and were higher compared to the 3 days age which was 2% for CM, 16% for SF5 and 10% for SF10. From CM, SF5 compressive strength had increased by 5% while SF10 by 12%.

At the age of 120 days, compressive strength has further increased. In CM mixes, the compressive strength has increased within the range of 10% to 30% when SF was added. The increment was not obvious and was to be almost stagnant. However, when SF was added, the strength changes were obvious. If compared to compressive strength obtained in CM, compressive strength in SF5 has increased by 10% while SF10 has increased by 60%.

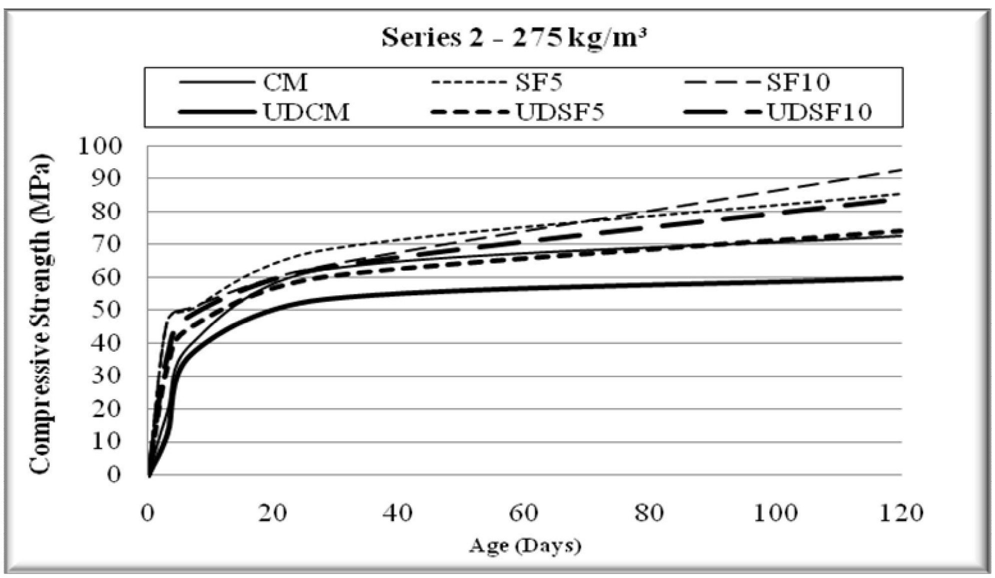

Figure 4.8 Compressive Strength Development of Series 2 (275 kg/m³)

From Figure 4.8, at the age of 28 days, the compressive strengths achieved between the 'Designed' and 'As-supplied' mixes for the control mixes (CM) with 100% OPC was 15%, addition of 5% SF (SF5) was 30% and addition of 10% SF (SF10) was 8% .

The compressive strength changed and was higher compared to the 3 days age that was 15% for CM, 20% for SF5 and 12% for SF10. With addition of 5% SF, the compressive strength increased 10% from CM and with the addition of 10% SF, the compressive strength has further increased by 20%.

At the age of 120 days, compressive strength has increased. However in CM mixes, the compressive strength has increased within the range of 10% to 30% when SF was added. However, when SF was added, the strength changes were obvious. If compared to compressive strength obtained in CM, with addition of 5% SF, compressive strength has increased by 20% while with 10% SF added, compressive strength has increased by 70%.

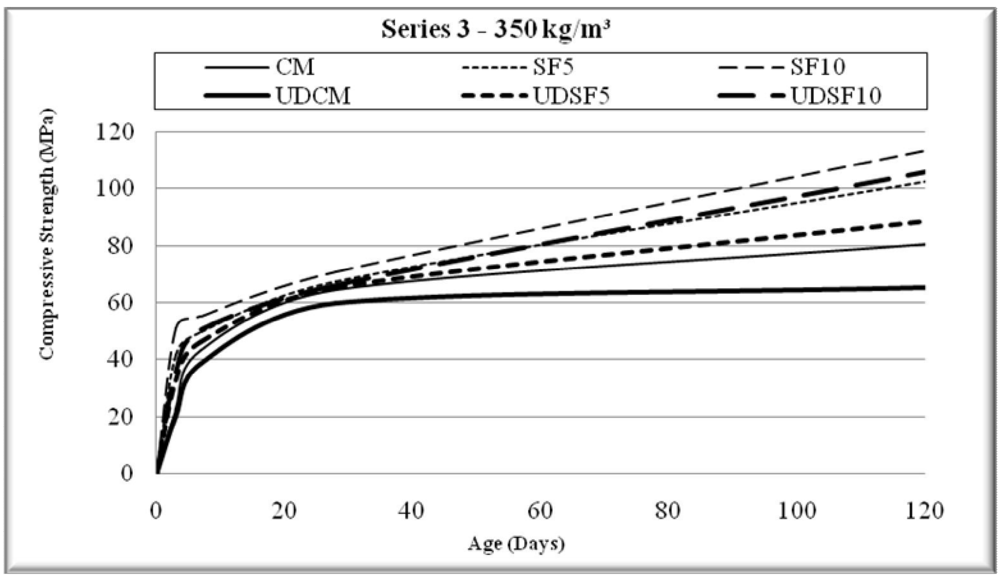

Figure 4.9 Compressive Strength Development of Series 3 (350 kg/m^3)

From Figure 4.9, at the age of 28 days, the compressive strengths achieved between the ‘Designed’ and ‘As-supplied’ mixes for the control mixes (CM) with 100% OPC was 20%, addition of 5% SF (SF5) was 14% and addition of 10% SF (SF10) was 10% . The compressive strength changed and was higher compared to the 3 days age that was 10% for CM, 5% for SF5 and 10% for SF10. With addition of 5% SF, the compressive strength increased 5% from CM and with the addition of 10% SF, the compressive strength has further increased by 15%.

At the age of 120 days, compressive strength has increased. However in CM mixes, the compressive strength has increased 15% when SF was added. The strength changes were obvious. If compared to compressive strength obtained in CM, with SF5, compressive strength has increased by 15% while with SF10, compressive strength has increased by 45%.

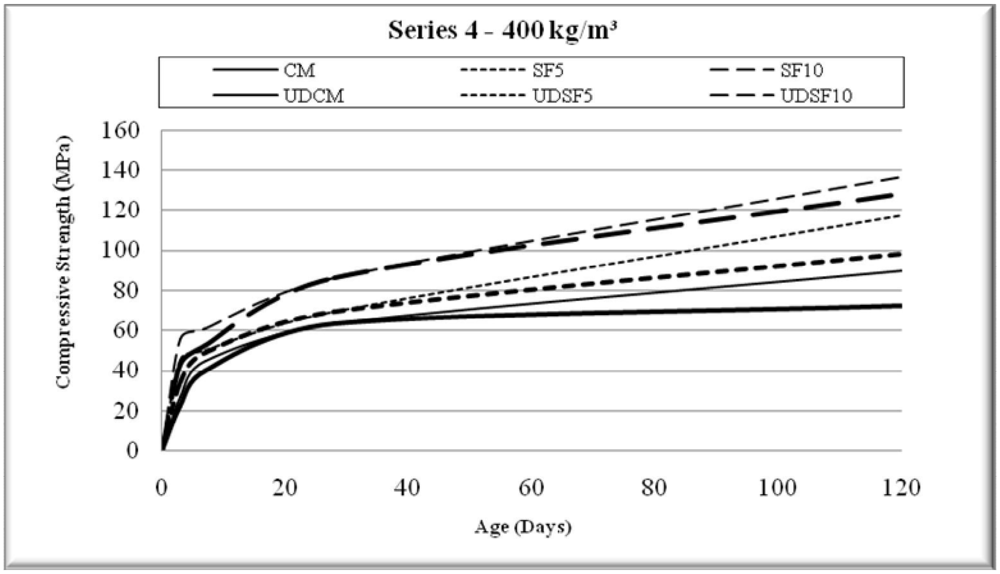

Figure 4.10 Compressive Strength Development of Series 4 (400 kg/m³)

From Figure 4.10, at the age of 28 days, the compressive strengths achieved between the ‘Designed’ and ‘As-supplied’ mixes for the control mixes (CM) with 100% OPC was 20%, addition of 5% SF (SF5) was 16% and addition of 12% SF (SF10) was 10% . The compressive strength changed and was higher compared to the 3 days age that was 5% for CM, 3% for SF5 and 20% for SF10. With addition of 5% SF, the compressive strength increased 10% from CM and with the addition of 10% SF, the compressive strength has further increased by 30%.

At the age of 120 days, compressive strength has increased. However in CM mixes, the compressive strength has increased 15% when SF was added. The strength changes were obvious. If compared to compressive strength obtained in CM, with SF5, compressive strength has increased by 15% while with SF10, compressive strength has increased by 50%.

As proven by T.W. Bremner (1997), the impact of aggregate segregation and distribution in concrete affects the compressive strength development of concrete. This resulted that well graded and finely distributed aggregates in concrete has contributed to the high compressive strength of concrete. SF has proved to be an ideal cement replacing material (CRM). SF has contributed greatly in the high strength development of the concrete. With the small amount of cement used in mix proportion, high strength was achieved thus OPC was not the main consideration to obtain high strength in concrete.

'Designed' mixes has the characteristics of being well compact, solid and no segregation. Fine pores or micro-cracks were filled with aggregates and with the addition of silica fume (SF), reduces bleeding in concrete. The addition of SF in each mix series has also contributed to the high strength obtained at the 28 days age as much as 20%. Thus in terms of performance, cement content is not the main consideration to obtain high strength in concrete. With reduced cement content in concrete mixes, high strength in performance can still be obtained. Thus the ideal mix design was Series 1 of the 'Designed' mixes.

4.3.2.2 High Early Compressive Strength Analyses.

The early compressive strength was analyzed to determine the impact of SF addition into the concrete mix series. The strength developments of concrete samples were measured at 3 and 7 days of age for both 'Designed' and 'As-supplied' concrete mixes. The data obtained were arranged in Table 4.8 ('Designed' Mixes) and Table 4.9 ('As-supplied' Mixes) as shown;

Table 4.8: Early Compressive Strength for 'Designed' Mixes

Mix Series ('Designed')	Age (Days)	
	3	7
	Compressive Strength (MPa)	
250CM	14.65	18.22
250SF5	38.18	43.12
250SF10	37.13	43.62
275CM	19.10	40.14
275SF5	46.70	50.50
275SF10	46.75	51.08
350CM	22.30	43.44
350SF5	41.83	49.67
350SF10	50.95	55.33
400CM	26.67	44.98
400SF5	45.55	49.95
400SF10	55.48	60.72

Table 4.9 Early Compressive Strength for 'As-supplied' Mixes

Mix Series ('As-supplied')	Age (Days) 3	7
	Compressive Strength (MPa)	
250CM	9.65	12.21
250SF5	27.18	33.42
250SF10	30.13	40.21
275CM	12.23	36.91
275SF5	32.80	45.28
275SF10	35.89	48.82
350CM	20.21	38.54
350SF5	32.95	46.31
350SF10	35.92	50.35
400CM	22.58	40.13
400SF5	33.81	48.90
400SF10	42.95	52.27

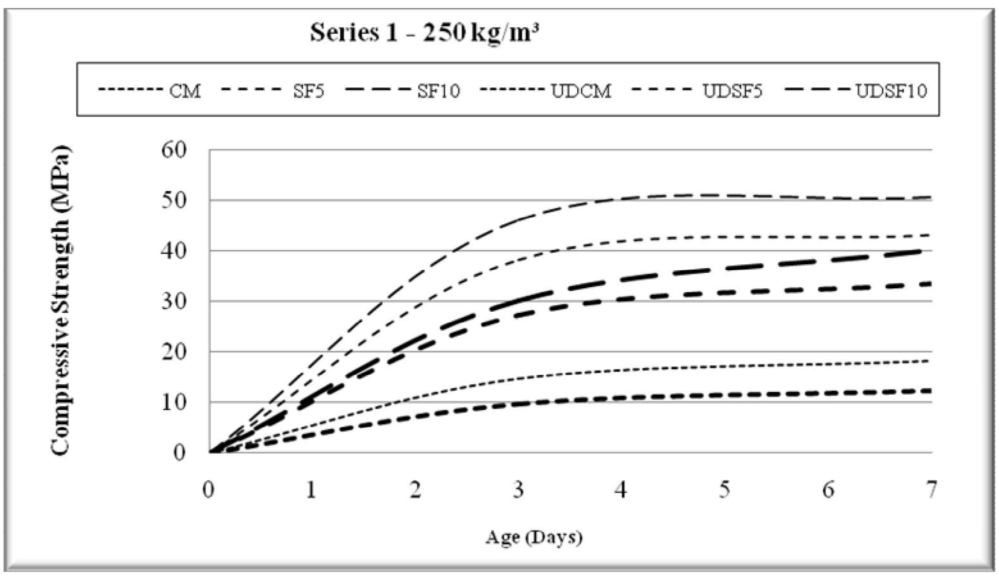

Figure 4.11 High Early Compressive Strength – Series 1 (250 kg/m³)

From Figure 4.11, at the 3 days age, there were increment in compressive strengths between the 'Designed' and 'As-supplied' mixes. For CM, the strength increased 40%, SF5 with 33% and SF10 with 40%. At 7 days age, with the addition of SF, compressive strength has greatly increased by 60% in SF5 and 70% in SF10

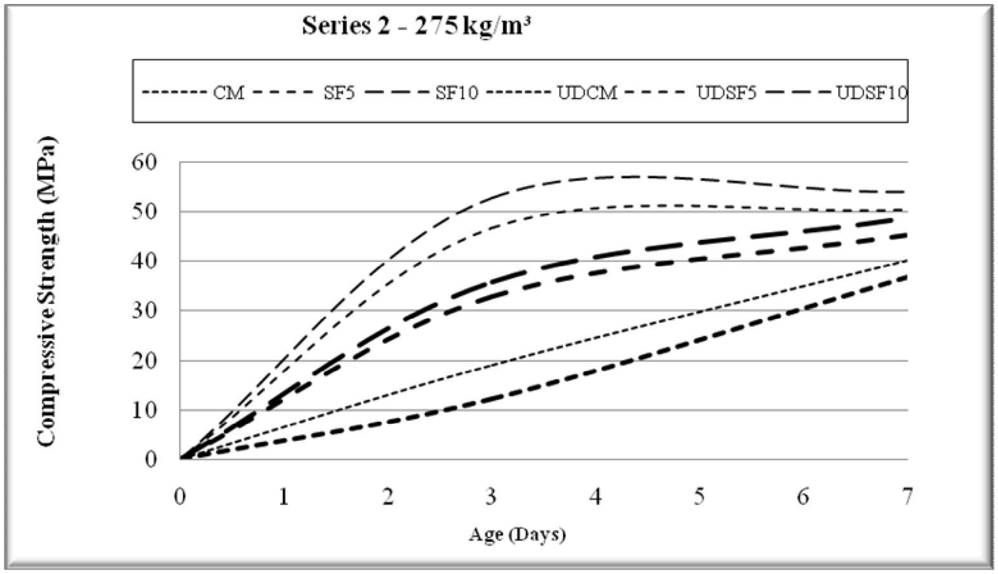

Figure 4.12 High Early Compressive Strength – Series 2 (275 kg/m³)

From Figure 4.12, at the 3 days age, there were increment in compressive strengths between the 'Designed' and 'As-supplied' mixes. For CM, the strength increased 40%, SF5 with 36% and SF10 with 40%. At 7 days age, with the addition of SF, compressive strength has greatly increased by 62% in SF5 and 70% in SF10

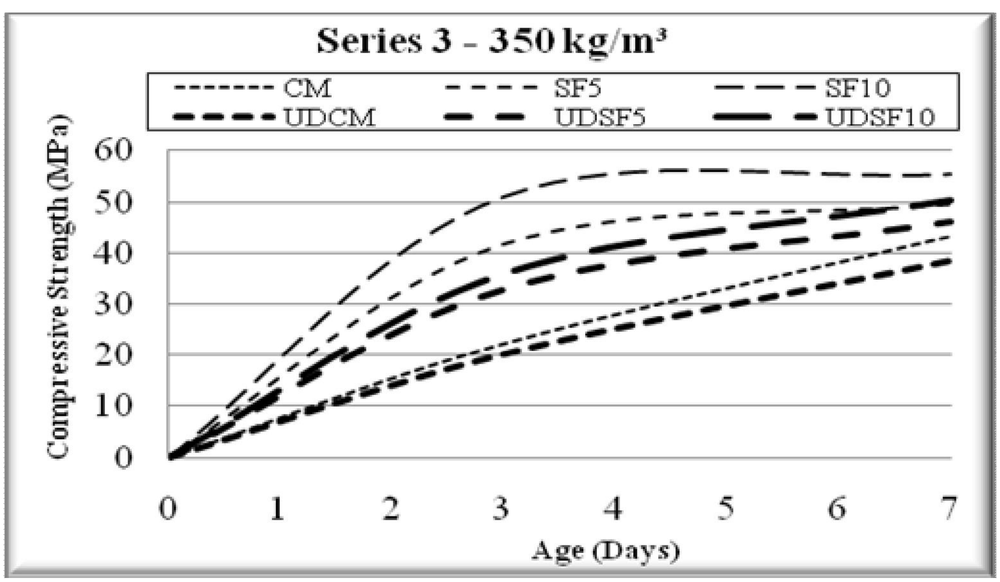

Figure 4.13 High Early Compressive Strength – Series 3 (350 kg/m³)

From Figure 4.13, at the 3 days age, there were increment in compressive strengths between the ‘Designed’ and ‘As-supplied’ mixes. For CM, the strength increased 34%, SF5 with 40% and SF10 with 42%. At 7 days age, with the addition of SF, compressive strength has greatly increased by 50% in SF5 and 70% in SF10.

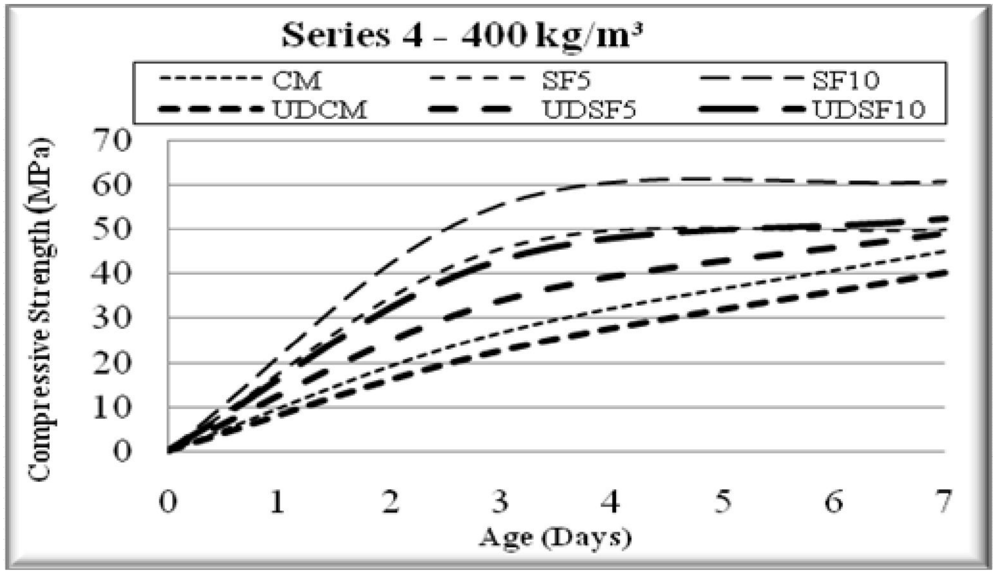

Figure 4.14 High Early Compressive Strength – Series 4 (400 kg/m³)

From Figure 4.14, at the 3 days age, there were increment in compressive strengths between the ‘Designed’ and ‘As-supplied’ mixes. For CM, the strength increased 33%, SF5 with 40% and SF10 with 40%. At 7 days age, with the addition of SF, compressive strength has greatly increased by 43% in SF5 and 60% in SF10.

Overall, as observed from the figures, the early compressive strength obtained from ‘Designed’ mixes were higher than ‘As-supplied’ mixes as much as 5% - 10% in each mix series. The strength values obtained from CM in each mix series were high which is around 20 MPa and is suitable for land constructions. The addition of SF has enhanced the concrete’s performance in high early strength development and was ideal for marine structures constructions where the strength value obtained from this research was more than 40 MPa. SF has contributed greatly to the increase of high early strength in concrete.

As can be observed from the figures, compressive strength of SF5 and SF10 obtained were more than 40 MPa. The compressive strength results obtained were higher than minimum 35 MPa. SF being an ideal CRM is not a myth but a great CRM. 10% of SF added contributes to 30% of strength increase as it forms a surface coating on cement particles increasing the chemical reactions among particles with improved interfacial layer (bond) (K. Day, 1993). With the application of well graded and finely distributed aggregates as produced from ‘Designed’ mixes, an improved concrete material has developed.

This was so, as mixes will be more workable, compact, solid, reduced in material size as less formwork will be used but with maintained high strength or higher strength, reduces cost and maximizes profits of parties involved. Such high strength of 40 MPa, is high in demand by contractors and developers for fast pace constructions in this modern urbanization. Thus the ideal mix design was Series 1 of the ‘Designed’ mixes.

4.3.2.3 Porosity Test

The porosity test was conducted to determine the impact of OPC and SF addition into the concrete mix series. The porosity (%) of concrete samples were measured at 3, 7, 28, 56 and 120 days of age for both ‘Designed’ and ‘As-supplied’ concrete mixes. The data obtained were arranged in Table 4.10 (‘Designed’ Mixes) and Table 4.11 (‘As-supplied’ Mixes).

Table 4.10 Porosity for ‘Designed’ Mixes

Mix Series ('Designed')	Age (Days)				
	3	7	28	56	120
	Porosity (%)				
250CM	8.34	6.03	4.01	3.22	3.17
250SF5	8.32	6.75	4.00	3.08	1.89
250SF10	8.23	6.80	4.00	3.20	2.92
275CM	4.51	4.37	3.08	2.52	1.10
275SF5	6.91	4.08	3.82	3.05	2.69
275SF10	6.59	6.44	4.02	3.13	2.24
350CM	7.11	5.85	5.37	4.72	4.61
350SF5	6.84	5.05	4.15	3.53	2.62
350SF10	7.28	6.80	4.81	3.10	1.07
400CM	6.89	6.37	4.93	3.89	2.25
400SF5	6.35	6.27	5.67	5.28	3.60
400SF10	6.20	6.12	5.05	4.04	2.01

Table 4.11 Porosity for ‘As-supplied’ Mixes

Mix Series ('As-supplied')	Age (Days)				
	3	7	28	56	120
	Porosity (%)				
250CM	8.80	6.34	4.21	3.40	3.33
250SF5	9.20	7.43	4.40	3.76	2.08
250SF10	9.06	7.50	4.76	3.52	3.22
275CM	6.77	6.56	4.62	3.80	1.70
275SF5	10.37	6.12	5.73	4.60	4.04
275SF10	9.90	8.40	5.23	4.07	2.92
350CM	9.24	7.61	7.00	6.14	6.00
350SF5	8.90	6.57	5.40	4.60	3.41
350SF10	9.50	8.84	6.26	4.03	1.40
400CM	10.34	9.56	7.40	5.84	3.38
400SF5	9.53	9.41	8.51	7.92	5.40
400SF10	9.30	9.20	7.60	6.06	3.02

From Figure 4.15, 4.16, 4.17 and 4.18, the porosity values in each mix series reduced with age. From Figure 4.15, at the 3 days age, the porosity of ‘Designed’ mixes has reduced 27% while ‘Undesigned’ mixes has reduced 25% with a difference of 2%. Gradual decrease of values occurred as much as 2% in every age day. However as cement consumption in mix series for ‘Designed’ mixes increases significant decrease as much as 50% - 70% in porosity values compared to ‘As-supplied’ mixes were observed from Figure 4.16, 4.17 and 4.18.

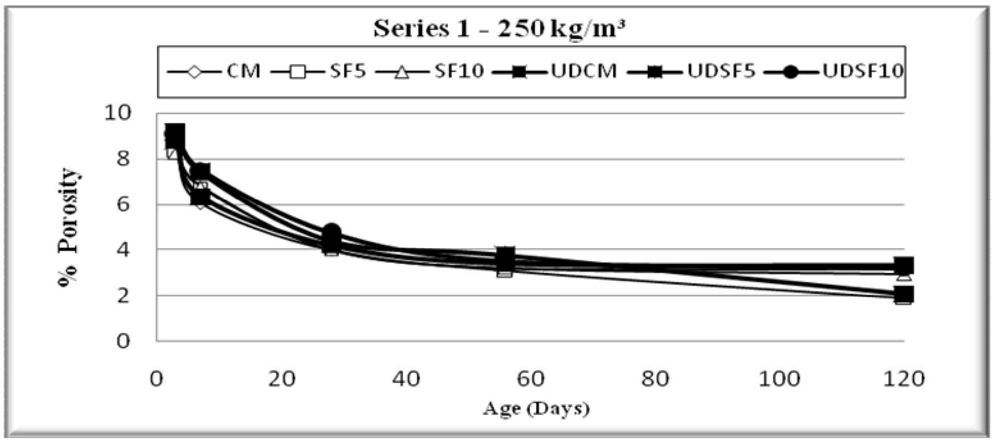

Figure 4.15 Total Porosity Development – Series 1 (250 kg/m³)

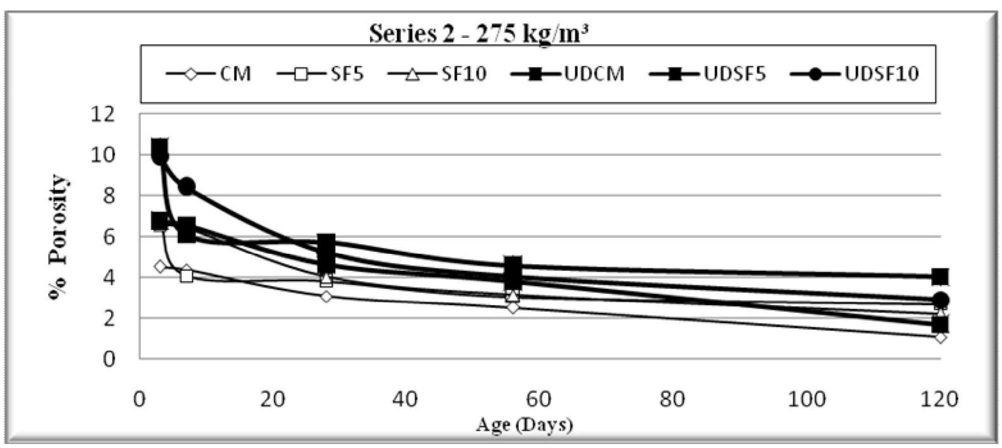

Figure 4.16 Total Porosity Development – Series 2 (275 kg/m³)

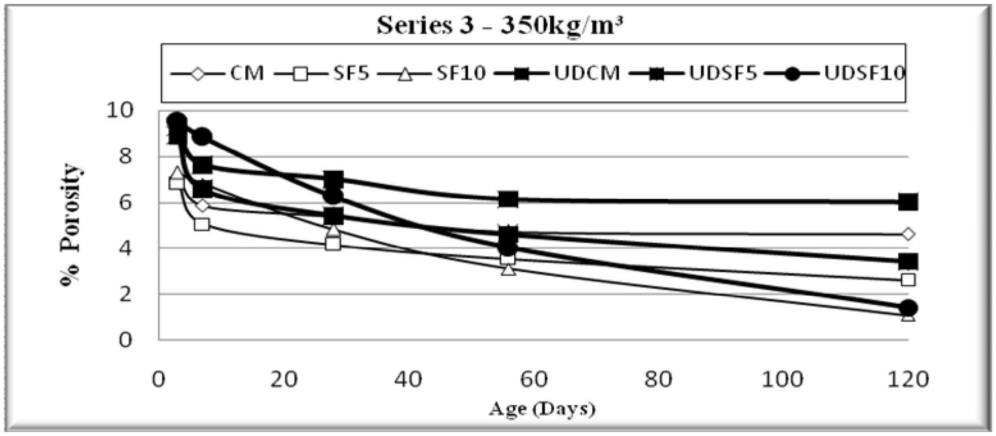

Figure 4.17 Total Porosity Development – Series 3 (350 kg/m³)

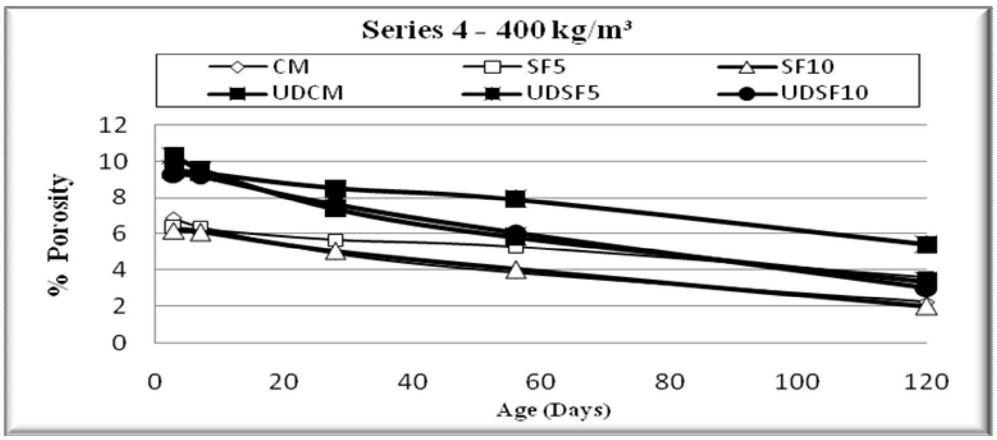

Figure 4.18 Total Porosity Development – Series 4 (400 kg/m³)

Low percentage values in porosity are good as it shows that the concrete is durable, solid and compact. It can be determined that no segregation of aggregates in concrete during mixing process. From this research, the impact of OPC and SF can be determined in detail. Based on results analysis, it is determined that 'Designed' mixes performed better than 'As-supplied' mixes. With the addition of SF, the qualities of the concrete mixes produced were further enhanced.

The addition of SF into concrete mixes caused big reductions in porosity values as much as 3%-4% in every age day in each mix series. SF has filled the pores that was inside the concrete directly reduces bleeding effects. SF also has very small particle size, 1µm. It takes about 6 000,000 particles to form a particle of OPC (SFA, 1997).

Based on discussions, the decrease in total porosity was observed during the hydration process. Large capillary pore spaces were filled with the hydration products, for this research is SF as CRM during cement hydration. Thus, this refined the size of the pores where it directly increased the cumulative volume of very fine gel pores. Figure 4.19 shows the overall total porosity development in every mix series for both 'Designed' and 'As-supplied' Mixes.

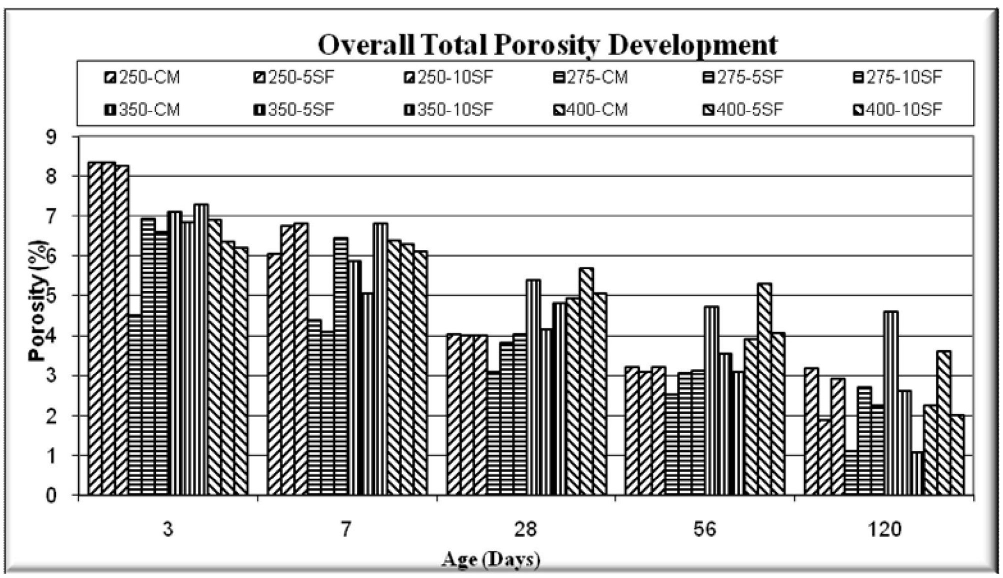

Figure 4.19: Overall Porosity Development-'Designed' and 'As-supplied' Mixes

The overall total porosity developments in both mixes were ideal. Percentage of porosity reduced with age. Reduced cement content has managed to maintain high strength with low porosity adding durability benefits to the concrete material. Cement content was not the main consideration to maintain durability of a concrete but well graded and finely distributed aggregates also played the main role in high durability of concrete.

4.3.2.4 Split Cylinder Test

The tensile strength developments (MPa) of concrete samples were obtained at 28 and 90 days of age for both 'Designed' and 'As-supplied' concrete mixes. The datas obtained were arranged in Table 4.12 ('Designed' Mixes) and Table 4.13 ('As-supplied' Mixes).

Table 4.12: Split Tensile Strength Development (MPa) – Designed Mixes

Mix Series ('Designed')	Age (Days)	
	28	120
	Tensile Strength (MPa)	
250CM	3.250	3.363
250SF5	3.180	3.260
250SF10	2.207	2.932
275CM	2.892	3.304
275SF5	3.675	4.625
275SF10	3.677	4.706
350CM	2.853	3.256
350SF5	3.530	4.177
350SF10	4.756	4.981
400CM	3.220	3.586
400SF5	3.478	4.387
400SF10	4.698	4.894

Table 4.13: Split Tensile Strength Development (MPa) – 'As-supplied' Mixes

Mix Series ('As-supplied')	Age (Days)	
	28	120
	Tensile Strength (MPa)	
250CM	2.600	2.700
250SF5	2.540	2.610
250SF10	1.770	2.350
275CM	2.320	2.640
275SF5	2.940	3.700
275SF10	3.120	3.850
350CM	2.300	2.610
350SF5	2.820	3.360
350SF10	3.840	4.040
400CM	2.580	2.900
400SF5	2.780	3.600
400SF10	3.800	3.920

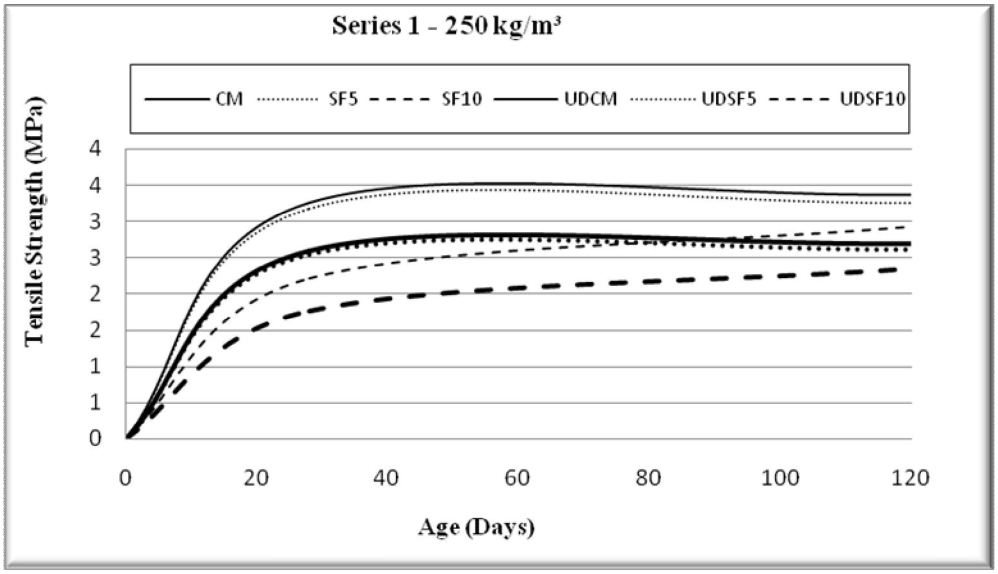

Figure 4.20: Split Tensile Strength Development (MPa) – Series 1 (250 kg/m³)

From Figure 4.20, at 28 days age, the tensile strength has increased in both mixes. In CM, the tensile strength has increased 20%, SF5 with 30% and SF10 with 40%. At 90 days, the tensile strength increased 20% in CM, 40% in SF5 and 52% in SF10.

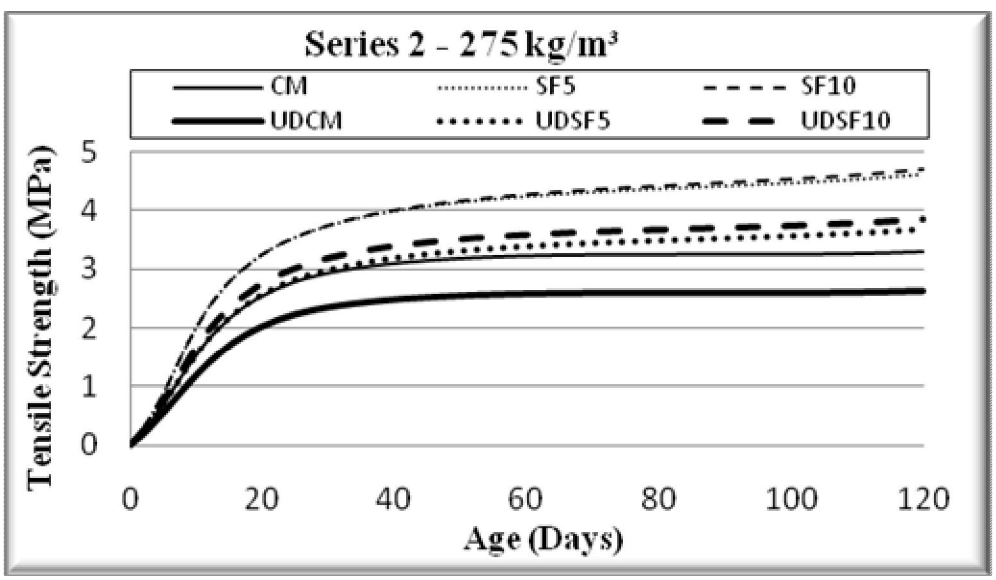

Figure 4.21: Split Tensile Strength Development (MPa) – Series 2 (275 kg/m³)

From Figure 4.21, at 28 days age, the tensile strength has increased in both mixes. In CM, the tensile strength has increased 20%, SF5 with 35% and SF10 with 45%. At 90 days, the tensile strength increased 30% in CM, 45% in SF5 and 60% in SF10.

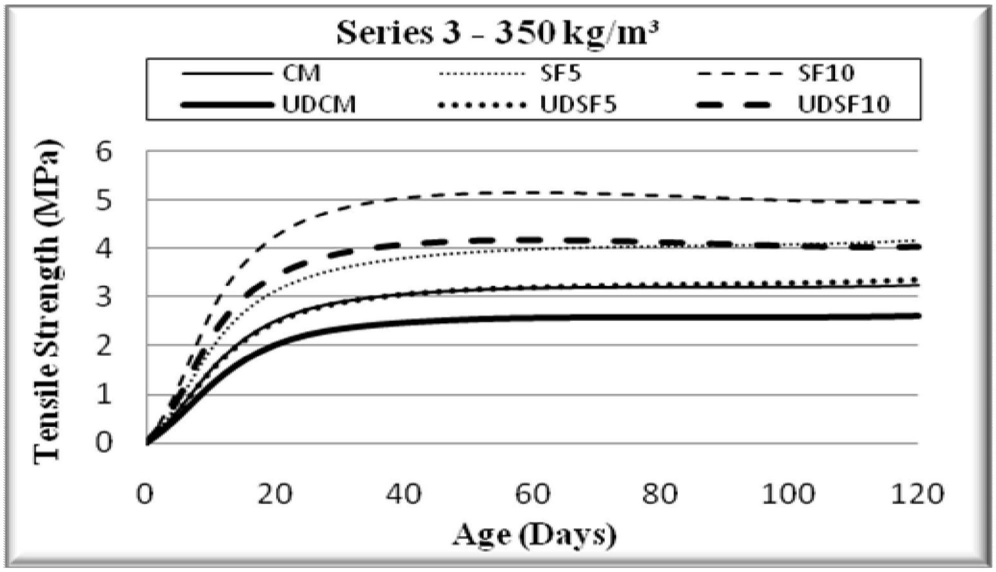

Figure 4.22: Split Tensile Strength Development (MPa) – Series 3 (350 kg/m³)

From Figure 4.22, at 28 days age, the tensile strength has increased in both mixes. In CM, the tensile strength has increased 20%, SF5 with 30% and SF10 with 40%. At 90 days, the tensile strength increased 20% in CM, 50% in SF5 and 62% in SF10.

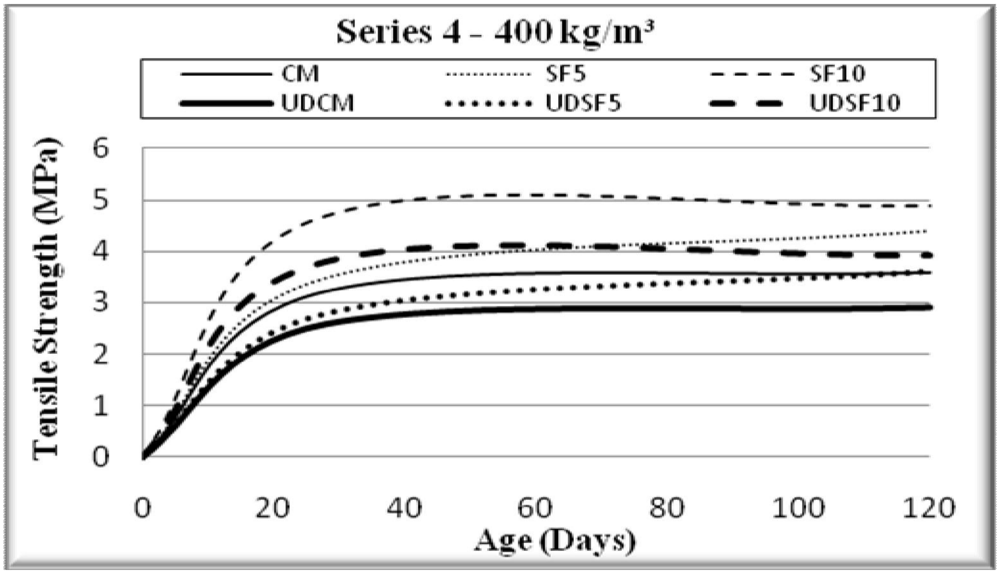

Figure 4.23: Split Tensile Strength Development (MPa) – Series 4 (400 kg/m³)

From Figure 4.23, at 28 days age, the tensile strength has increased in both mixes. In CM, the tensile strength has increased 20%, SF5 with 30% and SF10 with 45%. At 90 days, the tensile strength increased 30% in CM, 60% in SF5 and 70% in SF10.

Low tensile strength has values ranging from 1-2 MPa (Nawa and Horita, 2004). Tensile strength values obtained were more than 2 MPa and have a maximum value of 5MPa (Table 4.14). Low tensile strength in concrete at 28 days of age brings out great risk of material defects such as cracking.

High tensile strength values contribute to high durability of material characteristics. Tensile strength represents the brittleness of a material and the behaviour of material in sustaining different environment conditions. Although with reduced cement content, high strength was achieved. SF was an ideal CRM. Thus, Series 1 of the 'Designed' mixes was the ideal mix design with high tensile values.

4.3.2.5 Chloride Migration Test

The chloride penetration results of concrete samples were obtained at 28, 120 and 180 days of age for both 'Designed' and 'As-supplied' concrete mixes. The results obtained were arranged in Table 4.14 ('Designed' Mixes) and Table 4.15 ('As-supplied' Mixes).

Table 4.14: Chloride Penetration – 'Designed' Mixes

Mix Series ('Designed')	Age (Days)		
	28	120	180
	Chloride Penetration Depth (mm)		
250CM	2.94	5.24	6.15
250SF5	1.53	2.72	4.93
250SF10	1.37	2.61	4.13
275CM	1.35	2.87	5.19
275SF5	1.25	2.24	4.06
275SF10	1.19	2.12	3.90
350CM	2.83	3.54	4.27
350SF5	2.21	3.44	3.88
350SF10	2.08	3.35	3.49
400CM	2.00	2.56	3.15
400SF5	1.88	2.39	2.82
400SF10	1.84	2.24	2.73

From Table 4.16, at the 28 days age, the chloride penetration depth decreased in every mix series with the addition of SF into the sample mixes. SF has micro-filler effects that filled the pores of the concrete. The capillary and pore networks are somewhat disconnected due to the development of self-desiccation (P.C. Aitcin, 2003). As the concrete developed from 28 days age to 180 days age, the penetration depth increased between 5% to 20%. Low penetration values obtained proved that concrete produced from mix designs were durable in the marine environment.

The mechanical properties of concrete were highly dependent on the properties and proportions of aggregates (T. Fuminori and M. Takafumi, 1997). Thus, well graded and finely distributed aggregates contributed to improve durability of concrete. The concrete produced from this mix were compact and solid.

Table 4.15: Chloride Penetration Development – 'As-supplied' Mixes

Mix Series ('As-supplied')	Age (Days)		
	28	120	180
	Chloride Penetration Depth (mm)		
250CM	3.82	6.82	8.05
250SF5	2.15	3.53	6.50
250SF10	1.87	3.46	5.37
275CM	1.76	3.73	6.74
275SF5	1.63	2.91	5.28
275SF10	1.57	2.76	5.07
350CM	3.68	4.61	5.56
350SF5	2.87	4.47	5.04
350SF10	2.70	4.36	4.54
400CM	2.63	3.33	4.10
400SF5	2.45	3.11	3.67
400SF10	2.39	2.92	3.55

From Table 4.17, at the 28 days age, the chloride penetration depth decreased in every mix series with the addition of SF into the sample mixes. SF has helped by having micro-filler effects that filled the pores of the concrete. However, the penetration depth in this mix design was higher compared to the 'Designed' mixes with difference as much as 5%. As the concrete developed from 28 days age to 180 days age, the penetration depth increased as much as 70%. High penetration depth values obtained proved that concrete produced from this mix design especially in CM mix samples in every mix series with maximum depth of 4mm, not very durable in the marine environment.

This was so due to aggregate segregation that occurred in the concrete during hydration. Uneven sizes between aggregates (coarse and fine) were not taken into consideration. Micro-pores existed inside the concrete thus created space for the chloride ions to penetrate further into concrete.

The rate of chloride ion migration into concrete is principally a function of concrete association with chloride ions and concentration of the surrounding salt (Funahashi, 1990). Thus, well graded and finely distributed aggregates should be considered to improve durability of concrete besides increasing the amount of cement consumption.

4.3.2.6. Durability Efficiency.

From Figure 4.24, 180 age day was made 100% chloride penetration efficient. As observed, the durability efficiency increased in 28 and 120 age day. Chloride ion penetration occurred within the mentioned development days but in a very slow rate with maximum increase of 20%. In general, concrete produced from 'Designed' mixes were more efficient compared to the 'As-supplied' mixes.

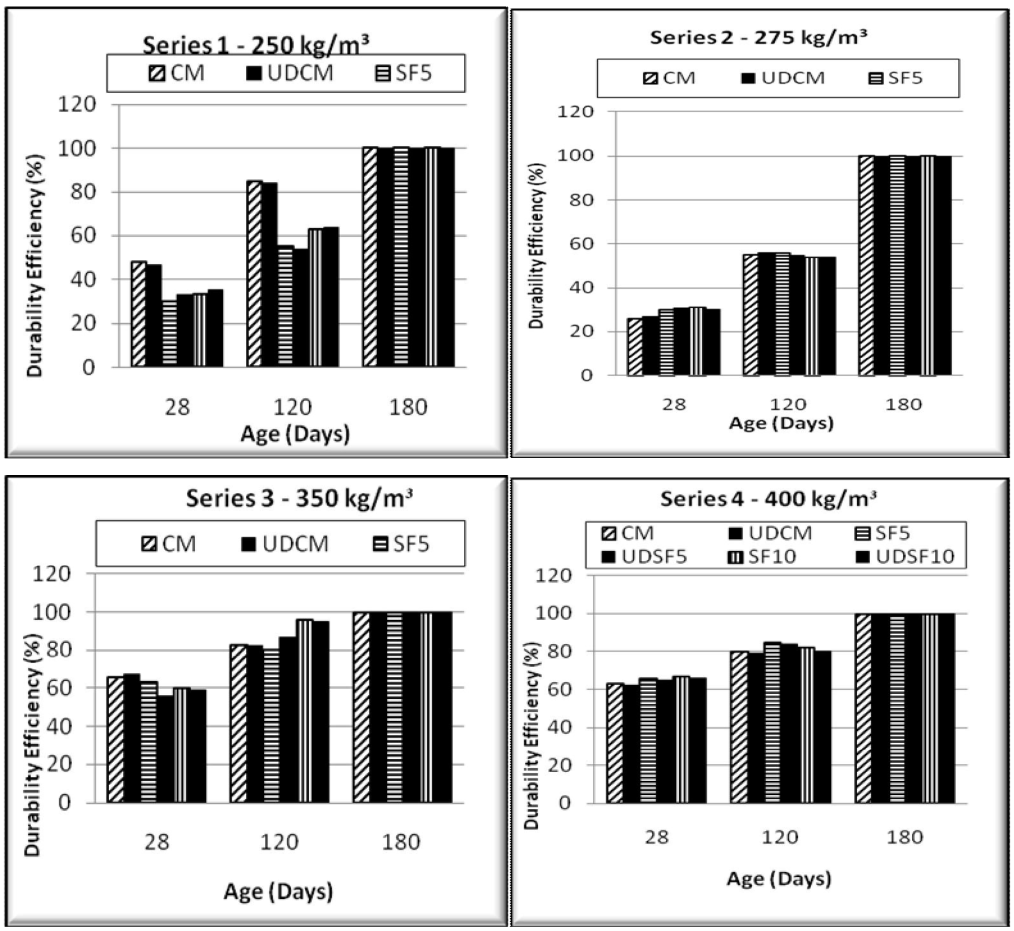

Figure 4.24: Chloride Penetration Efficiency – 'Designed' and 'As-supplied' Mixes.

The addition of SF in sample mixes lead to the process of pore-size and grain-size refinement, which reduces both size and volume of voids, micro-cracks and calcium hydroxide crystals (K.P. Mehta, 1993). The filling space effects of CRMs are as important as pozzolanic effects and for some researchers it can be more important than the pozzolanic effect (A. Goldman, 1992). This proved that concrete produced in this research were durable in the marine environment and able to resists from the attacks of chloride ion salts.

4.3.2.7. Modulus of Elasticity. (Flexural Tensile Strength)

Modulus of Elasticity of concrete is frequently expressed in terms of compressive strength. The mechanical properties of concrete are highly dependent on the properties of aggregates used. It is the key factor to estimate the deformation of buildings and members as well as in designing section of members subjected to flexure (T. Fuminori and M. Takafumi, 1997).

Modulus of Elasticity was described as the stress to strain ratio value for hardened concrete at whatever age and curing condition. The E- Compressive Modulus results were obtained from calculations while the E-Flexural Modulus was taken directly from Universal Testing Machine. The results obtained from were arranged in Table 4.16 (‘Designed’ Mixes) and Table 4.19 (‘As-supplied’ Mixes).

Table 4.16: Modulus of Elasticity – ‘Designed’ Mixes

Mix Series ('Designed')	E - Flexural Modulus (GPa)	E - Compressive Modulus (GPa)
250CM	19.00	20.03
250CM	18.28	22.71
250SF5	17.74	25.12
250SF10	18.97	22.98
275CM	18.91	25.15
275SF5	16.16	27.16
350CM	18.72	22.19
350SF5	18.00	25.56
350SF10	17.14	30.68
400CM	16.67	20.07
400SF5	17.60	26.36
400SF10	18.00	32.24

For the ‘Designed’ Mixes (E- Flexural Modulus), from Table 4.16, in every mix series, the Modulus values decreased at the age of 28 days with the addition of SF as much as 2% to 10% compared to CM. The values corresponded to the characteristic of concrete where it is weak in tension condition.

For the ‘Designed’ Mixes (E- Compressive Modulus), in Table 4.16, in every mix series, the Modulus values were high and increased at the age of 28 days with the addition of SF as much as 10% to 40% compared to CM. The values corresponded to the characteristic of concrete where it is good in compression.

Table 4.17: Modulus of Elasticity – ‘As-supplied’ Mixes

Mix Series ('As-supplied')	E - Flexural Modulus (GPa)	E - Compressive Modulus (GPa)
250CM	12.35	13.02
250CM	12.00	14.80
250SF5	12.2	16.33
250SF10	12.33	14.94
275CM	12.35	16.35
275SF5	10.51	17.65
350CM	12.17	14.43
350SF5	11.86	16.62
350SF10	11.14	20.00
400CM	10.84	13.05
400SF5	11.44	17.13
400SF10	11.70	20.96

For ‘As-supplied’ Mixes (E- Flexural Modulus), compared with ‘Designed’ mixes in Table 4.17, in this mix, the Modulus values also decreased and were lower 35% at the age of 28 days. With the addition of SF, the modulus values of SF5 and SF10 have decreased compared to CM as much as 2% to 5%. The values corresponded to the characteristic of concrete where it is weak in tension condition.

For ‘As-supplied’ Mixes (E- Compressive Modulus), compared with ‘Designed’ mixes in Table 4.18, in every mix series, the compressive modulus values obtained were lower by 35% and increased at the age of 28 days with the addition of SF as much as 7% to 38% compared to CM. The values corresponded to the characteristic of concrete where it is good in compression.

In overall, the concrete produced were deformation resistance. No obvious changes in values occurred although the cement content was increased in every mix series. OPC was not the main consideration in high modulus values in concrete. Well graded and finely distributed aggregates were considered. To predict the E-Modulus in concrete, it is good to have the ideal designed aggregate contents and segregation as well as their compressive strength (W. Baalbaki, 1997).

Concretes which have the same compressive strength and made of various types of aggregates have different E-Modulus values. The compressive strength varied because of the properties of the aggregate sizes and distribution (P.C. Aitcin, 2003). Thus as proposed, Series 1 (250 kg/m^3) was the ideal mix design. The results were shown in Figure 4.25.

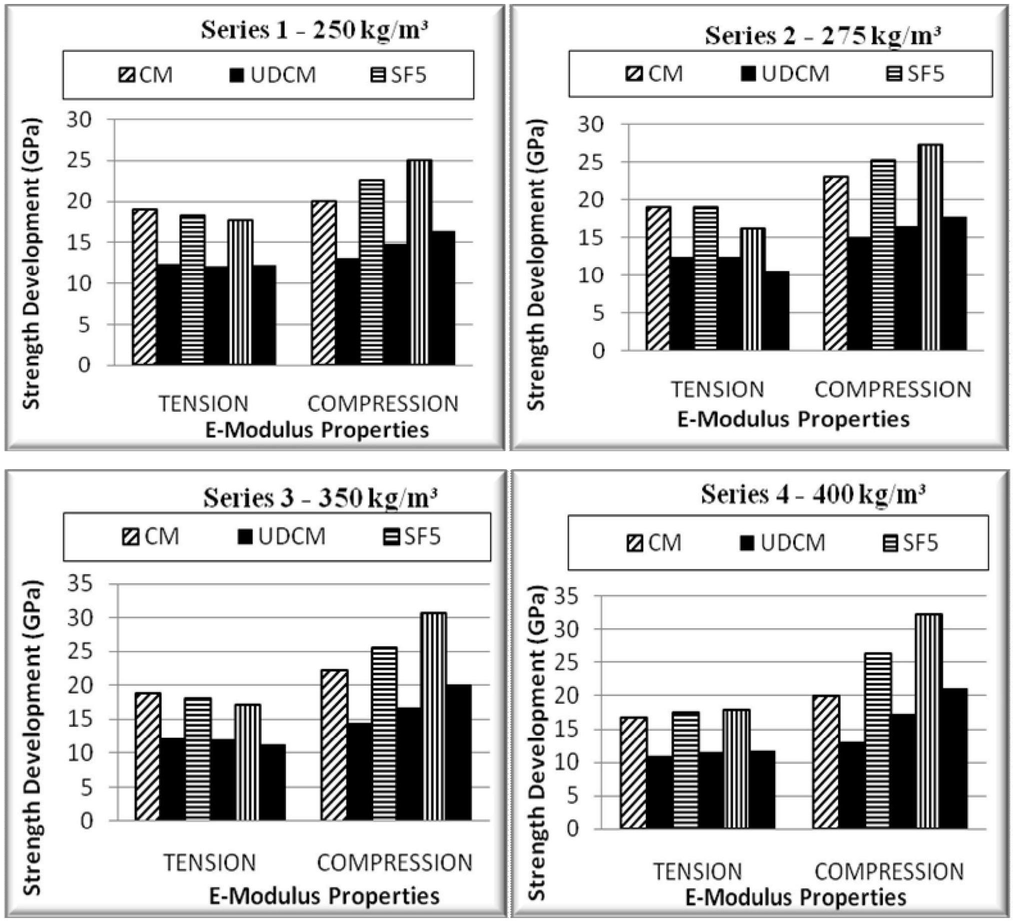

Figure 4.25: Modulus of Elasticity – ‘Designed’ and ‘As-supplied’ Mixes.

The mix design produced fulfilled the characteristic of concrete that is weak in tension conditions. From this, designers were able to estimate the deformation limit which is the modular ratio, n, in structures and structural elements (columns and beams) (T. Tomosawa and M. Nogouchi, 1997).

4.4. Efficiency Analysis.

The following sub-sections discussed the result analysis for the efficiency of the concrete mixes with respect to the eco-friendliness and the green technology requirements. Since the 'Designed' mixes has better performance in potential durability, detail analysis were focused and discussed in the following sub-sections.

4.4.1. Cement Consumption in Mixes

The cement consumed in mix series were considered in two sections

1. Mixes with 100% OPC (Table 4.20)
2. Mixes with 100 % OPC, 5% SF and 10% SF (Table 4.21)

The sections were illustrated in a Matrix Efficiency Table which was Table 4.18 and Table 4.19.

Table 4.18: Matrix Efficiency – 100% OPC

COST	CEMENT CONSUMPTION (KG/M³/MPa)										
(RM/MPa/M³)	4.0 - 4.5	4.5 - 5.0	5.0 - 5.5	5.5 - 6.0	6.0 - 6.5	7.0 - 7.5	7.5 - 8.0	8.0 - 8.5	8.5 - 9.0	9.0 - 9.5	9.5 - 10.0
5.00 - 5.50	LT-A										
5.50 - 6.00											
6.00 - 6.50	LT-B										
6.50 - 7.00			LT-C	LT-D	R1-A, R3-B, R4-B, R5-C		R5-B				
7.00 - 7.50					R1-B, R2-A, R2-C						
7.50 - 8.00					R2-B, R4-A						
8.00 - 8.50		R4-C			R1-C	R3-C					
8.50 - 9.00						R5-A					
9.00 - 9.50											
9.50 - 10.00											
10.00 - 10.50											
10.50 - 11.00											
11.00 - 11.50											R3-A

ECO-FRIENDLY MIXES
ACCEPTABLE MIXES
NON-ECO-FRIENDLY MIXES

A SERIES 250 KG/M³
B SERIES 275 KG/M³
C SERIES 350 KG/M³
D SERIES 400 KG/M³

From Table 4.18, with comparison with five other researches, all mixes conducted from Laboratory Test (LT) were eco-friendly mixes. These mixes fulfilled the criteria of being the most effective in cost and low in cement consumption during production.

Table 4.19: Matrix Efficiency – 100% OPC, 5% SF and 10% SF

COST	**CEMENT CONSUMPTION (KG/M³/MPa)**										
(RM/MPa/M³)	**4.0 - 4.5**	**4.5 - 5.0**	**5.0 - 5.5**	**5.5 - 6.0**	**6.0 - 6.5**	**6.5 - 7.0**	**7.0 - 7.5**	**7.5 - 8.0**	**8.0 - 8.5**	**8.5 - 9.0**	**9.0 - 9.5**
4.00 - 4.50	A1										
4.50 - 5.00											
5.00 - 5.50											
5.50 - 6.00	B1										
6.00 - 6.50	A2, A3, B2								R1-4		
6.50 - 7.00	B3	D3	C1							R1-1	
7.00 - 7.50		C3, R1-3, R1-6, R1-9	C2	R1-5, R1-8	R1-17						
7.50 - 8.00		R1-14		D2	D1						
8.00 - 8.50				R1-2	R1-18		R1-7				
8.50 - 9.00	R1-15						R1-16	R1-12			
9.00 - 9.50											
9.50 - 10.00											
10.00 - 10.50											
10.50 - 11.00											R1-13
11.00 - 11.50										R1-11	R1-10

ECO-FRIENDLY MIXES (white)
ACCEPTABLE MIXES (light grey)
NON-ECO-FRIENDLY MIXES (dark grey)

A	SERIES 250 KG/M³	1	CM
B	SERIES 275 KG/M³	2	SF5
C	SERIES 350 KG/M³	3	SF10
D	SERIES 400 KG/M³		

From Table 4.19, with comparison with other research, most mixes conducted from this research were eco-friendly mixes. Eco-friendly as defined by the Environmental Council of Concrete Organization, 2006, as something that is doing good to the environment not giving any negative effects. In this research, the efficiency table is produced by taking into consideration the cement consumption and the cost of produced concrete. The tables were used as standards of determination where the objective is to have less cement as possible in the produced concrete with maintained high strength. These mixes fulfilled the criterias of being the most effective in cost and low in cement consumption during production.

As mentioned, comparisons were done with other researchers in both conditions based on the approximate same amount of cement content used in their mixes and the approximate similar compressive strength of 28 days. Table 4.20 showed the results of 100% OPC comparison and was illustrated in Figure 4.26 while Table 4.21 showed the results of 100% OPC, 5% SF and 10% SF comparison, illustrated in Figure 4.27.

Table 4.20: 100% OPC Comparisons

Mix Samples	**Cement Content (kg/m^3)**	**Cement Consumption ($kg/m^3/MPa$)**
Current Research LT (Laboratory Test, 2010)	**A - 250 kg/m^3**	4.02
	B - 275 kg/m^3	4.34
	C - 350 kg/m^3	5.20
	D - 400 kg/m^3	5.80
R1 (M.G. Alexander & B.J. Magee, 1999)	**A - 265 kg/m^3**	5.96
	B - 315 kg/m^3	5.53
	C - 360 kg/m^3	5.63
R2 (G.C. Isaia *et.al.*, 2003)	**A - 367 kg/m^3**	6.17
	B - 428 kg/m^3	6.05
	C - 367 kg/m^3	6.17
R3 (J. Lindgard & S. Smeplass, 1992)	**A - 648 kg/m^3**	9.83
	B - 455 kg/m^3	5.75
	C - 586 kg/m^3	6.87
R4 (F. de-Larrard & R.LeRoy, 1992)	**A - 426 kg/m^3**	6.34
	B - 412 kg/m^3	5.52
	C - 422 kg/m^3	4.52
R5 (G.G. Carette & V.M. Malhotra, 1992)	**A - 410 kg/m^3**	7.26
	B - 524 kg/m^3	7.90
	C - 478 kg/m^3	5.67

Figure 4.26 showed that mixes conducted in this research consumed less cement compared to other researchers. Research mixes saved approximately 25% of cement consumption during production. With reduced cement content, high strength in concrete has achieved compared with other researchers who used more cement to achieve the required high strength.

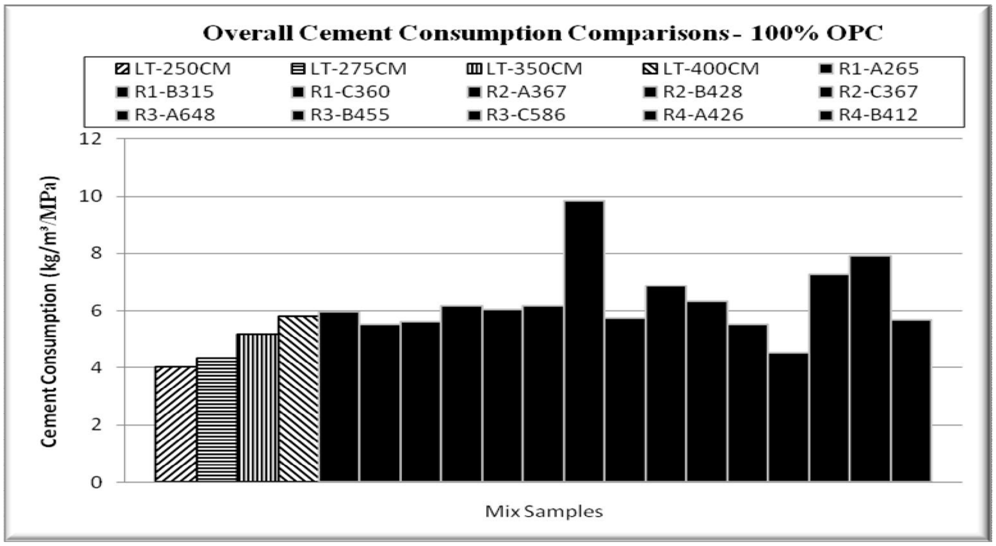

Figure 4.26: Overall Cement Consumption Comparisons – 100% OPC

Table 4.21: 100% OPC, 5%SF and 10% SF Comparisons

Mix Samples	Cement Content (kg/m³)	Cement Consumption (kg/m³/MPa)
Current Research LT (Laboratory Test, 2010)	**250 kg/m³**	4.03
		4.02
		4.01
	275 kg/m³	4.40
		4.34
		4.32
	350 kg/m³	5.42
		5.20
		4.95
	400 kg/m³	6.32
		5.80
		4.70
R1 (M.G. Alexander & B.J. Magee, 1999)	**265 kg/m³**	8.55
		5.96
		4.73
R2 (M.G. Alexander & B.J. Magee, 1999)	**315 kg/m³**	8.08
		5.53
		4.70
R3 (M.G. Alexander & B.J. Magee, 1999)	**360 kg/m³**	7.06
		5.63
		4.80
R4 (G.G. Carette & V.M. Malhotra, 1992)	**410 kg/m³**	9.00
		8.56
		7.70
R5 (W. Baalbaki *et.al*, 1992)	**450 kg/m³**	9.06
		6.20
		5.50
R6 (G.G. Carette & V.M. Malhotra, 1992)	**480 kg/m³**	7.24
		6.50
		5.87

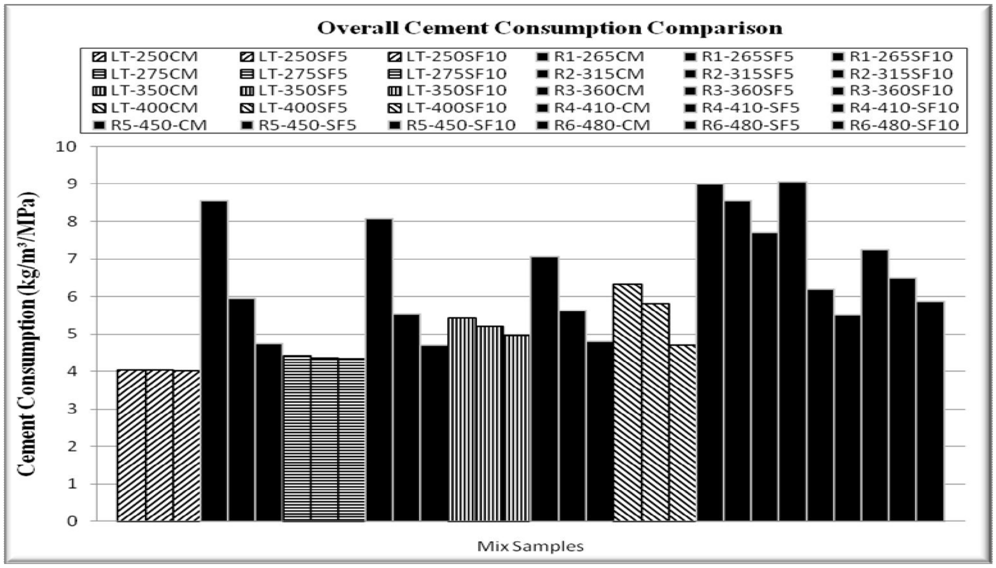

Figure 4.27: Cement Consumption Comparisons – 100% OPC, 5% SF and 10% SF

Figure 4.32 showed that mixes in this research consumed less cement compared to other researchers. Research mixes saved approximately 60% of cement consumption during production. With reduced cement content, high strength in concrete has achieved compared with other researchers who used more cement to achieve the required high strength.

Cement content was not the main contribution to high strength in concrete but also depended on the aggregates and SF addition. With the addition of SF into the concrete mixes, as much as 20% of OPC was saved from consumption for this research.

4.4.1.1 Cement Efficiency in Mix Series

The cement efficiency (kg/m³/MPa) were arranged and compared in Table 4.22. The results were illustrated in Figure 4.28.

Table 4.22: Cement Efficiency (kg/m³/MPa) Comparisons

Compressive Strength 28 Days (MPa)	**Research**					
	LT	**R1**	**R2**	**R3**	**R4**	**R5**
	Feasibilty (kg/m³/MPa)					
60-70	4.30	4.73	6.20	6.34	7.26	9.83
70-80	4.95	4.70	6.05	5.52	7.90	5.75
80-90	4.70	4.80	4.85	4.52	5.67	6.87

Legends

LT	Current Research (2010)
R1	M.G. Alexander & B.J. Magee (1999)
R2	G.C. Isaia et.al (2001)
R3	F. de-Larrard & R. LeRoy (1992)
R4	G.G. Carrette & V.M. Malhotra (1992)
R5	J. Lingard & S. Smeplass (1992)

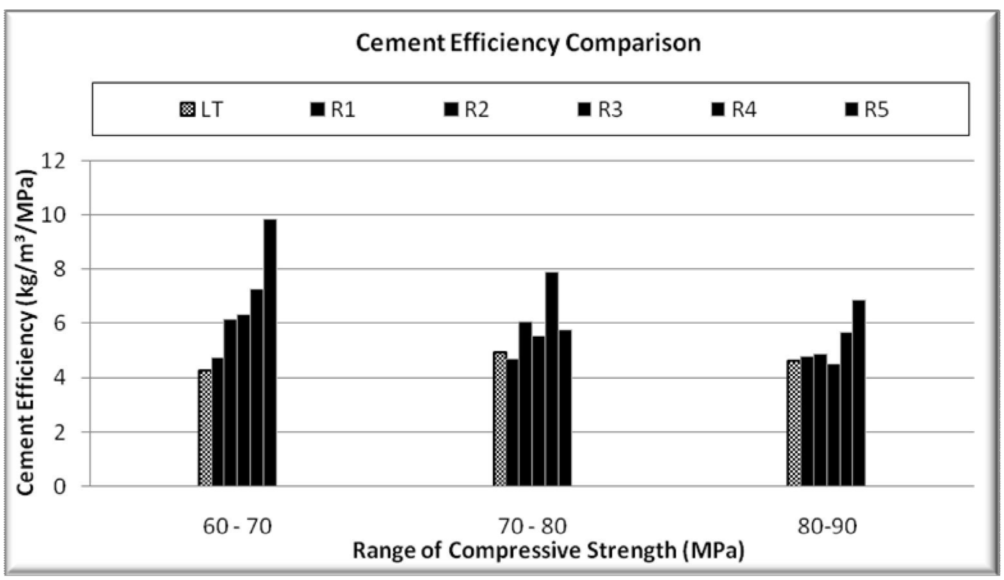

Figure 4.28: Cement Efficiency (kg/m³/MPa) Comparisons

In Figure 4.28, the cement efficiency of the research mixes were low. This was so as less cement was used. The amount of cement consumed were the lowest compared to other researchers. High cement efficiency results in low cement consumption in production. Concrete mixtures are to be modified to achieve less porosity, reduced cracking potentials and increased strength. The handling characteristics and workability are to be maintained (Narotam *et.al*, 2003). Thus, with reduced cement content, research mixes has achieved high compressive strength within the range of 60MPa to 90MPa.

4.4.2. Economic Considerations (Cost Analysis)

The economic consideration is very important so that time and money can be save catering for fast pace construction. The results were obtained from simple calculations and were arranged in Table 4.23. The cost was compared in terms of 3 compressive strength ranges that were 60-70 MPa, 70-80 MPa and 80-90 MPa.

Comparisons are made with other research based on approximate similar compressive strength of 28 days and cement content as well as the cement replacing material used, SF. The results are as shown from Figure 4.34. Figure 4.35 displayed the overall cost effectiveness of the research with other researchers.

Table 4.23: Cost Effectiveness between cost and compressive strength (RM/MPa)

Mix Series	LT - 250	LT - 275	LT - 350	R1 - 265	R1 - 315	R1 - 360
Mix Samples	LT -1	LT-2	LT -3	R1 - 1	R1-2	R1-3
100 % OPC	4.11	5.93	7.05	6.64	6.13	8.40
5 % SF	6.03	6.19	7.20	8.45	7.40	7.22
10 % SF	6.34	6.51	7.30	7.41	7.06	7.00
Mix Series	R2 - 367	R2 - 428	R2 - 367	R3 - 648	R3 - 455	R3 - 586
Mix Samples	R2-1	R2-2	R2-3	R3-1	R3-2	R3-3
100 % OPC	6.86	7.48	6.86	11.37	7.02	8.05
5 % SF	7.47	8.10	7.47	12.35	7.60	8.74
10 % SF	8.09	8.70	8.09	13.33	8.20	9.43
Mix Series	R4 - 426	R4 - 412	R4 - 422	R5 - 410	R5 - 524	R5 - 478
Mix Samples	R4-1	R4-2	R4-3	R5-1	R5-2	R5-3
100 % OPC	7.84	6.88	6.00	9.03	6.56	6.87
5 % SF	8.50	7.43	6.13	9.75	7.35	7.44
10 % SF	9.11	8.00	6.60	10.48	8.14	8.00
Legends	R1 - (M.G. Alexander & B.J. Magee, 1999) R2 - (G.C. Isaia *et.al*., 2003)		R3 - (J. Lindgard & S. Smeplass, 1992) R4 - (F. de-Larrard & R. LeRoy1992)		R5 - (G.G. Carette & V.M. Malhotra, 1992)	

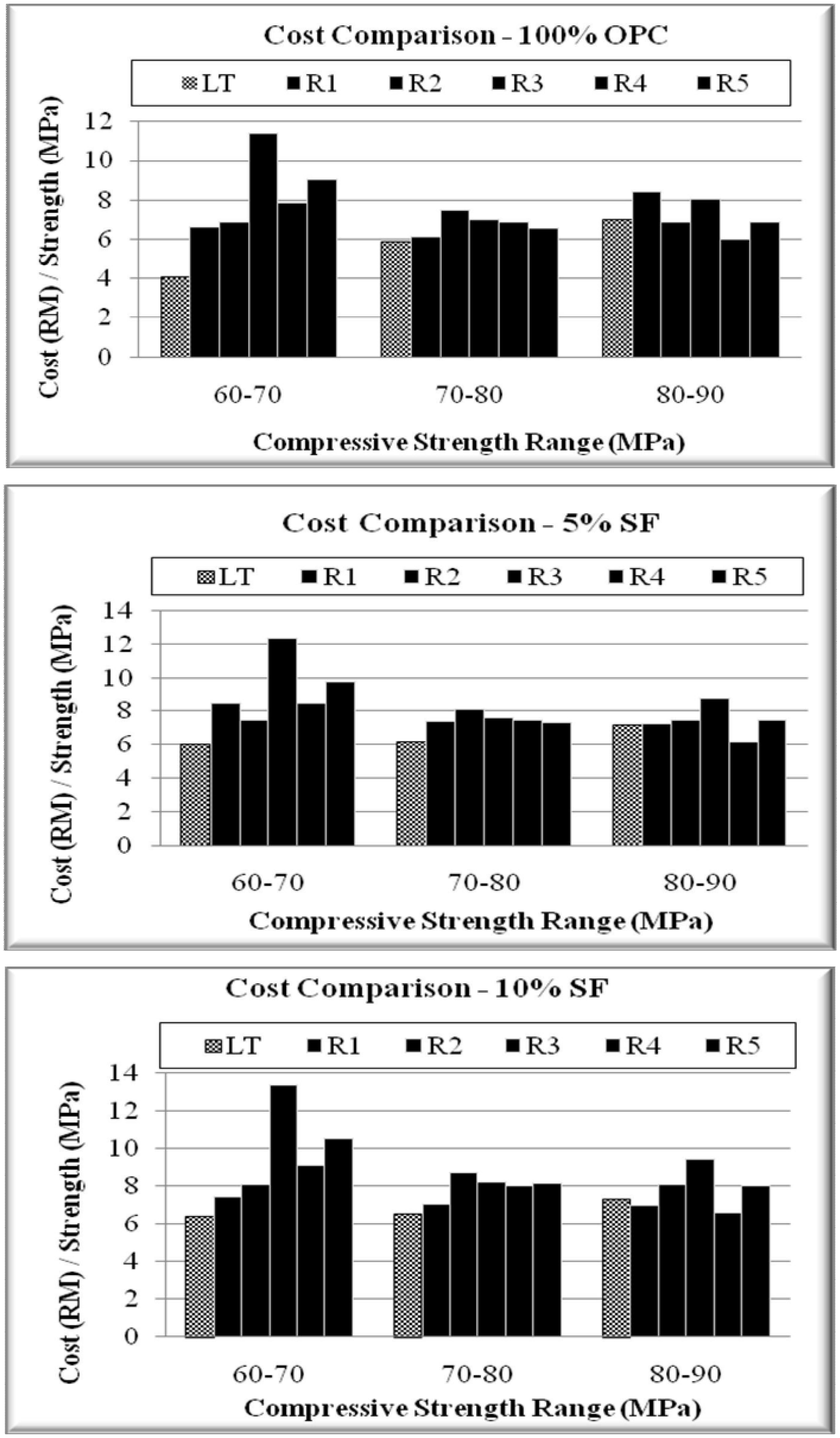

Figure 4.29: Cost Effectiveness (RM/MPa) Comparisons in Mix Series

In overall discussion, Figure 4.29, the range of the cost in every compressive strength, MPa, compared with other researchers was from RM4.00 to RM7.00. Research mixes saved about RM1.00 to RM8.00 in LT mixes, RM1.00 to RM7.00 in mixes with added 5% SF and RM2.00 to RM7.00 in mixes with added 10% SF. Each series has a percentage difference of 30%, 34% and 43%. High percentage values results in huge cost savings. Thus research mixes were very cost effective and feasible in construction applications.

This was so as materials used in this research were natural and locally available. This was proven by H.G. Russell (2000) where stated that the mix proportions for high performance to meet the specified performance criteria at a reasonable cost using locally available materials. The total cost of a produced and finished concrete material is more important than the cost of an individual material. Figure 4.30 showed the overall cost effectiveness of research mixes (LT) with comparisons to other researchers.

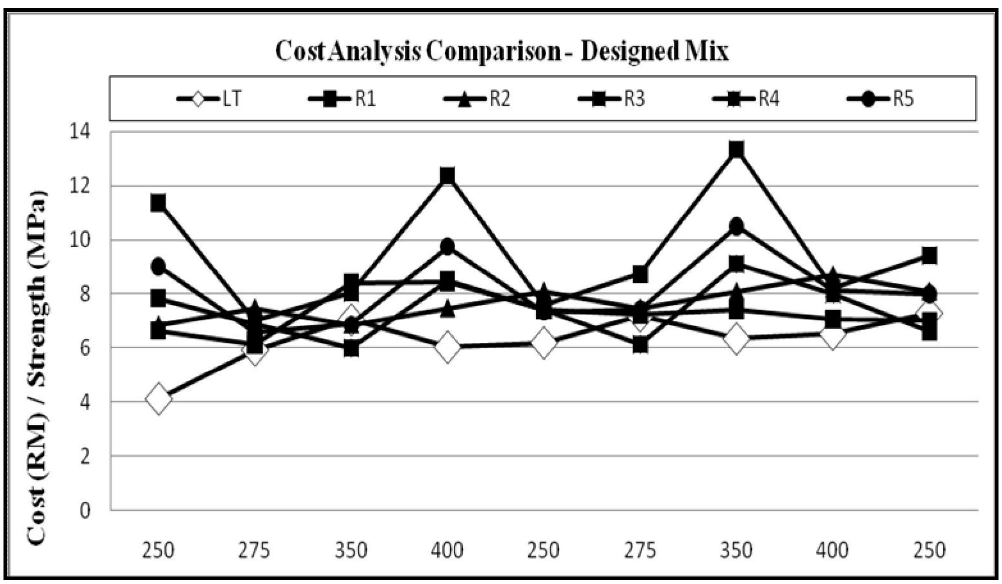

Figure 4.30: Overall Cost Effectiveness (RM/MPa) Comparisons in Mix Series

4.4.3. Energy Consumption

The amount of energy consumed by the mixes during production were calculated. The standard energy table used can be referred in Appendix E. Comparisons with other research are also made to determine the energy efficiency of the mixes. The results were arranged in Table 4.24 and Figure 4.36 shows the efficiency of the amount of energy consumed.

Table 4.24: Energy Consumption Efficiency (kwh/tonne)

Mix Samples	**Cement Content**	**Energy Consumed (kwh/tonne)**
Current Research LT (Laboratory Test, 2010)	250 kg/m³	182
	275 kg/m³	196
	350 kg/m³	237
	400 kg/m³	238
R1 (M.G. Alexander & B.J. Magee, 1999)	265 kg/m³	191
	315 kg/m³	218
	360 kg/m³	243
R2 (G.C. Isaia *et.al*., 2003)	367 kg/m³	247
	428 kg/m³	280
	367 kg/m³	247
R3 (J. Lindgard & S. Smeplass, 1992)	648 kg/m³	400
	455 kg/m³	295
	586 kg/m³	367
R4 (F. de-Larrard & R. LeRoy, 1992)	426 kg/m³	279
	412 kg/m³	271
	422 kg/m³	277
R5 (G.G. Carette & V.M. Malhotra, 1992)	410 kg/m³	270
	524 kg/m³	333
	478 kg/m³	307

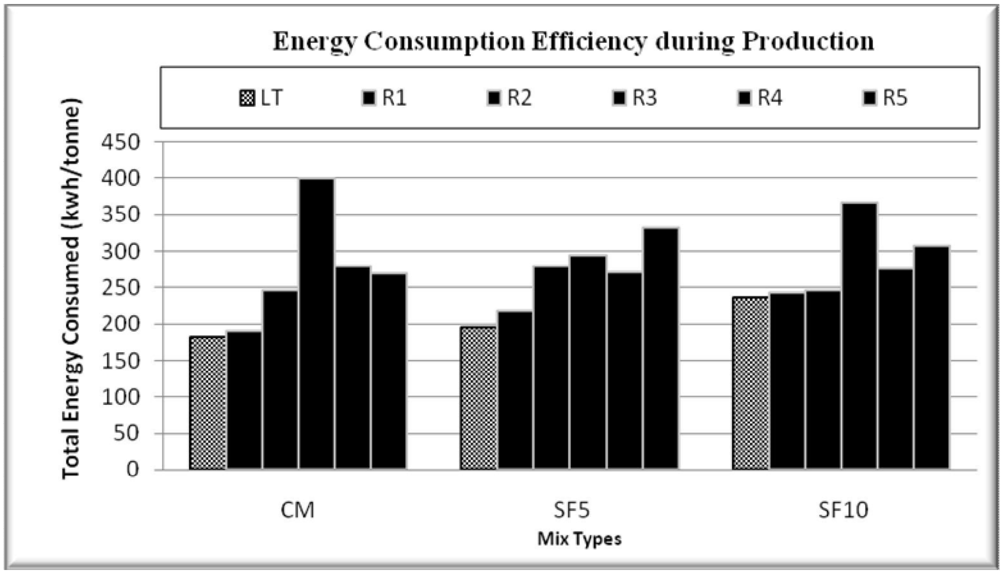

Figure 4.36: Energy Consumption Efficiency

From Figure 4.36, the energy consumed during production by LT were lower compared to other researchers. The increased amount of cement content in mixes consumed more energy during production. This was because more energy was required to create chemical reactions among particles in mixes. LT has saved 21% of energy if compared to R1, 15% from R2, 41% from R3, 15% from R4 and 30% from R5. Thus, LT is energy effective. LT consumed lower energy during production. With approximately same amount of cement used compared to other researchers, LT managed to achieve high strength. Thus cement is not the main contributor to concrete's high strength but also affected by aggregate gradings and SF content in the concrete mix. The addition of SF as CRM has helped in reduced energy consumption where it enhances the hydration of concrete with the added characteristic of the filler effects.

4.4.5. Carbon Dioxide (CO_2) Emissions.

The environmental impact is also another main consideration and it's emission into the atmosphere is a great concern to many parties. In this research, the amount of CO_2 emission is obtained based on the global understanding of 1 tonne of cement produced emits 1 tonne of CO_2 into the atmosphere. The amount of CO_2 is obtained for the three section tests:

1. Cubes (150 mm x150 mm x150 mm) – Compressive Strength Test
2. Cylinders (100 mm diameter, 200 mm Height), Cores (40 mm diameter)

   and Cubes (100 mm x 100 mm x 100 mm)

   (Tensile Test, Porosity Test and Chloride Migration Test)
3. Prisms (500 mm x 100 mm x 100 mm) – Modulus of Elasticity

Calculations were done from the worksheet in Appendix B, Appendix C and Appendix D created using the Microsoft Excel Software. The results are discussed in the following sub-sections. The percentage of CO_2 emission depends on the type of concrete samples tested from their volumes. This application is most useful in industrial practice where concrete were batched in large quantities.

4.4.5.1. Compressive Strength – Cube Test.

From calculations done from worksheet (Appendix A), this research saved 6% of CO_2 emission with comparison with R1 (M.G. Alexander & B.J. Magee, 1999), 25% with R2 (G.C. Isaia et.al, 2003), 48% with R3 (J. Lindgard & S. Smeplass, 1992), 31% with R4 (F. de-Larrard & R. LeRoy, 1992) and 38% with R5 (G.G. Carrette & V.M. Malhotra, 1992). The percentage values were high. This proved that concrete produced from research is eco-green and have high compressive strength in performance as shown in Table 4.25.

Table 4.25: Amount of CO_2 saved (%) - LT with other research (Cube Test)

Other Research	Amount of CO_2 saved (%) - LT with other research
R1	6
R2	25
R3	48
R4	31
R5	38

4.4.5.2. Potential Durability Performance.

From calculations done from worksheet (Appendix B), this research saved 21% of CO_2 emission with comparison with R1 (M.G. Alexander & B.J. Magee, 1999), 25% with R2 (G.C. Isaia et.al, 2003), 48% with R3 (J. Lindgard & S. Smeplass, 1992), 31% with R4 (F. de-Larrard & R. LeRoy, 1992) and 38% with R5 (G.G. Carrette & V.M. Malhotra, 1992). The percentage values were high. This proved that concrete produced from research is eco-green and is highly durable in performance in terms of porosity, tensile strength and chloride ion migration (marine environment) as shown in Table 4.26;

Table 4.26: Amount of CO_2 saved (%) - LT with other research (Durability Test)

Other Research	Amount of CO_2 saved (%) - LT with other research
R1	21
R2	25
R3	48
R4	31
R5	38

4.4.5.3. Modulus of Elasticity

From calculations done from worksheet (Appendix C), this research saved 6% of CO_2 emission with comparison with R1 (M.G. Alexander & B.J. Magee, 1999), 25% with R2 (G.C. Isaia *et.al*, 2003), 48% with R3 (J. Lindgard & S. Smeplass, 1992), 31% with R4 (F. de-Larrard & R. LeRoy, 1992) and 38% with R5 (G.G. Carrette & V.M. Malhotra, 1992). The percentage values were high. This proved that concrete produced from research is eco-green and is highly flexible in performance. High modulus of elasticity values provides stiffer structure which has less lateral deflection under wind loads (H. Russell, 1999) as shown in Table 4.27;

Table 4.27: Amount of CO_2 saved (%) - LT with other research (E-Modulus)

Other Research	Amount of CO_2 saved (%) - LT with other research
R1	6
R2	25
R3	48
R4	31
R5	38

4.4.5.4. Overall Discussions.

As discussed in previous sub-sections, concrete produced in research have saved huge amount of CO_2 emissions into the atmosphere. Thus concrete is ecological friendly and meets the demand of the society in terms of overcoming environmental crisis where the demand for less pollution in CO_2 emissions is critically required so to reduce the ease of carbon generation within concrete which is important to enhance durability (C.L. Narotam *et.al*, 2003). Concrete produced from research were ideal mix designs.

4. 5. Overall Chapter Discussion.

As an overall for this chapter, mix series samples have good performance in terms of compressive strength, porosity, tensile strength, chloride migration and modulus of elasticity. The mixing was also conducted in proper and no obvious as well as serious micro-cracks occurred during the time of curing and testing. Curing techniques and tests were conducted with accordance to the standard obtained in theory and real-site condition. HPC are specified today to have increased workability, high ultimate strength, high early strength, high durability and high modulus of elasticity (T. Holland, 2009)

The compressive strength results obtained from research were high and increased further after the 28 days age. High early strength was obviously shown by the concrete and the illustrations were illustrated in figures. The concrete's performance is determined by a combination of many factors, not only depending on the amount of OPC used and types of CRM but also the aggregates, well graded and finely distributed (C.L. Narotam *et.al*, 2003). Concrete compressive strength is closely related to the compactness of the hardened matrix (R. Feret, 1892). Thus, when compressive strength is limited by aggregates, the only way to get higher strength is to use well graded and finely distributed aggregates (P.C. Aitcin, 2003). Cement content is no more the major concern that affects the concrete strength and high early strength.

The concrete also have great performance in potential durability. It is low in porosity efficiency, high in tensile strength, low chloride ion penetration in both urban and marine environment and high modulus of elasticity. To tackle for economic, energy crisis and environmental concerns, the mix designs were cost effective, energy efficient, and eco-friendly. According to A.M. Fouzi and B. Mouloud (2007), more slender structural elements, more audacious designs and the service life for HPC should exceed that of ordinary concrete in the same environment are very critically in demand.

The addition of SF has contributed greatly to the early compressive strength and the strength development in concrete. SF played the role as an ideal CRM. CRM working with OPC improves strength and durability when added during mixing. Reduction of CO_2 by 70% is possible with CRM typical usage values ranging between 15% and 40% (M.A. Iyad *et.al*, 1997). For each concrete strength level, there is an optimum size for the aggregates that will yield the greatest compressive strength per unit mass of cement. A smaller size aggregate will result in higher compressive strength of concrete. The use of largest possible coarse aggregate size is important in increasing the modulus of elasticity (H.G. Russell, 2000)

Worksheets were produced using the Microsoft Excel Software. This is to ease designers in calculations during production (custom or industrial). K. Day (1993) mentioned that laboratory trial mixes may be very useful but for some purposes, computerization is really required in major ready-mix organization as there are hundreds of mixes in dozens of plants with many alternative materials.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

For this research study, the principal objectives were focused to obtain high compressive strength of 28 days age (50MPa – 80MPa), high performance and 'eco-green' concrete for the future construction industry. Well graded and finely distributed aggregates with reduced cement content were the main considerations to achieve the principal objective. In view of this, a detail experimental program was designed and the results as obtained were discussed for the different behavior of concrete that incorporated SF of different dosages which also acts as the cement replacing material (CRM). It was then compared with the behavior of normal conventional concrete mixes which were the control mixes (CM). Later, the cost effectiveness, energy efficiency during production and CO_2 emissions were determined. Based on results and discussions, the following conclusions were drawn;

1. Chemical compositions of OPC and SF obtained were similar to the chemical compositions of the control mixes. There were no hazardous and/or detrimental products such as chloride, heavy metals and excessive alkalis were traced.

2. Well graded and finely distributed aggregates in concrete mixes (good aggregate gradings) were the main objective This was well shown in the 'Designed' mixes and 'As-supplied' mixes. The British Standard (BS) was used as the basic for the mix design proportions. The coarse aggregates were not changed in proportions as the objective specified well graded and finely distributed aggregates for this investigation. The sizes of the coarse

aggregates used were standard 20mm diameter maximum from the same aggregate source.

3. The compressive strength of concrete produced was determined by a fix water cementatious ratio and a constant amount of superplasticizer (SP) was used throughout this investigation. The slump was fixed in the range of 40mm – 70mm. The compressive strength achieved by the ‘Designed’ mixes were 20% and is better than the ‘As-supplied’ mixes when compared to CM in every mix series. With the addition of SF, at 28 days age compressive strength achieved by SF5 was approximately 16% - 40% higher and 12% -50% higher in SF10. After the 28 days age, 5% - 10% of strength increment was obvious especially with the addition of SF.

4. The high early strength of 3 and 7 days age achieved were 5%-10% higher with comparison with the CM mixes in every mix series. At 3 days age, SF5 and SF10 mixes achieved compressive strength of more than 40MPa. The research has fulfilled the main objective in obtaining high strength high performance concrete between strength of 50MPa – 80MPa. The application of well graded and finely distributed aggregates with reduced cement content and SF as CRM and additive had contributed well throughout this investigation.

5. The total porosity development of concrete in both mixes was ideal. The porosity development reduced with age. Between both mixes, ‘Designed’ mixes performed better 2%-10% in CM. With SF added, porosity reduced by 3%-4% for both mixes. Low porosity is better as it will increase concrete’s durability. Thus, ‘Designed’ mixes performed better than ‘As- supplied’ mixes in reduced cement content condition and also in well graded and finely distributed aggregates condition.

6. Tensile strength achieved by 'Designed' mixes was 20% higher in CM, 30%-35% higher in SF5 and 52% - 72% higher in SF10 in every mix series. High tensile strength values were obtained in 28 days age where almost all values were more than 2MPa. The concrete produced by research has high chance of resistance against cracking.

7. Besides taking into consideration the urban construction, the marine environment was also considered to cater for research flexibility and reliability. Concrete produced by research has high durability against chloride ion penetration. Maximum increase of 20% which is 15mm penetration was obtained throughout the investigation. This showed slow rate of penetration depth of chloride in concrete. The 'Designed' mixes performed better 5% - 20% than the 'As-supplied' mixes. With SF added, the rate of chloride ion penetration into concrete after 28 days slowed down. This proved that cement content was not the main contribution to high durability. High durability also depended on the well graded and finely distributed aggregates of the mix proportions. Research is flexible in the marine environment.

8. The Modulus of Elasticity achieved by 'Designed' mixes was 5%-20% better than the 'As-supplied' mixes in CM mixes. When 5% SF was added, 'Designed' mixes achieved 5%-40% higher than 'As-supplied' mixes. With 10% addition of SF the modulus values of 'Designed' mixes increased greatly as much as 5%-60% compared to 'As-supplied' mixes. . Concrete produced from research is good in compression, high resistance to deformation but very poor in tension condition as tension values obtained from machine were low.

9. From the development of the potential durability and strength achievements of the 2 main mix designs; ‘Designed’ mixes and ‘As-supplied’ mixes, ‘Designed’ mixes were considered to be the ideal mix design. Thus, in terms of cost effectiveness, energy consumption during production and CO_2 emissions, with the assistance of worksheets produced, concrete produced from research saved approximately RM8/m^3 in CM mixes and approximately RM7/m^3 in mixes with added SF with comparison with other research. There was also energy saving during production as much as 15%-41% and reduces CO_2 emissions by approximately 50% compared with the standard global CO_2 emission statistics.

10. The Matrix Efficiency Chart and Worksheets created from simple programming knowledge was utilized to conduct the analysis of this investigation. They were created to ease the designers in calculating structural designs. This is also another effort not to loose the engineering and structural behavior of concrete produced where it is to be high strength, high performance, high durability and ‘eco-green’. (Refer to Appendices).

11. As an overall, the optimum mix proportion that was obtained from this research was based on the compressive strength and SF addition which also acts as the CRM in mix samples. It comprises of

Mix Type	:	‘Designed’ aggregate mixes
OPC TYPE 1	:	250 kg/m^3
Silica Fume (SF)	:	25 kg/m^3
Water	:	113 kg/m^3
Fine Aggregates	:	860 kg/m^3
Coarse Aggregates	:	1290 kg/m^3
w/c	:	0.50

12. It is recommended that in further investigations in this area to continue in order to investigate in detail the potential of this research. The future recommendations are as below:

- The research could include detail investigation of micro-cracks effects, Loadings in different conditions effects and thermal as well as surface permeability effects of High Performance Eco-Green concrete in four climate seasons and fire conditions.

- The research should be conducted in detailing effects with SF as a major role in being the ideal CRM in concrete mixes.

- Application of various types of other technologies should be applied such as aerospace and Nanotechnology in terms of changing the material properties for better production of concrete.

- Simple computer models and fun worksheets should be introduced for portability and mobility.

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APPENDIX A

AMOUNT OF OPC AND CO_2 EMISSION SAVED FROM RESEARCH (COMPRESSIVE STRENGTH)

R1: M.G. Alexander and B.J. Magee (1999).

THE DEVELOPMENT OF HIGH PERFORMANCE ECO-GREEN CONCRETE MIXES

Cement Consumption cum Carbon Dioxide (CO2) Emission Calculation Worksheet

Prepared by : Foong Kah Yen (Cheryl) Checked by : Assoc.Prof. Dr. Nasir Shafiq July 2009

Welcome !!! Welcome !!!

START CALCULATING YOUR CO2 EMISSION & SEE HOW MUCH YOU CAN SAVE

Step 1 : Enter mix sample volumes.

Volume of mix samples (Enter Value) 0.00338 m³

Step 2 : Enter Research Cement Consumption

		Enter cement consumed				
Cement Consumed in Research	1	250	kg/m³	=	0.85	kg
	2	275	kg/m³	=	0.93	kg
	3	350	kg/m³	=	1.18	kg
	4	400	kg/m³	=	1.35	kg
Cement Consumed in Other Research	1	265	kg/m³	=	0.90	kg
	2	315	kg/m³	=	1.06	kg
	3	360	kg/m³	=	1.22	kg
	4	410	kg/m³	=	1.39	kg

Step 3 : Enter values to determine no. of samples for every series

No. of testing days for mix samples	(Enter Value)	=	4	days
No. of mix samples required for each testing days	(Enter Value)	=	3	mixes
	TOTAL	=	**12**	samples
No. of sets for each series	(Enter Value)	=	3	series
	TOTAL	=	**36**	samples for every series

Total Cement Consumed in each Mix Series / **Converting kg to Tonne**

	kg	kg		Tonne	Tonne
1	30.42	32.25	1	0.03	0.03
2	33.46	38.33	2	0.03	0.04
3	42.59	43.80	3	0.04	0.04
4	48.67	49.89	4	0.05	0.05

Your Cement Consumption & Carbon Dioxide Emission are discovered !!! The Values are as shown:

	Tonne	Tonne		kg	kg
1	0.030	0.03	1	30.42	32.25
2	0.033	0.04	2	33.46	38.33
3	0.043	0.04	3	42.59	43.80
4	0.049	0.05	4	48.67	49.89

The total cement consumed & CO_2 emission from Research Study : 155.14 **kg**

The total cement consumed & CO_2 emission from Other Research : 164.27 **kg**

% Difference >>> **5.56** %

CONGRATULATIONS !!!! CONGRATULATIONS !!!

You have helped to save cement consumption & CO2 emission by >> **6** **%**

HAPPY SAVING & HAVE A GREAT DAY !!! :):)

R2: Isaia *et.al* (2003).

THE DEVELOPMENT OF HIGH PERFORMANCE ECO-GREEN CONCRETE MIXES

Cement Consumption cum Carbon Dioxide (CO2) Emission Calculation Worksheet

Prepared by : Foong Kah Yen (Cheryl) Checked by : Assoc.Prof. Dr. Nasir Shafiq July 2009

Welcome !!! Welcome !!!

START CALCULATING YOUR CO2 EMISSION & SEE HOW MUCH YOU CAN SAVE

Step 1 : Enter mix sample volumes.

Volume of mix samples (Enter Value) 0.00338 m³

Step 2 : Enter Research Cement Consumption

		Enter cement consumed				
Cement Consumed in Research	1	250	kg/m³	=	0.85	kg
	2	275	kg/m³	=	0.93	kg
	3	350	kg/m³	=	1.18	kg
	4	400	kg/m³	=	1.35	kg
Cement Consumed in Other Research	1	367	kg/m³	=	1.24	kg
	2	428	kg/m³	=	1.45	kg
	3	367	kg/m³	=	1.24	kg
	4	545	kg/m³	=	1.84	kg

Step 3 : Enter values to determine no. of samples for every series

No. of testing days for mix samples	(Enter Value)	=	4	days
No. of mix samples required for each testing days	(Enter Value)	=	3	mixes
	TOTAL	=	**12**	samples
No. of sets for each series	(Enter Value)	=	3	series
	TOTAL	=	**36**	samples for every series

Total Cement Consumed in each Mix Series / **Converting kg to Tonne**

	kg	kg		Tonne	Tonne
1	30.42	44.66	1	0.03	0.04
2	33.46	52.08	2	0.03	0.05
3	42.59	44.66	3	0.04	0.04
4	48.67	66.32	4	0.05	0.07

Your Cement Consumption & Carbon Dioxide Emission are discovered !!! The Values are as shown:

	Tonne	Tonne		kg	kg
1	0.030	0.04	1	30.42	44.66
2	0.033	0.05	2	33.46	52.08
3	0.043	0.04	3	42.59	44.66
4	0.049	0.07	4	48.67	66.32

The total cement consumed & CO_2 emission from Research Study : 155.14 **kg**

The total cement consumed & CO_2 emission from Other Research : 207.71 **kg**

% Difference >>> 25.31 %

CONGRATULATIONS !!!! CONGRATULATIONS !!!

You have helped to save cement consumption & CO2 emission by >> **25 %**

HAPPY SAVING & HAVE A GREAT DAY !!! :):)

R3: J. Lindgard and S. Smeplass (1992).

UNIVERSITI TEKNOLOGI PETRONAS

THE DEVELOPMENT OF HIGH PERFORMANCE ECO-GREEN CONCRETE MIXES

Cement Consumption cum Carbon Dioxide (CO2) Emission Calculation Worksheet

Prepared by : Foong Kah Yen (Cheryl) Checked by : Assoc.Prof. Dr. Nasir Shafiq July 2009

Welcome !!! Welcome !!!

START CALCULATING YOUR CO2 EMISSION & SEE HOW MUCH YOU CAN SAVE

Step 1 : Enter mix sample volumes.

Volume of mix samples (Enter Value) 0.00338 m³

Step 2 : Enter Research Cement Consumption

		Enter cement consumed				
Cement Consumed in Research	1	250	kg/m³	=	0.85	kg
	2	275	kg/m³	=	0.93	kg
	3	350	kg/m³	=	1.18	kg
	4	400	kg/m³	=	1.35	kg
Cement Consumed in Other Research	1	455	kg/m³	=	1.54	kg
	2	586	kg/m³	=	1.98	kg
	3	648	kg/m³	=	2.19	kg
	4	750	kg/m³	=	2.54	kg

Step 3 : Enter values to determine no. of samples for every series

No. of testing days for mix samples	(Enter Value)	=	4	days
No. of mix samples required for each testing days	(Enter Value)	=	3	mixes
	TOTAL	=	**12**	samples
No. of sets for each series	(Enter Value)	=	3	series
	TOTAL	=	**36**	samples for every series

Total Cement Consumed in each Mix Series / **Converting kg to Tonne**

	kg	kg		Tonne	Tonne
1	30.42	55.36	1	0.03	0.06
2	33.46	71.30	2	0.03	0.07
3	42.59	78.85	3	0.04	0.08
4	48.67	91.26	4	0.05	0.09

Your Cement Consumption & Carbon Dioxide Emission are discovered !!! The Values are as shown:

	Tonne	Tonne		kg	kg
1	0.030	0.06	1	30.42	55.36
2	0.033	0.07	2	33.46	71.30
3	0.043	0.08	3	42.59	78.85
4	0.049	0.09	4	48.67	91.26

The total cement consumed & CO_2 emission from Research Study : 155.14 **kg**

The total cement consumed & CO_2 emission from Other Research : 296.78 **kg**

% Difference >>> 47.72 %

CONGRATULATIONS !!!! CONGRATULATIONS !!!

You have helped to save cement consumption & CO2 emission by >> **48** **%**

HAPPY SAVING & HAVE A GREAT DAY !!! :):)

R4: F. de-Larrard and R. Le-Roy (1992).

UNIVERSITI TEKNOLOGI PETRONAS

THE DEVELOPMENT OF HIGH PERFORMANCE ECO-GREEN CONCRETE MIXES

Cement Consumption cum Carbon Dioxide (CO_2) Emission Calculation Worksheet

Prepared by : Foong Kah Yen (Cheryl) Checked by : Assoc.Prof. Dr. Nasir Shafiq July 2009

Welcome !!! Welcome !!!

START CALCULATING YOUR CO2 EMISSION & SEE HOW MUCH YOU CAN SAVE

Step 1 : Enter mix sample volumes.

Volume of mix samples (Enter Value) 0.00338 m³

Step 2 : Enter Research Cement Consumption

		Enter cement consumed				
Cement Consumed in Research	1	250	kg/m³	=	0.85	kg
	2	275	kg/m³	=	0.93	kg
	3	350	kg/m³	=	1.18	kg
	4	400	kg/m³	=	1.35	kg
Cement Consumed in Other Research	1	412	kg/m³	=	1.39	kg
	2	422	kg/m³	=	1.43	kg
	3	426	kg/m³	=	1.44	kg
	4	600	kg/m³	=	2.03	kg

Step 3 : Enter values to determine no. of samples for every series

No. of testing days for mix samples	(Enter Value)	=	4	days
No. of mix samples required for each testing days	(Enter Value)	=	3	mixes
	TOTAL	=	**12**	samples
No. of sets for each series	(Enter Value)	=	3	series
	TOTAL	=	**36**	samples for every series

Total Cement Consumed in each Mix Series / **Converting kg to Tonne**

	kg	kg		Tonne	Tonne
1	30.42	50.13	1	0.03	0.05
2	33.46	51.35	2	0.03	0.05
3	42.59	51.84	3	0.04	0.05
4	48.67	73.01	4	0.05	0.07

Your Cement Consumption & Carbon Dioxide Emission are discovered !!! The Values are as shown:

	Tonne	Tonne		kg	kg
1	0.030	0.05	1	30.42	50.13
2	0.033	0.05	2	33.46	51.35
3	0.043	0.05	3	42.59	51.84
4	0.049	0.07	4	48.67	73.01

The total cement consumed & CO_2 emission from Research Study : 155.14 **kg**

The total cement consumed & CO_2 emission from Other Research : 226.32 **kg**

% Difference >>> 31.45 %

CONGRATULATIONS !!!! CONGRATULATIONS !!!

You have helped to save cement consumption & CO2 emission by >> **31 %**

HAPPY SAVING & HAVE A GREAT DAY !!! :):)

R5: G.G. Carette and V.M. Malhotra (1992).

THE DEVELOPMENT OF HIGH PERFORMANCE ECO-GREEN CONCRETE MIXES

Cement Consumption cum Carbon Dioxide (CO2) Emission Calculation Worksheet

Prepared by : Foong Kah Yen (Cheryl) Checked by : Assoc.Prof. Dr. Nasir Shafiq July 2009

Welcome !!! Welcome !!!

START CALCULATING YOUR CO2 EMISSION & SEE HOW MUCH YOU CAN SAVE

Step 1 : Enter mix sample volumes.

Volume of mix samples (Enter Value) 0.00338 m³

Step 2 : Enter Research Cement Consumption

		Enter cement consumed				
Cement Consumed in Research	1	250	kg/m³	=	0.85	kg
	2	275	kg/m³	=	0.93	kg
	3	350	kg/m³	=	1.18	kg
	4	400	kg/m³	=	1.35	kg
Cement Consumed in Other Research	1	410	kg/m³	=	1.39	kg
	2	478	kg/m³	=	1.62	kg
	3	524	kg/m³	=	1.77	kg
	4	650	kg/m³	=	2.20	kg

Step 3 : Enter values to determine no. of samples for every series

No. of testing days for mix samples	(Enter Value)	=	4	days
No. of mix samples required for each testing days	(Enter Value)	=	3	mixes
	TOTAL	=	**12**	samples
No. of sets for each series	(Enter Value)	=	3	series
	TOTAL	=	**36**	samples for every series

Total Cement Consumed in each Mix Series / **Converting kg to Tonne**

	kg	kg		Tonne	Tonne
1	30.42	49.89	1	0.03	0.05
2	33.46	58.16	2	0.03	0.06
3	42.59	63.76	3	0.04	0.06
4	48.67	79.09	4	0.05	0.08

Your Cement Consumption & Carbon Dioxide Emission are discovered !!! The Values are as shown:

	Tonne	Tonne		kg	kg
1	0.030	0.05	1	30.42	49.89
2	0.033	0.06	2	33.46	58.16
3	0.043	0.06	3	42.59	63.76
4	0.049	0.08	4	48.67	79.09

The total cement consumed & CO_2 emission from Research Study : 155.14 **kg**

The total cement consumed & CO_2 emission from Other Research : 250.90 **kg**

% Difference >>> 38.17 %

CONGRATULATIONS !!!! CONGRATULATIONS !!!

You have helped to save cement consumption & CO2 emission by >> **38** **%**

HAPPY SAVING & HAVE A GREAT DAY !!! :):)

APPENDIX B

AMOUNT OF OPC AND CO_2 EMISSION SAVED FROM RESEARCH (POTENTIAL DURABILTY PERFORMANCE)

R1: M.G. Alexander and B.J. Magee (1999).

THE DEVELOPMENT OF HIGH PERFORMANCE ECO-GREEN CONCRETE MIXES

Cement Consumption cum Carbon Dioxide (CO2) Emission Calculation Worksheet

Prepared by : Foong Kah Yen (Cheryl) Checked by : Assoc.Prof. Dr. Nasir Shafiq July 2009

Welcome !!! Welcome !!!

START CALCULATING YOUR CO2 EMISSION & SEE HOW MUCH YOU CAN SAVE

Step 1 : Enter mix sample volumes.

Volume of mix samples (Enter Value) 0.007 m³

Step 2 : Enter Research Cement Consumption

		Enter cement consumed				
Cement Consumed in Research	1	250	kg/m³	=	1.75	kg
	2	275	kg/m³	=	1.93	kg
	3	350	kg/m³	=	2.45	kg
	4	400	kg/m³	=	2.80	kg
Cement Consumed in Other Research	1	265	kg/m³	=	1.86	kg
	2	315	kg/m³	=	2.21	kg
	3	360	kg/m³	=	2.52	kg
	4	680	kg/m³	=	4.76	kg

Step 3 : Enter values to determine no. of samples for every series

No. of testing days for mix samples	(Enter Value)	=	3	days
No. of mix samples required for each testing days	(Enter Value)	=	3	mixes
	TOTAL	=	**9**	samples
No. of sets for each series	(Enter Value)	=	3	series
	TOTAL	=	**27**	samples for every series

Total Cement Consumed in each Mix Series / **Converting kg to Tonne**

	kg	kg		Tonne	Tonne
1	47.25	50.09	1	0.05	0.05
2	51.98	59.54	2	0.05	0.06
3	66.15	68.04	3	0.07	0.07
4	75.60	128.52	4	0.08	0.13

Your Cement Consumption & Carbon Dioxide Emission are discovered !!! The Values are as shown:

	Tonne	Tonne		kg	kg
1	0.047	0.05	1	47.25	50.09
2	0.052	0.06	2	51.98	59.54
3	0.066	0.07	3	66.15	68.04
4	0.076	0.13	4	75.60	128.52

The total cement consumed & CO_2 emission from Research Study : 240.98 **kg**

The total cement consumed & CO_2 emission from Other Research : 306.18 **kg**

% Difference >>> 21.30 %

CONGRATULATIONS !!!! CONGRATULATIONS !!!

You have helped to save cement consumption & CO2 emission by >> **21** %

HAPPY SAVING & HAVE A GREAT DAY !!! :):)

R2: Isaia *et.al* (2003).

THE DEVELOPMENT OF HIGH PERFORMANCE ECO-GREEN CONCRETE MIXES

Cement Consumption cum Carbon Dioxide (CO_2) Emission Calculation Worksheet

Prepared by : Foong Kah Yen (Cheryl) Checked by : Assoc.Prof. Dr. Nasir Shafiq July 2009

Welcome !!! Welcome !!!

START CALCULATING YOUR CO2 EMISSION & SEE HOW MUCH YOU CAN SAVE

Step 1 : Enter mix sample volumes.

Volume of mix samples (Enter Value) 0.007 m³

Step 2 : Enter Research Cement Consumption

		Enter cement consumed				
Cement Consumed in Research	1	250	kg/m³	=	1.75	kg
	2	275	kg/m³	=	1.93	kg
	3	350	kg/m³	=	2.45	kg
	4	400	kg/m³	=	2.80	kg
Cement Consumed in Other Research	1	367	kg/m³	=	2.57	kg
	2	428	kg/m³	=	3.00	kg
	3	367	kg/m³	=	2.57	kg
	4	545	kg/m³	=	3.82	kg

Step 3 : Enter values to determine no. of samples for every series

No. of testing days for mix samples	(Enter Value)	=	3	days
No. of mix samples required for each testing days	(Enter Value)	=	3	mixes
	TOTAL	=	**9**	samples
No. of sets for each series	(Enter Value)	=	3	series
	TOTAL	=	**27**	samples for every series

Total Cement Consumed in each Mix Series / **Converting kg to Tonne**

	kg	kg		Tonne	Tonne
1	47.25	69.36	1	0.05	0.07
2	51.98	80.89	2	0.05	0.08
3	66.15	69.36	3	0.07	0.07
4	75.60	103.01	4	0.08	0.10

Your Cement Consumption & Carbon Dioxide Emission are discovered !!! The Values are as shown:

	Tonne	Tonne		kg	kg
1	0.047	0.07	1	47.25	69.36
2	0.052	0.08	2	51.98	80.89
3	0.066	0.07	3	66.15	69.36
4	0.076	0.10	4	75.60	103.01

The total cement consumed & CO_2 emission from Research Study : 240.98 **kg**

The total cement consumed & CO_2 emission from Other Research : 322.62 **kg**

% Difference >>> 25.31 %

CONGRATULATIONS !!!! CONGRATULATIONS !!!

You have helped to save cement consumption & CO2 emission by >> **25** **%**

HAPPY SAVING & HAVE A GREAT DAY !!! :):)

R3: J. Lindgard and S. Smeplass (1992).

THE DEVELOPMENT OF HIGH PERFORMANCE ECO-GREEN CONCRETE MIXES

Cement Consumption cum Carbon Dioxide (CO_2) Emission Calculation Worksheet

Prepared by : Foong Kah Yen (Cheryl) Checked by : Assoc.Prof. Dr. Nasir Shafiq July 2009

Welcome !!! Welcome !!!

START CALCULATING YOUR CO2 EMISSION & SEE HOW MUCH YOU CAN SAVE

Step 1 : Enter mix sample volumes.

Volume of mix samples (Enter Value) 0.007 m³

Step 2 : Enter Research Cement Consumption

	No.	Enter cement consumed	Unit		Result	Unit
Cement Consumed in Research	1	250	kg/m³	=	1.75	kg
	2	275	kg/m³	=	1.93	kg
	3	350	kg/m³	=	2.45	kg
	4	400	kg/m³	=	2.80	kg
Cement Consumed in Other Research	1	455	kg/m³	=	3.19	kg
	2	586	kg/m³	=	4.10	kg
	3	648	kg/m³	=	4.54	kg
	4	750	kg/m³	=	5.25	kg

Step 3 : Enter values to determine no. of samples for every series

No. of testing days for mix samples	(Enter Value)	=	3	days
No. of mix samples required for each testing days	(Enter Value)	=	3	mixes
	TOTAL	=	**9**	samples
No. of sets for each series	(Enter Value)	=	3	series
	TOTAL	=	**27**	samples for every series

Total Cement Consumed in each Mix Series / **Converting kg to Tonne**

	kg	kg		Tonne	Tonne
1	47.25	86.00	1	0.05	0.09
2	51.98	110.75	2	0.05	0.11
3	66.15	122.47	3	0.07	0.12
4	75.60	141.75	4	0.08	0.14

Your Cement Consumption & Carbon Dioxide Emission are discovered !!! The Values are as shown:

	Tonne	Tonne		kg	kg
1	0.047	0.09	1	47.25	86.00
2	0.052	0.11	2	51.98	110.75
3	0.066	0.12	3	66.15	122.47
4	0.076	0.14	4	75.60	141.75

The total cement consumed & CO_2 emission from Research Study : 240.98 **kg**

The total cement consumed & CO_2 emission from Other Research : 460.97 **kg**

% Difference >>> **47.72** %

CONGRATULATIONS !!!! CONGRATULATIONS !!!

You have helped to save cement consumption & CO2 emission by >> **48** **%**

HAPPY SAVING & HAVE A GREAT DAY !!! :):)

R4: F. de-Larrard and R. Le-Roy (1992).

THE DEVELOPMENT OF HIGH PERFORMANCE ECO-GREEN CONCRETE MIXES

UNIVERSITI TEKNOLOGI PETRONAS

Cement Consumption cum Carbon Dioxide (CO2) Emission Calculation Worksheet

Prepared by : Foong Kah Yen (Cheryl) Checked by : Assoc.Prof. Dr. Nasir Shafiq July 2009

Welcome !!! Welcome !!!

START CALCULATING YOUR CO2 EMISSION & SEE HOW MUCH YOU CAN SAVE

Step 1 : Enter mix sample volumes.

Volume of mix samples (Enter Value) 0.007 m³

Step 2 : Enter Research Cement Consumption

		Enter cement consumed				
Cement Consumed in Research	1	250	kg/m³	=	1.75	kg
	2	275	kg/m³	=	1.93	kg
	3	350	kg/m³	=	2.45	kg
	4	400	kg/m³	=	2.80	kg
Cement Consumed in Other Research	1	412	kg/m³	=	2.88	kg
	2	422	kg/m³	=	2.95	kg
	3	426	kg/m³	=	2.98	kg
	4	600	kg/m³	=	4.20	kg

Step 3 : Enter values to determine no. of samples for every series

No. of testing days for mix samples	(Enter Value)	=	3	days
No. of mix samples required for each testing days	(Enter Value)	=	3	mixes
	TOTAL	=	**9**	samples
No. of sets for each series	(Enter Value)	=	3	series
	TOTAL	=	**27**	samples for every series

Total Cement Consumed in each Mix Series / **Converting kg to Tonne**

	kg	kg		Tonne	Tonne
1	47.25	77.87	1	0.05	0.08
2	51.98	79.76	2	0.05	0.08
3	66.15	80.51	3	0.07	0.08
4	75.60	113.40	4	0.08	0.11

Your Cement Consumption & Carbon Dioxide Emission are discovered !!! The Values are as shown:

	Tonne	Tonne		kg	kg
1	0.047	0.08	1	47.25	77.87
2	0.052	0.08	2	51.98	79.76
3	0.066	0.08	3	66.15	80.51
4	0.076	0.11	4	75.60	113.40

The total cement consumed & CO_2 emission from Research Study : 240.98 **kg**

The total cement consumed & CO_2 emission from Other Research : 351.54 **kg**

% Difference >>> 31.45 %

CONGRATULATIONS !!!! CONGRATULATIONS !!!

You have helped to save cement consumption & CO2 emission by >> **31** **%**

HAPPY SAVING & HAVE A GREAT DAY !!! :):)

R5: G.G. Carette and V.M. Malhotra (1992).

THE DEVELOPMENT OF HIGH PERFORMANCE ECO-GREEN CONCRETE MIXES

Cement Consumption cum Carbon Dioxide (CO_2) Emission Calculation Worksheet

Prepared by : Foong Kah Yen (Cheryl) Checked by : Assoc.Prof. Dr. Nasir Shafiq July 2009

Welcome !!! Welcome !!!

START CALCULATING YOUR CO2 EMISSION & SEE HOW MUCH YOU CAN SAVE

Step 1 : Enter mix sample volumes.

Volume of mix samples (Enter Value) 0.007 m³

Step 2 : Enter Research Cement Consumption

		Enter cement consumed				
Cement Consumed in Research	1	250	kg/m³	=	1.75	kg
	2	275	kg/m³	=	1.93	kg
	3	350	kg/m³	=	2.45	kg
	4	400	kg/m³	=	2.80	kg
Cement Consumed in Other Research	1	410	kg/m³	=	2.87	kg
	2	478	kg/m³	=	3.35	kg
	3	524	kg/m³	=	3.67	kg
	4	650	kg/m³	=	4.55	kg

Step 3 : Enter values to determine no. of samples for every series

No. of testing days for mix samples	(Enter Value)	=	3	days
No. of mix samples required for each testing days	(Enter Value)	=	3	mixes
	TOTAL	=	**9**	samples
No. of sets for each series	(Enter Value)	=	3	series
	TOTAL	=	**27**	samples for every series

Total Cement Consumed in each Mix Series

	kg	kg
1	47.25	77.49
2	51.98	90.34
3	66.15	99.04
4	75.60	122.85

Converting kg to Tonne

	Tonne	Tonne
1	0.05	0.08
2	0.05	0.09
3	0.07	0.10
4	0.08	0.12

Your Cement Consumption & Carbon Dioxide Emission are discovered !!! The Values are as shown:

	Tonne	Tonne
1	0.047	0.08
2	0.052	0.09
3	0.066	0.10
4	0.076	0.12

	kg	kg
1	47.25	77.49
2	51.98	90.34
3	66.15	99.04
4	75.60	122.85

The total cement consumed & CO_2 emission from Research Study : 240.98 **kg**

The total cement consumed & CO_2 emission from Other Research : 389.72 **kg**

% Difference >>> 38.17 %

CONGRATULATIONS !!!! CONGRATULATIONS !!!

You have helped to save cement consumption & CO2 emission by >> **38** **%**

HAPPY SAVING & HAVE A GREAT DAY !!! :):)

APPENDIX C

AMOUNT OF OPC AND CO_2 EMISSION SAVED FROM RESEARCH (MODULUS OF ELASTICITY)

R1: M.G. Alexander and B.J. Magee (1999).

THE DEVELOPMENT OF HIGH PERFORMANCE ECO-GREEN CONCRETE MIXES

Cement Consumption cum Carbon Dioxide (CO2) Emission Calculation Worksheet

Prepared by : Foong Kah Yen (Cheryl) Checked by : Assoc.Prof. Dr. Nasir Shafiq July 2009

Welcome !!! Welcome !!!

START CALCULATING YOUR CO2 EMISSION & SEE HOW MUCH YOU CAN SAVE

Step 1 : Enter mix sample volumes.

Volume of mix samples (Enter Value) 0.005 m³

Step 2 : Enter Research Cement Consumption

		Enter cement consumed				
Cement Consumed in Research	1	250	kg/m³	=	1.25	kg
	2	275	kg/m³	=	1.38	kg
	3	350	kg/m³	=	1.75	kg
	4	400	kg/m³	=	2.00	kg
Cement Consumed in Other Research	1	265	kg/m³	=	1.33	kg
	2	315	kg/m³	=	1.58	kg
	3	360	kg/m³	=	1.80	kg
	4	410	kg/m³	=	2.05	kg

Step 3 : Enter values to determine no. of samples for every series

No. of testing days for mix samples	(Enter Value)	=	3	days
No. of mix samples required for each testing days	(Enter Value)	=	3	mixes
	TOTAL	=	**9**	samples
No. of sets for each series	(Enter Value)	=	3	series
	TOTAL	=	**27**	samples for every series

Total Cement Consumed in each Mix Series / **Converting kg to Tonne**

	kg	kg		Tonne	Tonne
1	33.75	35.78	1	0.03	0.04
2	37.13	42.53	2	0.04	0.04
3	47.25	48.60	3	0.05	0.05
4	54.00	55.35	4	0.05	0.06

Your Cement Consumption & Carbon Dioxide Emission are discovered !!! The Values are as shown:

	Tonne	Tonne		kg	kg
1	0.034	0.04	1	33.75	35.78
2	0.037	0.04	2	37.13	42.53
3	0.047	0.05	3	47.25	48.60
4	0.054	0.06	4	54.00	55.35

The total cement consumed & CO_2 emission from Research Study : 172.13 **kg**

The total cement consumed & CO_2 emission from Other Research : 182.25 **kg**

% Difference >>> **5.56** %

CONGRATULATIONS !!!! CONGRATULATIONS !!!

You have helped to save cement consumption & CO2 emission by >> **6** %

HAPPY SAVING & HAVE A GREAT DAY !!! :):)

R2: Isaia *et.al* (2003).

THE DEVELOPMENT OF HIGH PERFORMANCE ECO-GREEN CONCRETE MIXES

Cement Consumption cum Carbon Dioxide (CO_2) Emission Calculation Worksheet

Prepared by : Foong Kah Yen (Cheryl) Checked by : Assoc.Prof. Dr. Nasir Shafiq July 2009

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Welcome !!! Welcome !!!

START CALCULATING YOUR CO2 EMISSION & SEE HOW MUCH YOU CAN SAVE

Step 1 : Enter mix sample volumes.

Volume of mix samples (Enter Value) 0.005 m³

Step 2 : Enter Research Cement Consumption

		Enter cement consumed				
Cement Consumed in Research	1	250	kg/m³	=	1.25	kg
	2	275	kg/m³	=	1.38	kg
	3	350	kg/m³	=	1.75	kg
	4	400	kg/m³	=	2.00	kg
Cement Consumed in Other Research	1	367	kg/m³	=	1.84	kg
	2	428	kg/m³	=	2.14	kg
	3	367	kg/m³	=	1.84	kg
	4	545	kg/m³	=	2.73	kg

Step 3 : Enter values to determine no. of samples for every series

No. of testing days for mix samples	(Enter Value)	=	3	days
No. of mix samples required for each testing days	(Enter Value)	=	3	mixes
	TOTAL	=	**9**	samples
No. of sets for each series	(Enter Value)	=	3	series
	TOTAL	=	**27**	samples for every series

Total Cement Consumed in each Mix Series / **Converting kg to Tonne**

	kg	kg		Tonne	Tonne
1	33.75	49.55	1	0.03	0.05
2	37.13	57.78	2	0.04	0.06
3	47.25	49.55	3	0.05	0.05
4	54.00	73.58	4	0.05	0.07

Your Cement Consumption & Carbon Dioxide Emission are discovered !!! The Values are as shown:

	Tonne	Tonne		kg	kg
1	0.034	0.05	1	33.75	49.55
2	0.037	0.06	2	37.13	57.78
3	0.047	0.05	3	47.25	49.55
4	0.054	0.07	4	54.00	73.58

The total cement consumed & CO_2 emission from Research Study : 172.13 **kg**

The total cement consumed & CO_2 emission from Other Research : 230.45 **kg**

% Difference >>> 25.31 %

CONGRATULATIONS !!!! CONGRATULATIONS !!!

You have helped to save cement consumption & CO2 emission by >> **25** **%**

HAPPY SAVING & HAVE A GREAT DAY !!! :):)

R3: J. Lindgard and S. Smeplass (1992).

THE DEVELOPMENT OF HIGH PERFORMANCE ECO-GREEN CONCRETE MIXES

Cement Consumption cum Carbon Dioxide (CO_2) Emission Calculation Worksheet

Prepared by : Foong Kah Yen (Cheryl) Checked by : Assoc.Prof. Dr. Nasir Shafiq July 2009

Welcome !!! Welcome !!!

START CALCULATING YOUR CO2 EMISSION & SEE HOW MUCH YOU CAN SAVE

Step 1 : Enter mix sample volumes.

Volume of mix samples (Enter Value) 0.005 m³

Step 2 : Enter Research Cement Consumption

		Enter cement consumed				
Cement Consumed in Research	1	250	kg/m³	=	1.25	kg
	2	275	kg/m³	=	1.38	kg
	3	350	kg/m³	=	1.75	kg
	4	400	kg/m³	=	2.00	kg
Cement Consumed in Other Research	1	455	kg/m³	=	2.28	kg
	2	586	kg/m³	=	2.93	kg
	3	648	kg/m³	=	3.24	kg
	4	750	kg/m³	=	3.75	kg

Step 3 : Enter values to determine no. of samples for every series

No. of testing days for mix samples	(Enter Value)	=	3	days
No. of mix samples required for each testing days	(Enter Value)	=	3	mixes
	TOTAL	=	**9**	samples
No. of sets for each series	(Enter Value)	=	3	series
	TOTAL	=	**27**	samples for every series

Total Cement Consumed in each Mix Series / **Converting kg to Tonne**

	kg	kg		Tonne	Tonne
1	33.75	61.43	1	0.03	0.06
2	37.13	79.11	2	0.04	0.08
3	47.25	87.48	3	0.05	0.09
4	54.00	101.25	4	0.05	0.10

Your Cement Consumption & Carbon Dioxide Emission are discovered !!! The Values are as shown:

	Tonne	Tonne		kg	kg
1	0.034	0.06	1	33.75	61.43
2	0.037	0.08	2	37.13	79.11
3	0.047	0.09	3	47.25	87.48
4	0.054	0.10	4	54.00	101.25

The total cement consumed & CO_2 emission from Research Study : 172.13 **kg**

The total cement consumed & CO_2 emission from Other Research : 329.27 **kg**

% Difference >>> 47.72 %

CONGRATULATIONS !!!! CONGRATULATIONS !!!

You have helped to save cement consumption & CO2 emission by >> **48** **%**

HAPPY SAVING & HAVE A GREAT DAY !!! :):)

R4: F. de-Larrard and R. Le-Roy (1992).

THE DEVELOPMENT OF HIGH PERFORMANCE ECO-GREEN CONCRETE MIXES

Cement Consumption cum Carbon Dioxide (CO_2) Emission Calculation Worksheet

Prepared by : Foong Kah Yen (Cheryl) Checked by : Assoc.Prof. Dr. Nasir Shafiq July 2009

Welcome !!! Welcome !!!

START CALCULATING YOUR CO2 EMISSION & SEE HOW MUCH YOU CAN SAVE

Step 1 : Enter mix sample volumes.

Volume of mix samples (Enter Value) 0.005 m³

Step 2 : Enter Research Cement Consumption

		Enter cement consumed				
Cement Consumed in Research	1	250	kg/m³	=	1.25	kg
	2	275	kg/m³	=	1.38	kg
	3	350	kg/m³	=	1.75	kg
	4	400	kg/m³	=	2.00	kg
Cement Consumed in Other Research	1	412	kg/m³	=	2.06	kg
	2	422	kg/m³	=	2.11	kg
	3	426	kg/m³	=	2.13	kg
	4	600	kg/m³	=	3.00	kg

Step 3 : Enter values to determine no. of samples for every series

No. of testing days for mix samples	(Enter Value)	=	3	days
No. of mix samples required for each testing days	(Enter Value)	=	3	mixes
	TOTAL	=	**9**	samples
No. of sets for each series	(Enter Value)	=	3	series
	TOTAL	=	**27**	samples for every series

Total Cement Consumed in each Mix Series / **Converting kg to Tonne**

	kg	kg		Tonne	Tonne
1	33.75	55.62	1	0.03	0.06
2	37.13	56.97	2	0.04	0.06
3	47.25	57.51	3	0.05	0.06
4	54.00	81.00	4	0.05	0.08

Your Cement Consumption & Carbon Dioxide Emission are discovered !!! The Values are as shown:

	Tonne	Tonne		kg	kg
1	0.034	0.06	1	33.75	55.62
2	0.037	0.06	2	37.13	56.97
3	0.047	0.06	3	47.25	57.51
4	0.054	0.08	4	54.00	81.00

The total cement consumed & CO_2 emission from Research Study : 172.13 **kg**

The total cement consumed & CO_2 emission from Other Research : 251.10 **kg**

% Difference >>> 31.45 %

CONGRATULATIONS !!!! CONGRATULATIONS !!!

You have helped to save cement consumption & CO2 emission by >> **31** %

HAPPY SAVING & HAVE A GREAT DAY !!! :):)

R5: G.G. Carette and V.M. Malhotra (1992).

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THE DEVELOPMENT OF HIGH PERFORMANCE ECO-GREEN CONCRETE MIXES

Cement Consumption cum Carbon Dioxide (CO2) Emission Calculation Worksheet

Prepared by : Foong Kah Yen (Cheryl) Checked by : Assoc.Prof. Dr. Nasir Shafiq July 2009

Welcome !!! Welcome !!!

START CALCULATING YOUR CO2 EMISSION & SEE HOW MUCH YOU CAN SAVE

Step 1 : Enter mix sample volumes.

Volume of mix samples (Enter Value) 0.005 m^3

Step 2 : Enter Research Cement Consumption

		Enter cement consumed				
Cement Consumed in Research	1	250	kg/m^3	=	1.25	kg
	2	275	kg/m^3	=	1.38	kg
	3	350	kg/m^3	=	1.75	kg
	4	400	kg/m^3	=	2.00	kg
Cement Consumed in Other Research	1	410	kg/m^3	=	2.05	kg
	2	478	kg/m^3	=	2.39	kg
	3	524	kg/m^3	=	2.62	kg
	4	650	kg/m^3	=	3.25	kg

Step 3 : Enter values to determine no. of samples for every series

No. of testing days for mix samples	(Enter Value)	=	3	days
No. of mix samples required for each testing days	(Enter Value)	=	3	mixes
	TOTAL	=	**9**	samples
No. of sets for each series	(Enter Value)	=	3	series
	TOTAL	=	**27**	samples for every series

Total Cement Consumed in each Mix Series / **Converting kg to Tonne**

	kg	kg		Tonne	Tonne
1	33.75	55.35	1	0.03	0.06
2	37.13	64.53	2	0.04	0.06
3	47.25	70.74	3	0.05	0.07
4	54.00	87.75	4	0.05	0.09

Your Cement Consumption & Carbon Dioxide Emission are discovered !!! The Values are as shown:

	Tonne	Tonne		kg	kg
1	0.034	0.06	1	33.75	55.35
2	0.037	0.06	2	37.13	64.53
3	0.047	0.07	3	47.25	70.74
4	0.054	0.09	4	54.00	87.75

The total cement consumed & CO_2 emission from Research Study : 172.13 **kg**

The total cement consumed & CO_2 emission from Other Research : 278.37 **kg**

% Difference >>> **38.17** %

CONGRATULATIONS !!!! CONGRATULATIONS !!!

You have helped to save cement consumption & CO2 emission by >> **38** **%**

HAPPY SAVING & HAVE A GREAT DAY !!! :):)

APPENDIX D

SAMPLE OF ENERGY EFFICIENCY WORKSHEET

THE DEVELOPMENT OF HIGH PERFORMANCE
ECO-GREEN CONCRETE MIXES

UNIVERSITI TEKNOLOGI PETRONAS

Energy Consumption During Production Calculation Worksheet

Prepared by: Foong Kah Yen (Cheryl)   Checked by: Assoc.Prof. Dr. Nasir Shafiq   July 2009

A. Begin the calculation for the mix series conducted

Mix series conducted with reference with Energy Chart :

CONCRETE PROPERTIES	kwh/m³	kwh/tonne
Cement (250-500 kg/m³)	330-560	137-275
Aggregate (1750-1950 kg/m³)	20	8
Production in Handling Concrete	90	37
TOTAL	440-770	182-320

Paulo Monteiro (2008)

Enter the cement content of mix series conducted in Laboratory

	Cement content	
1	250	kg / m³
2	275	kg / m³
3	350	kg / m³
4	400	kg / m³

Total energy consumed during production:

1	440	kwh / m³	182	kwh/Tonne
2	473	kwh / m³	196	kwh/Tonne
3	572	kwh / m³	237	kwh/Tonne
4	638	kwh / m³	264	kwh/Tonne

B. With Comparison with other Research

Please state the Researcher that you want to compare with: **Alexander and Magee (2001)**

Calculations are done based on the Energy Chart

Formulaes used are based on the Energy Chart

Comparison between researchers are conducted to see the potential and the efficiency of mixes conducted via laboratory test

Enter the cement content of mixes conducted

	Cement content	
1	315	kg / m³
2	360	kg / m³
3	410	kg / m³
4	500	kg / m³

Total energy consumed during production :

1	526	kwh / m³	218	kwh/Tonne
2	585	kwh / m³	242	kwh/Tonne
3	651	kwh / m³	270	kwh/Tonne
4	770	kwh / m³	319	kwh/Tonne

How much of energy during production is saved ???

% of energy saved during production

	kwh / m³		kwh/Tonne	
1	**16**	%	**16**	%
2	**19**	%	**19**	%
3	**12**	%	**12**	%
4	**17**	%	**17**	%

Global Energy Saving
(Trillion Tonne KWH/Year)

1	**6**
2	**8**
3	**6**
4	**9**

SAVE **ENERGY !!!**

Are the mixes conducted **'Energy Efficient'** in consumption during production ???

1	**YES**
2	**YES**
3	**YES**
4	**YES**

CONGRATULATIONS !!!
YOU HAVE HELPED
TO CONSERVE
EARTH'S ENERGY

APPENDIX E

STANDARD ENERGY CONSUMPTION TABLE FOR CONCRETE DURING PRODUCTION (PAULO MONTEIRO, 2008)

CONCRETE PROPERTIES		
	kwh/m³	kwh/tonne
Cement (250-500 kg/m³)	330-660	137-275
Aggregate (1750-1950 kg/m³)	20	8
Production in Handling Concrete	90	37
TOTAL	**440-770**	**182-320**

APPENDIX F

LIST OF EXHIBITIONS, AWARDS, PAPERS & PUBLICATIONS

Gold medal, ‘ECOcrete’, Open Innovation Challenge (Civil Engineering) Category, *Engineering Design Exhibition (EDX23)*, Jan., 2009, Universiti Teknologi PETRONAS (UTP), Bandar Seri Iskandar, Perak, Malaysia.

Silver medal, ‘ECOcrete’-Concrete with High Cement Efficiency, Low Energy Consumption and Cost Effective, Postgraduate Research Project, *Engineering Design Exhibition (EDX24)*, Jul., 2009, Universiti Teknologi PETRONAS (UTP), Bandar Seri Iskandar, Perak, Malaysia.

Silver medal, ‘Duƒrete’- Concrete with High Cement Efficiency and High Durability, Postgraduate Research Project, *Engineering Design Exhibition (EDX25)*, Jan., 2010, Universiti Teknologi PETRONAS (UTP), Bandar Seri Iskandar, Perak, Malaysia.

K.Y. Foong and N. Shafiq (2010). ‘ECOcrete’-Concrete with High Cement Efficiency and Low Energy Consumption. *The International Conference on Sustainable Buildings and Infrastructures (ICSBI2010)*, Kuala Lumpur Convention Centre, Kuala Lumpur, Malaysia.

K.Y. Foong and N. Shafiq (2010). ‘ECOcrete’–Concrete with High Cement Efficiency, Low Energy Consumption and High Durability. *World Engineering Congress (WEC2010)*, Kuching, Sarawak, Malaysia.

K.Y. Foong and N. Shafiq (2010). 'ECOcrete'-Concrete with High Cement Efficiency and Low Energy Consumption, *Journal of Material Science and Engineering (JMSE)*, California, USA. (to be published)

K.Y. Foong and N. Shafiq (2010). The Development of High Performance Eco-Green Concrete Mixes, *International Conference in Postgraduate Education (ICPE 4)*, Cititel Hotel Midvalley Megamall, Kuala Lumpur, Malaysia.