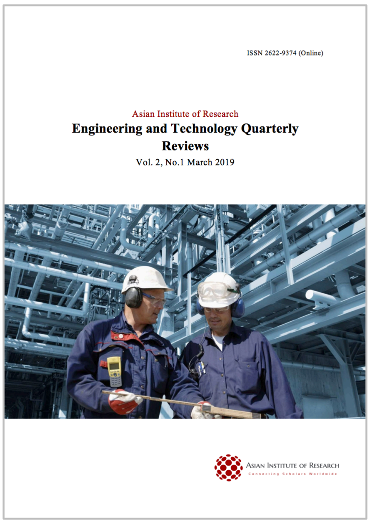

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Concrete Specification and Methods of Quality Testing

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Abstract
This manuscript is about the concrete specification. The concrete specification testing is a process by which different tests are carried out such as compressive strength, carbonation depth, ASTM rapid chloride permeability, NDT chloride and initial surface absorption test (ISAT-10) to determine the quality and performance of the concrete in terms of strength, carbonation depth, chloride permeability and surface absorption.

Key Words: Concrete Specification, Quality Testing, Compressive Strength, Carbonation Depth, ASTM Rapid Chloride Permeability, NDT Chloride, ISAT-10.

1. INTRODUCTION

1.1. Scope of work

The BS EN 206/ BS 8500 – Part 1: 2006 Method of specifying and guidance for the specifier (The British Standards Institution BSI, 2006), is set to provide the specifier with five approaches for designing concrete and aids in the determination of the appropriate concrete. This includes method of specifying the concrete.

The concrete specification testing in the structures lab consisted of five tests compressive strength, carbonation depth, ASTM rapid chloride permeability, NDT chloride and initial surface absorption test (ISAT-10). The testing was carried out on concrete specimens with different concrete mixes. The concrete mixes were 100% gravel, 100% recycled aggregate, 30% fly ash and 10% silica fume. In addition, each concrete mix had three specimens with different w/c ratios of 0.45, 0.60 and 0.75 as requested and with reference to (Halliday, 2010).

In the first section of this report, the material used, such as gravel, recycled aggregate, fly ash and silica fume will be described briefly in terms of their influence on carbonation, chloride attack and resistance. In addition, the methods for each test will be described briefly. The mix proportions that were obtained in lab 1: mix design and fresh properties of concrete for each group will be introduced in this report. Moreover, the engineering and durability properties results for each test that was obtained in the lab will be illustrated and discussed. Additionally, the appropriate mix designs for a reinforced concrete bridge deck over a river under carbonated environment, chloride environment and both will be presented and discussed. The design life for bridge deck is 50 years with a cover depth of 50mm. Finally, a conclusion to which of the concrete mix with w/c ratio is more suitable to be used for bridge deck under carbonated environment, chloride environment and both.

1.2. Aims of the paper

The main objectives of the manuscript are:

- Achieve a better understanding of concrete specification.
- Obtain a greater in-depth knowledge of concrete specification testing methods and tests carried out in the concrete structures lab.
- Become familiar with designing concrete using BS EN 206/ BS 8500.

2. MATERIALS USED

2.1. Gravel

Gravel is considered to be a coarse aggregate. The coarse aggregate sizes that were used in lab 1 concrete mixing vary from 5 to 10mm and 10 to 20mm with an absorption value of 1.0%. Generally, gravel maintains good compactability and finishability. It is believed that a good finishability means less cracks and voids appearing on concrete surface after curing. According to (Jackson et al., 1980), this indicates that the diffusion of chloride and carbon ions through concrete will be minimized, therefore, the concrete resistivity will be better.

2.2. Recycled aggregate

Recycled aggregate (RA) is considered to be cheaper than natural aggregates and good as far as the environmental issues are concerned. They consist mainly from recycled destruction remains with high amount of masonry. The recycled aggregates tend to reduce the quality of concrete in relation with natural aggregates. Moreover, recycled aggregates has high rate of water absorption and reduces the workability of concrete (Dhir et al., 1998). Since recycled aggregates reduce the concrete quality in terms of strength, it is assumed that a concrete with a large amount of RA will have low resistivity against carbon and chloride ions.

2.3. Fly ash

Fly ash is considered to be very high fine material. It combines with lime in the water to produce cementitious mix. The particles of fly ash has plain surface and are spherical in shape. In addition, the size and shape of fly ash particles are extremely alike to that of dispersed air bubbles. This provides air entrainment inhibition in cases where the carbon content is high. Also fly ash improves the fresh properties of concrete such as, reducing permeability, bleeding and segregation. Additionally, it has lots of advantages in fresh and hardened properties, such as, maintaining better cohesion, plasticity. Furthermore, it improves workability, durability and increases concrete strength. Moreover, the characteristics of fly ash give it an advantage in terms of reducing the water requirement in concrete mix. Thus, the reduction of water in concrete at a specific w/c ratio improves the quality of concrete in terms of strength. It is known that the strength of concrete is sufficient when considering the resistivity rate of concrete against carbonation and chloride attacks. As the concrete is higher in strength this means a harder concrete and more resistivity against the penetration of carbon or chloride ions in reference to (Day et al., 2006).

2.4. Silica fume

Silica fume is a new material in the construction industry. It is considered to be extremely fine material. Additionally, it consists mainly from pure silicon dioxide approximately 90% or more. Moreover, it is very small in terms of size between 0.03 to 0.3 µm and has greater surface area than fly ash. According to Day, 2006 "… Silica fume in concrete maintains high strength and provides a previously unattainable level of low permeability…" In addition, silica fume reduces water content and gives concrete good surface finishability, which means no existence of cracks. Moreover, the low electrical conductivity of concrete which contains silica fume maintains resistance to corrosion of reinforcement. Therefore, these factors give more protection against the penetration of chloride and carbon ion from environment.

3. TESTING METHODS

3.1. Compressive strength

The test was carried out in accordance to (The British Standards Institution BSI, 2002) BS EN 12390-3:2002 – Testing hardened concrete – Part 3: Compressive strength of test specimens. As shown in figure 1 the compression testing machine that has been used for functioning the test. The compression testing machine applies pressure on the concrete cube until it brakes and failure of specimen is noticed. After that the maximum sustained load is converted to a numerical reading and recorded. From the maximum sustained load the compressive strength of cube is calculated in N/mm².

The testing was carried out on 100mm concrete specimens. After the concrete was mix and cast it was then air-cured in concrete lab for 24 hours. Then it was immersed in water tank with a fixed temperature of 20ºC ± 2ºC. The specimen was then kept in the water tank for testing after 7 and 28 days. Before operating the testing, the cubes were cleaned with a dump cloth to remove any existing material on concrete surface. The next step was adjusting the cube in compression testing machine so that the load is applied equally on the cube surfaces. Each cube was then loaded to failure at a rate of 0.2-0.4 N/mm². The load was then applied until the cube breaks. After that the reading of maximum load was recorded in N. Subsequently, the compressive strength was calculated using the following equation 1.

Compressive strength (N/mm²) = Maximum load (N) / Surface area under test (mm²) (1)

Figure 1. Apparatus of compression testing machine.

3.2. Carbonation depth

The test was carried out in accordance to (University of Dundee, Department of Civil Engineering, 1995) CEN/TC51/WG12/TG5: draft 1995 – Measurement of hardened concrete carbonation depth (Modified by university of Dundee, 1998). The test works by measuring the carbonate depth of a concrete after applying indicator solution and calculating the mean value of readings.

The testing was carried out on 100mm concrete specimens. After the concrete was mix and cast it was then air-cured in concrete lab for 24 hours and kept for another 7 days in air. Then it was situated in exposure chamber for 4 weeks. Then the specimen was chopped in to two equal parts using special equipment for these purposes. The surface was then cleaned to remove the existence of dust. The next step was spraying the specimen surface with indicator solution which consists from 1% phenolphthalein in 70% ethyl alcohol. After that the carbonation depth was measured at four sides. The readings were then recorded and the mean value of the readings was determined.

3.3. ASTM rapid chloride permeability

The test was carried out with respect to the (American Society for testing and materials ASTM, 1997) American standard ASTM C 1202 – 97 / AASHTO T 277-831 Method: Rapid chloride permeability test. The test gives a quick indication of the concrete resistivity against the penetration of chloride ions by determining the electrical conductance of concrete, according to (Feldman et al., 1994). Figure 2 below illustrates the dimension of specimen for ASTM rapid chloride permeability test. While figure 3 demonstrates the microprocessor RCPT testing machine.

Figure 2. Shows the dimension of specimen for ASTM rapid chloride permeability test.

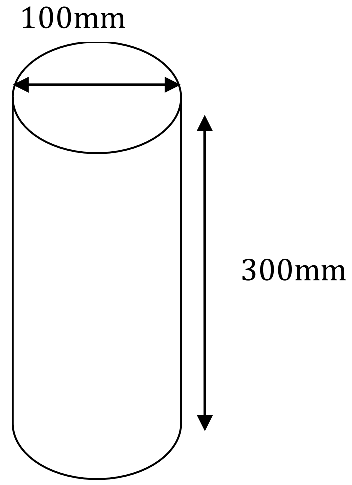
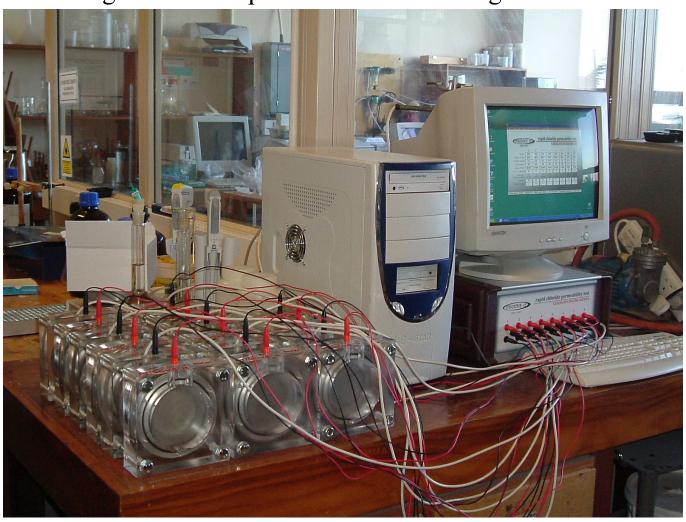


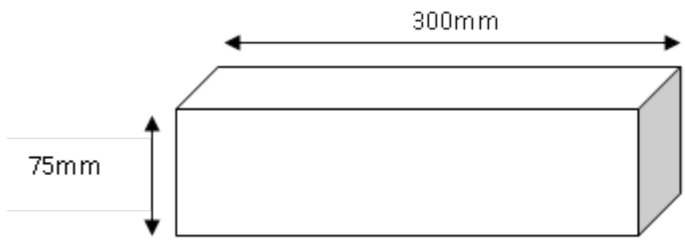
Figure 3. Microprocessor RCPT testing machine.



3.4. NDT Chloride

The test was carried out in accordance to (Nordic Council of Ministers, 1999) NT build 492 Nordtest method UDC 691.32/691.53/691.54 (Approved 1999 – 11) – Concrete mortar and cement-based repair materials: Chloride migration coefficient from non-steady-state migration experiments. The chloride ions from external atmosphere penetrate the specimen as an external electrical potential is operated axially. After approximately 24 hours the specimen is split equally and a solution of silver nitrate is spread on one of the sections. After 15 minutes a white silver colour appears on the split surface. This is due to the penetration of chloride which leads to the precipitation of solution. Then the coefficient of the chloride migration can be calculated from depth of penetration. Figure 4 presents the dimensions of NDT chloride test specimen.

Figure 4. Shows the dimension of specimen for NDT chloride test.



3.5. Initial surface absorption test (ISAT – 10)

The test was carried out with respect to (The British Standards Institution BSI, 1996) BS 1881: Part 208: 1996 – Recommendations for the determination of the initial surface absorption of concrete. Initial surface absorption test is used to measure the surface absorption of the external part of concrete and flow of water rate in concrete specimen Neville (1996, pp.488). The fill of reservoir with water and opening the tape after the adjustment of the apparatus initiates the water in reservoir to flow throw the rubber tube. After the water in rubber tube reaches concrete surface, time will be measured for 9 minutes. When the tape is closed after 9 minutes, the reading of the distance water moved in concrete surface along the capillary tube in 1 minute and 2 minutes is recorded and the ISAT value in $ml/m^2/s$ ($x10^{-2}$) is calculated.

4. MIX PROPORTIONS AND FRESH PROPERTIES

4.1. Mix proportions

Table 1 to 4 illustrates the mix proportions that has been used in lab 1 mixing concrete for 100% gravel, 100% recycled aggregate, 30% fly ash and 10% silica fume with reference to the research carried out by (Abdel Rahim et al., 2019).

Table 1. Mix proportions for 100% Gravel.

MIX, w/c ratio	MIX PROPORTIONS, kg/m³								
	CEM I	FA	SF	Water	RA		AGGREGATES		
					5/10	10/20	0/5	5/10	10/20
100% GRAVEL									
0.45	400	-	-	180	-	-	660	380	750
0.6	300	-	-	180	-	-	720	390	790
0.75	240	-	-	180	-	-	820	380	755
Particle density, kg/m³	3150	2250	2000	1000	2400		2600	2600	2600

Table 2. Mix proportions for 100% Recycled aggregate.

MIX, w/c ratio	MIX PROPORTIONS, kg/m³								
	CEM I	FA	SF	Water	RA		AGGREGATES		
					5/10	10/20	0/5	5/10	10/20
100% RA									

0.45	400	-	-	180	350	710	600	-	-
0.6	300	-	-	180	360	730	670	-	-
0.75	240	-	-	180	345	695	780	-	-
Particle density, kg/m³	3150	2250	2000	1000	2400		2600	2600	2600

Table 3. Mix proportions for 30% Fly ash.

MIX, w/c ratio	MIX PROPORTIONS, kg/m³								
	CEM I	FA	SF	Water	RA		AGGREGATES		
					5/10	10/20	0/5	5/10	10/20
30% FA									
0.36	355	150	-	180	-	-	560	380	755
0.47	265	115	-	180	-	-	690	375	755
0.59	215	90	-	180	-	-	740	385	770
Particle density, kg/m³	3150	2250	2000	1000	2400		2600	2600	2600

Table 4. Mix proportions for 10% Silica fume.

MIX, w/c ratio	MIX PROPORTIONS, kg/m³								
	CEM I	FA	SF	Water	RA		AGGREGATES		
					5/10	10/20	0/5	5/10	10/20
10% SF									
0.45	360	-	40	180	-	-	595	370	735
0.6	270	-	30	180	-	-	685	375	740
0.75	215	-	25	180	-	-	785	360	715
Particle density, kg/m³	3150	2250	2000	1000	2400		2600	2600	2600

4.2. Fresh properties

Table 5 to 8 illustrates the fresh properties that was obtained in lab 1 mixing concrete for 100% gravel, 100% recycled aggregate, 30% fly ash and 10% silica fume.

Table 5. Fresh concrete properties for 100% Gravel.

PROPERTY	W/C RATIO		
	0.45	0.6	0.75
Slump, mm	35	55	35
Plastic Density, kg/m³	2405	2385	2365
Bleeding	None	None	None
Segregation	None	None	None
Cohesiveness	Good	Good/fair	Good
Compactability	Fair	Good	Good
Finishability	Fair	Good	Good

General Observation - Good mixes generally and cement-rich pastes.

Table 6. Fresh concrete properties for 100% Recycled aggregate.

PROPERTY	W/C RATIO		
	0.45	0.6	0.75
Slump, mm	185 (Collapse)	195 (Collapse)	195 (Collapse)
PlasticDensity, kg/m³	2390	2375	2340
Bleeding	Slight	Slight	Slight
Segregation	Slight	Slight	Slight

Cohesiveness	Poor	Poor	Poor
Compactability	Good	Good	Good
Finishability	Good	Good	Good

General Observation - Absorption value probably too high for this RA, therefore more water in mix causing high slumps. Moreover, the density of this RA was probably more than 2400kg/m³ assumed in design stage, approximately 2550kg/m³.

Table 7. Fresh concrete properties for 30% Fly ash.

PROPERTY	W/C RATIO		
	0.37	0.45	0.6
Slump, mm	85	Collapse	190 Collapse
Plastic Density, kg/m³	2470	2455	2470
Bleeding	None	Slight	Slight
Segregation	None	None	Slight
Cohesiveness	Good	Poor	Poor
Compactability	Good	Good	Good
Finishability	Good	Good	Good
General Observation	Cement-rich mix	Too much SP	Too much SP

Table 8. Fresh concrete properties for 10% Silica fume.

PROPERTY	W/C RATIO		
	0.45	0.60	0.75
Slump, mm	95	80	75
Plastic Density, kg/m³	2410	2375	2380
Bleeding	None	None	None
Segregation	None	None	None
Cohesiveness	Good	Good	Good
Compactability	Good	Good	Good
Finishability	Good	Good	Good

5. RESULTS AND DISCUSSION

5.1. Engineering and durability properties (All Results)

Table 9 to 12 illustrates the concrete specification results that was obtained in lab 4 for concrete mixes of 100% gravel, 100% recycled aggregate, 30% fly ash and 10% silica fume (Abdel Rahim, 2019).

Table 9. Concrete specification results for 100% Gravel.

w/c	28 day strength	Carbonation depth	ASTM Chloride	NDT Chloride	ISAT-10
	N/mm²	28days, mm	Coulombs	mm	ml/m²/s ($x10^{-2}$)
0.45	57.5	6	5469	19.3	43.3
0.6	40.0	9	6667	24.8	39.6
0.75	27.0	14	6689	43.4	52.3

The compressive strength results for 100% gravel concrete mix was 57.5 N/mm^2, 40 N/mm^2, 27 N/mm^2 for 0.45, 0.60 and 0.75 w/c ratio respectively. Moreover, the carbonation depth after 28 days was 6mm, 9mm and 14mm with respect to a 0.45, 0.60 and 0.75 w/c ratio. Furthermore, the ASTM chloride results were 5469, 6667 and 6689 coulombs for w/c ratios of 0.45, 0.60 and 0.75. In addition, the NDT results illustrated an increase in value as w/c ratio increases. The results were 19.3mm, 24.8mm and 43.3mm for 0.45, 0.60 and 0.75 w/c ratios. Finally, the initial surface absorption results showed no relation with each other since the ISAT value increase from a w/c ratio 0.45 to 0.60 and decrease from w/c ratio 0.60 to 0.75. The results were 43.3 ml/m^2/s × 10^2 for 0.45 w/c ratio, 39.6 ml/m^2/s × 10^2 for 0.60 w/c ratio and 52.3 ml/m^2/s × 10^2 for 0.75 w/c ratio.

The above results indicate that as the w/c ratio increases the 28 day compressive strength decreases. It is known that a high compressive strength means fewer voids, pores in the concrete and more resistivity against chloride and carbon ions. Generally speaking, more compressive strength indicates better durability. On the other hand, an increase in w/c ratio increases carbonation depth, ASTM chloride, NDT chloride. In addition, it is believed that the w/c ratio has a major influence on all tests. To proof this mix of 0.45 w/c ratio had the highest compressive strength and lowest carbonation depth than other w/c ratios. Thus, the 0.45 w/c ratio had the best concrete quality in terms of strength and lowest penetration of carbon and chloride ions. As far as the permeability is concerned the lower the ISAT value the better. Alternatively, high ISAT means more pores in the concrete which results in more absorption of water. Though the highest ISAT – 10 value was for the 0.75 w/c ratio, the results showed a moderated for 0.45 w/c ratio concrete mix. Generally, gravel has provided the mix with strength since it is more functional in giving strength than recycled aggregates.

Table 10. Concrete specification results for 100% Recycled Aggregate.

w/c	28 day strength	Carbonation depth	ASTM Chloride	NDT Chloride	ISAT-10
	N/mm²	28days, mm	coulombs	mm	ml/m^2/s (x10^{-2})
0.45	43.0	5	6055	2.5	43.3
0.6	25.0	9	4969	26.4	50.5
0.75	17.0	12	7704	36.6	57.7

The compressive strength results for 100% recycled aggregate concrete mix was 43 N/mm^2, 25 N/mm^2, 17 N/mm^2 for 0.45, 0.60 and 0.75 w/c ratio respectively. Moreover, the carbonation depth after 28 days was 5mm, 9mm and 12mm with respect to a 0.45, 0.60 and 0.75 w/c ratio. Furthermore, the ASTM chloride results were 6055, 4969 and 7704 coulombs for w/c ratios of 0.45, 0.60 and 0.75. In addition, the NDT results illustrated an increase in value as w/c ratio increases. The results were 2.5mm, 26.4mm and 36.6mm for 0.45, 0.60 and 0.75 w/c ratios. Finally, the initial surface absorption results showed an increase with the increase in w/c ratio. The results were 43.3 ml/m^2/s × 10^2 for 0.45 w/c ratio, 50.5 ml/m^2/s × 10^2 for 0.60 w/c ratio and 57.7 ml/m^2/s × 10^2 for 0.75 w/c ratio.

According to the results obtained, the 0.45 w/c ratio mix for 100% recycled aggregate is the most durable. (Glanville, 1995) has mentioned that "the usual primary requirement of a good concrete in its hardened state is compressive strength" Though it has the lowest ISAT value and moderated results for ASTM chloride, it is still good in quality with the highest compressive strength and lowest in carbonation depth and NDT chloride. Furthermore, the NDT chloride result for 0.45 w/c ratio might be wrong due to its very low value and having no relation with the others. As can be seen from the results recycled aggregate provided the mix with more resistivity against carbonation if compared with other mixes.

Table 11. Concrete specification results for 30% Fly Ash.

w/c	28 day strength	Carbonation depth	ASTM Chloride	NDT Chloride	ISAT-10
	N/mm²	28days, mm	Coulombs	mm	ml/m^2/s (x10^{-2})
0.36	59.0	6	2624	23.0	38.2
0.47	37.5	11	-	28.0	45.4
0.59	25.0	23	3240	31.2	60.7

The compressive strength results for 30% fly ash concrete mix was 59 N/mm^2, 37.5 N/mm^2 and 25 N/mm^2 for 0.36, 0.47 and 0.59 w/c ratio respectively. Moreover, the carbonation depth after 28 days was 6mm, 11mm and 23mm with respect to a 0.36, 0.47 and 0.59 w/c ratio. Furthermore, the ASTM chloride results were 2624 and 3240 coulombs for w/c ratios of 0.36 and 0.59. In addition, the NDT results illustrated an increase in value as w/c ratio increases. The results were 23mm, 28mm and 31.2mm for 0.36, 0.47 and 0.59 w/c ratios. Finally, the initial surface absorption results showed an increase with the increase in w/c ratio. The results were 38.2 $ml/m^2/s \times 10^2$ for 0.36 w/c ratio, 45.4 $ml/m^2/s \times 10^2$ for 0.47 w/c ratio and 60.7 $ml/m^2/s \times 10^2$ for 0.59 w/c ratio.

The fly ash demonstrated the worst result among all the other mixes. Though it provided high strength, it still had the highest ISAT results. In addition, fly ash had greatest chloride and carbonation penetration value when evaluated with other mixes. This might be due to less amount of calcium hydroxide. Thus, fly ash did not give sufficient durability property to the concrete. The mix could have been improved by reducing the percentage of fly ash in the mix, approximately between 6 to 10% with respect to the British Standards BS 8500.

Table 12. Concrete specification results for 10% Silica Fume.

w/c	28 day strength	Carbonation depth	ASTM Chloride	NDT Chloride	ISAT-10
	N/mm^2	28days, mm	Coulombs	mm	$ml/m^2/s$ ($x10^{-2}$)
0.45	62.0	5.5	1600	9.9	19.2
0.6	49.0	12	2501	18.5	30.6
0.75	33.0	19	4780	30.8	33.0

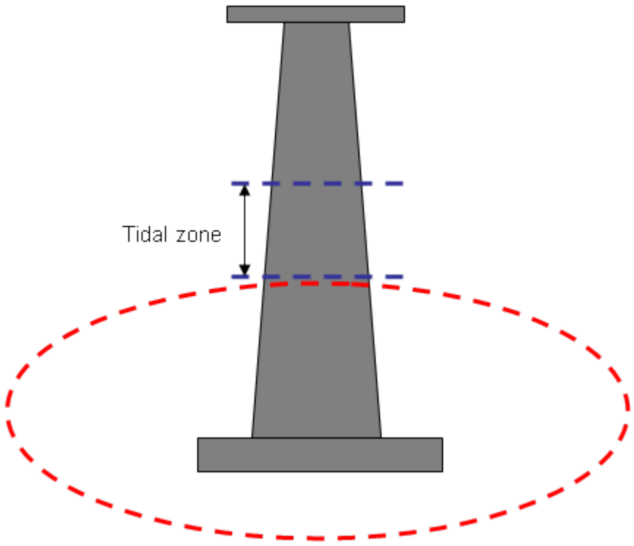
The compressive strength results for 10% silica fume concrete mix was 62 N/mm^2, 49 N/mm^2 and 33 N/mm^2 for 0.45, 0.60 and 0.75 w/c ratio respectively. Moreover, the carbonation depth after 28 days was 5.5mm, 12mm and 19mm with respect to a 0.45, 0.60 and 0.75 w/c ratio. Furthermore, the ASTM chloride results were 1600, 2501 and 4780 coulombs for w/c ratios of 0.45, 0.60 and 0.75. In addition, the NDT results illustrated an increase in value as w/c ratio increases. The results were 9.9mm, 18.5mm and 30.8mm for 0.45, 0.60 and 0.75 w/c ratios. Finally, the initial surface absorption results showed an increase with the increase in w/c ratio. The results were 19.2 $ml/m^2/s \times 10^2$ for 0.45 w/c ratio, 30.6 $ml/m^2/s \times 10^2$ for 0.60 w/c ratio and 33 $ml/m^2/s \times 10^2$ for 0.75 w/c ratio.

The results demonstrated the most reliable in terms of durability comparing with other concrete mixes. Silica fume is known for producing a denser concrete, by which it did fully established its properties in this concrete mix. In addition, the results for 10% silica fume had the highest strength, lowest carbonation depth, chloride penetration and ISAT values among all other mixes. In the author point of view, the best concrete mix to be used in the concrete design for bridge deck under both carbonation and chloride atmospheres is 10% silica fume with a 0.45 w/c ratio. This was decided due to the high compressive strength and low carbonation depth, chloride penetration and initial surface absorption. Additionally, these properties demonstrated good durable concrete for that mix.

6. APPROPRIATE MIX DESIGNS

Design requirements are to design concrete for a bridge deck below tidal zone as shown in figure 5 with a minimum cover of 50mm and 50 years design life. The designs was carried out with accordance to BS EN 206-1, BS 8500.

Figure 5. Shows tidal zone of the bridge.



6.1. Carbonated environment

- Step 1 Choosing exposure class
- From Table A.1 Exposure classes

  Choose **XC3 and XC4** (Moderate humidity or cyclic wet and dry) illustrated in table 13 of this report.

- Step 2 Finding compressive strength class
- From Table A.4 Compressive strength class

  Form XC3 and XC4 (Moderate humidity or cyclic wet and dry) ~ choose XC3 (Moderate humidity) the minimum strength is **C25/30** with a maximum w/c ratio of 0.65 and minimum cement content is 260 kg/m^3. The following is shown in table 14.

Table 13. Exposure class Table A.1 from BS8500-1.

Table A.1 **Exposure classes**

Class designation	Class description	Informative examples applicable in the United Kingdom
No risk of corrosion or attack (X0 class)		
X0	For concrete without reinforcement or embedded metal: all exposures except where there is freeze-thaw, abrasion or chemical attack For concrete with reinforcement or embedded metal: very dry	Unreinforced concrete surfaces inside structures Unreinforced concrete completely buried in soil classed as AC-1 and with a hydraulic gradient not greater than 5 Unreinforced concrete permanently submerged in non-aggressive water Unreinforced concrete surfaces in cyclic wet and dry conditions not subject to abrasion, freezing or chemical attack Reinforced concrete surfaces exposed to very dry conditions
Corrosion induced by carbonation (XC classes) [A)] *(where concrete containing reinforcement or other embedded metal is exposed to air and moisture)*		
XC1	Dry or permanently wet	Reinforced and prestressed concrete surfaces inside enclosed structures except areas of structures with high humidity Reinforced and prestressed concrete surfaces permanently submerged in non-aggressive water
XC2	Wet, rarely dry	Reinforced and prestressed concrete completely buried in soil classed as AC-1 and with a hydraulic gradient not greater than 5 [B)]
XC3 and XC4	Moderate humidity or cyclic wet and dry	External reinforced and prestressed concrete surfaces sheltered from, or exposed to, direct rain Reinforced and prestressed concrete surfaces subject to high humidity (e.g. poorly ventilated bathrooms, kitchens) Reinforced and prestressed concrete surfaces exposed to alternate wetting and drying Interior concrete surfaces of pedestrian subways not subject to de-icing salts, voided superstructures or cellular abutments Reinforced or prestressed concrete beneath waterproofing

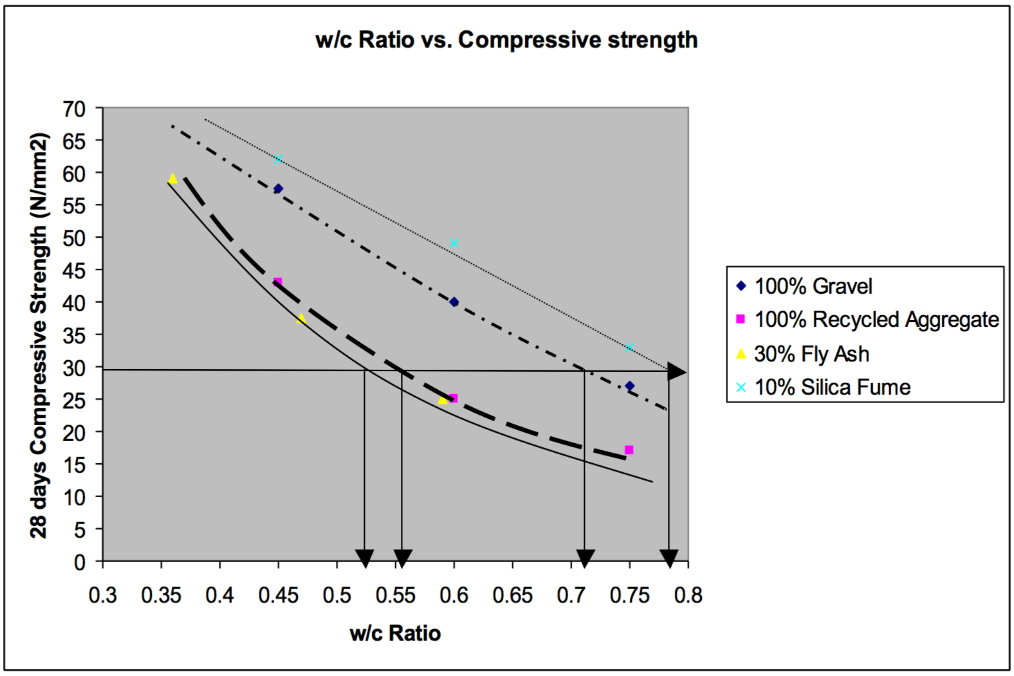
Table 14. Compressive strength class Table A.4 from BS8500-1.

Table A.4 Durability [A] recommendations for reinforced or prestressed elements with an intended working life of at least 50 years

Nominal cover [B]	Compressive strength class where recommended, maximum water-cement ratio and minimum cement or combination content for normal-weight concrete [C] with 20 mm maximum aggregate size [D]								Cement/combination types
mm	15 + Δc	20 + Δc	25 + Δc	30 + Δc	35 + Δc	40 + Δc	45 + Δc	50 + Δc	
Corrosion induced by carbonation (XC exposure classes)									
XC1	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	C20/25 0.70 240	All in Table A.6
XC2	—	—	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	All in Table A.6
XC3/4	—	C40/50 0.45 340	C30/37 0.55 300	C28/35 0.60 280	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	All in Table A.6 except IVB-V
	—	—	C40/50 0.45 340	C30/37 0.55 300	C28/35 0.60 280	C25/30 0.65 260	C25/30 0.65 260	C25/30 0.65 260	IVB-V
Corrosion induced by chlorides (XS from sea water, XD other than sea water) *Also adequate for any associated carbonation induced corrosion (XC)*									
XD1	—	—	C40/50 0.45 360	C32/40 0.55 320	C28/35 0.60 300	C28/35 0.60 300	C28/35 0.60 300	C28/35 0.60 300	All in Table A.6
XS1	—	—	—	C45/55[E] 0.35[F] 380	C35/45[E] 0.45 360	C32/40[E] 0.50 340	C32/40[E] 0.50 340	C32/40[E] 0.50 340	CEM I, IIA, IIB-S, SRPC
	—	—	—	C40/50[E] 0.35[F] 380	C32/40[E] 0.45 360	C28/35 0.50 340	C25/30 0.55 320	C25/30 0.55 320	IIB-V, IIIA
	—	—	—	C32/40[E] 0.40 380	C25/30 0.50 340	C25/30 0.50 340	C25/30 0.55 320	C25/30 0.55 320	IIIB
	—	—	—	C32/40[E] 0.40 380	C28/35 0.50 340	C25/30 0.50 340	C25/30 0.55 320	C25/30 0.55 320	IVB-V
XD2 or XS2	—	—	—	C40/50[E] 0.40 380	C32/40[E] 0.50 340	C28/35 0.55 320	C28/35 0.55 320	C28/35 0.55 320	CEM I, IIA, IIB-S, SRPC
	—	—	—	C35/45[E] 0.40 380	C28/35 0.50 340	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	IIB-V, IIIA
	—	—	—	C32/40[E] 0.40 380	C25/30 0.50 340	C20/25 0.55 320	C20/25 0.55 320	C20/25 0.55 320	IIIB, IVB-V

- Step 3 Determining the w/c ratio for compressive strength

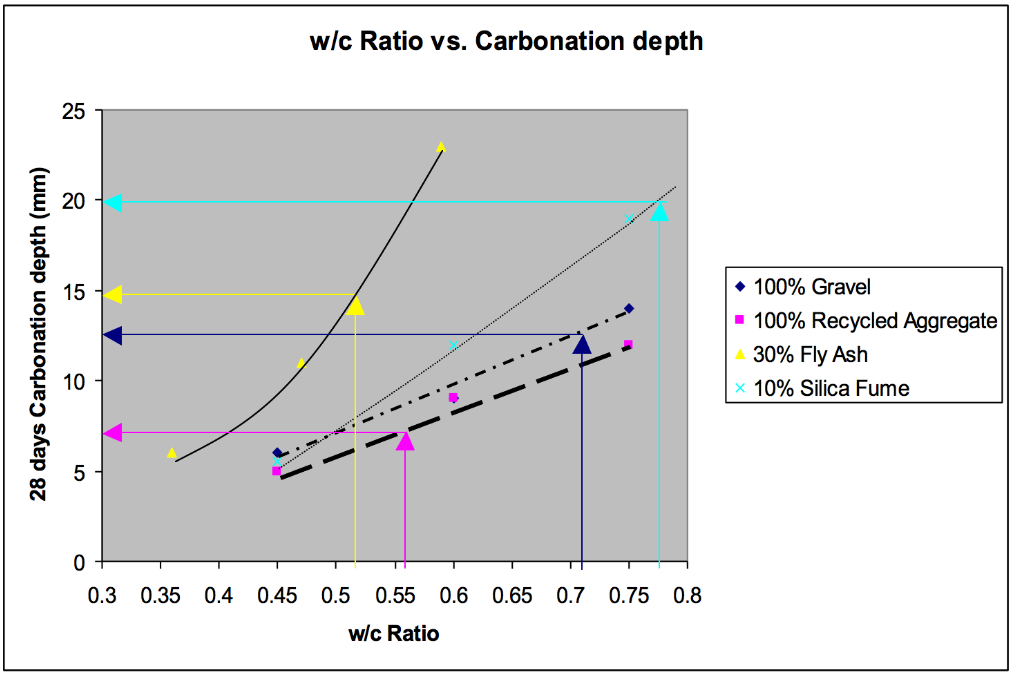
Graph 1. w/c Ratio vs. Compressive strength for carbonate environment.



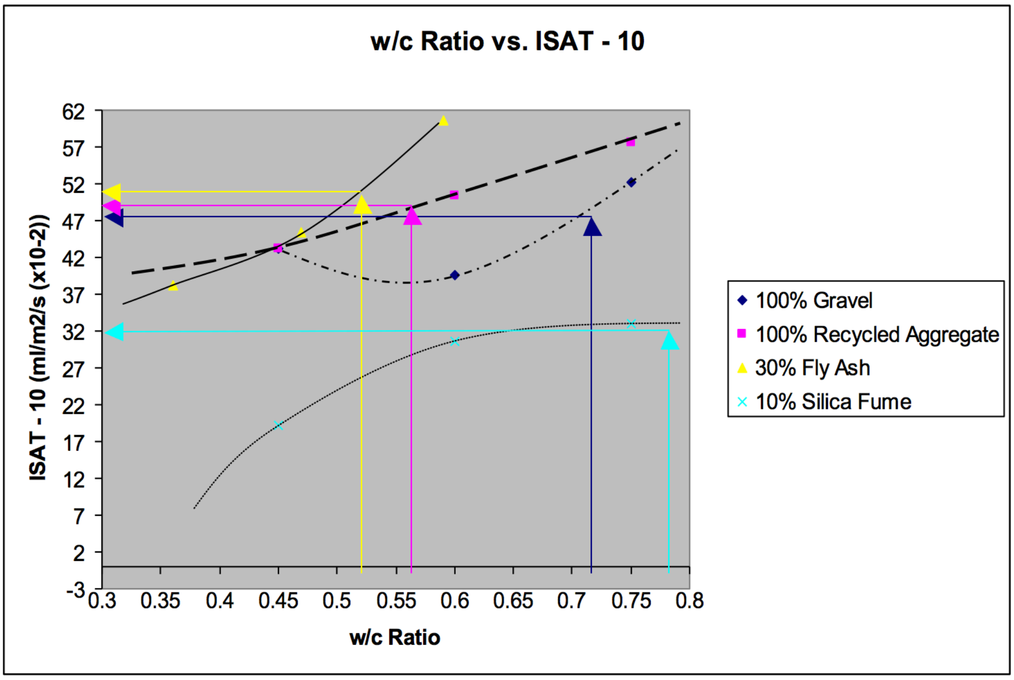
The w/c ratios for 30 N/mm^2 target strength are as follow:

- 100% Gravel = 0.71 w/c ratio
- 100% Recycled aggregate = 0.56 w/c ratio
- 30% Fly ash = 0.52 w/c ratio
- 10% Silica fume = 0.78 w/c ratio

Graph 2. w/c Ratio vs. Carbonation depth.



Graph 3. w/c Ratio vs. ISAT - 10.



Therefore, for 30% fly ash choose the composition IIB-V with 21% Portland cement to 35% fly ash and comprises cement and combination types CEM II/B-V, CIIB-V. Moreover, for 10% silica fume choose the composition IIA with 6% to 10% fly ash and comprises cement and combination types CEM II/A-V, CIIA-V, CEM II/A-D. In accordance to the results presented in graphical illustration Graphs 1 to 3 for the w/c ratio vs. compressive strength, carbonation depth and ISAT-10 respectively.

6.2. Chloride environment (Not from sea water)

- Step 1 Choosing exposure class
- From Table A.1 Exposure classes
  Choose **XD1** (Moderate humidity) illustrated in table 13 of this report.

- Step 2 Finding compressive strength class

- From Table A.4 Compressive strength class

  For XD1 the minimum strength is **C28/35** with a maximum w/c ratio of 0.65 and minimum cement content is 300 kg/m^3. The selection is shown in table 15.

- Identifying cement combinations:

  From Table A.6 Cement and combination types

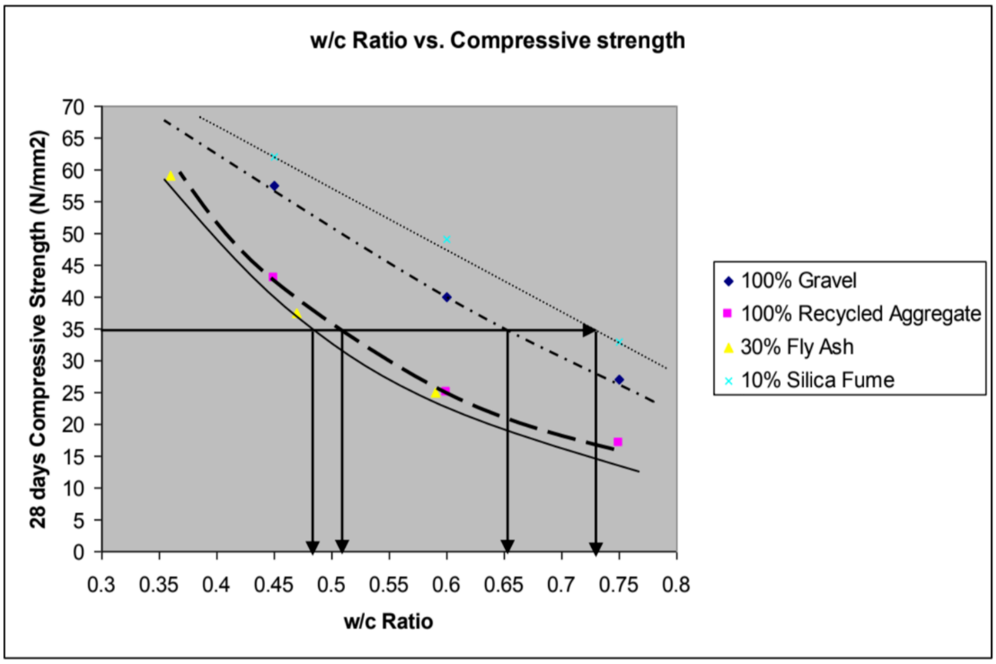
  For XD1 the minimum strength is **C28/35** with a maximum w/c ratio of 0.60 and minimum cement content is 300 kg/m^3 for CEM I (Gravel and recycled aggregate), IIA (Silica fume) and IIB-V (Fly ash). The selection is shown in table 16.

Table 15. Compressive strength class Table A.4 from BS8500-1.

			0.45 340	0.55 300	0.60 280	0.65 260	0.65 260	0.65 260	
Corrosion induced by chlorides (XS from sea water, XD other than sea water)									
Also adequate for any associated carbonation induced corrosion (XC)									
XD1	–	–	C40/50 0.45 360	C32/40 0.55 320	C28/35 0.60 300	C28/35 0.60 300	C28/35 0.60 300	C28/35 0.60 300	All in Table A.6
XS1	–	–	–	C45/55[E] 0.35[F] 380	C35/45[E] 0.45 360	C32/40[E] 0.50 340	C32/40[E] 0.50 340	C32/40[E] 0.50 340	CEM I, IIA, IIB-S, SRPC
	–	–	–	C40/50[E] 0.35[F] 380	C32/40[E] 0.45 360	C28/35 0.50 340	C25/30 0.55 320	C25/30 0.55 320	IIB-V, IIIA
	–	–	–	C32/40[E] 0.40 380	C25/30 0.50 340	C25/30 0.50 340	C25/30 0.55 320	C25/30 0.55 320	IIIB
	–	–	–	C32/40[E] 0.40 380	C28/35 0.50 340	C25/30 0.50 340	C25/30 0.55 320	C25/30 0.55 320	IVB-V
XD2 or XS2	–	–	–	C40/50[E] 0.40 380	C32/40[E] 0.50 340	C28/35 0.55 320	C28/35 0.55 320	C28/35 0.55 320	CEM I, IIA, IIB-S, SRPC
	–	–	–	C35/45[E] 0.40 380	C28/35 0.50 340	C25/30 0.55 320	C25/30 0.55 320	C25/30 0.55 320	IIB-V, IIIA
	–	–	–	C32/40[E] 0.40 380	C25/30 0.50 340	C20/25 0.55 320	C20/25 0.55 320	C20/25 0.55 320	IIIB, IVB-V

- Step 3 Determining the w/c ratio for compressive strength

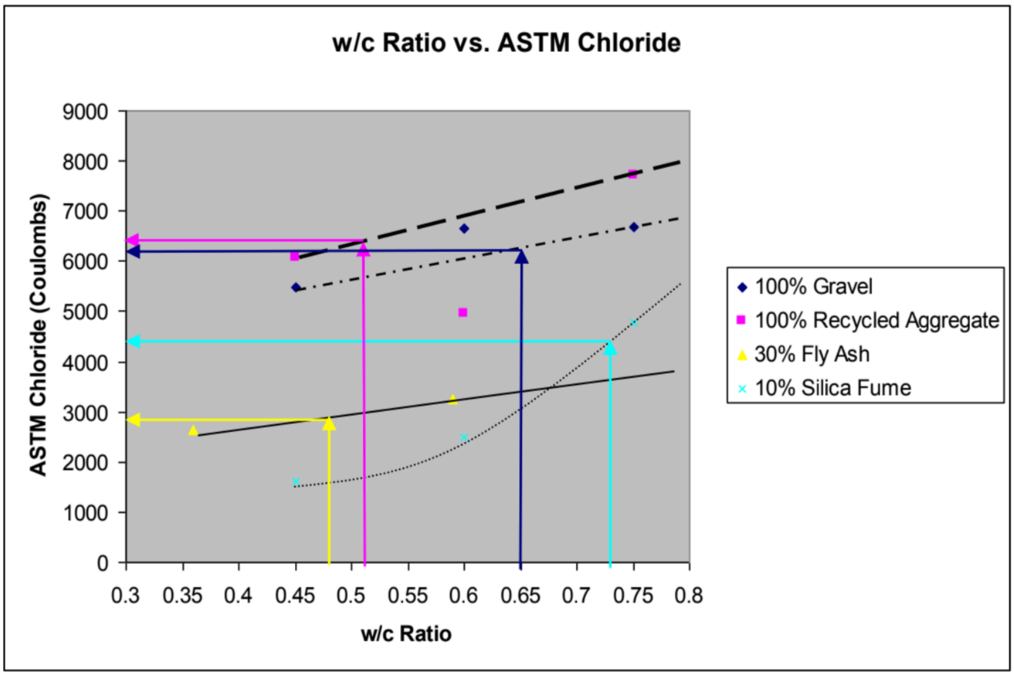
Graph 4. w/c Ratio vs. compressive strength for chloride environment.



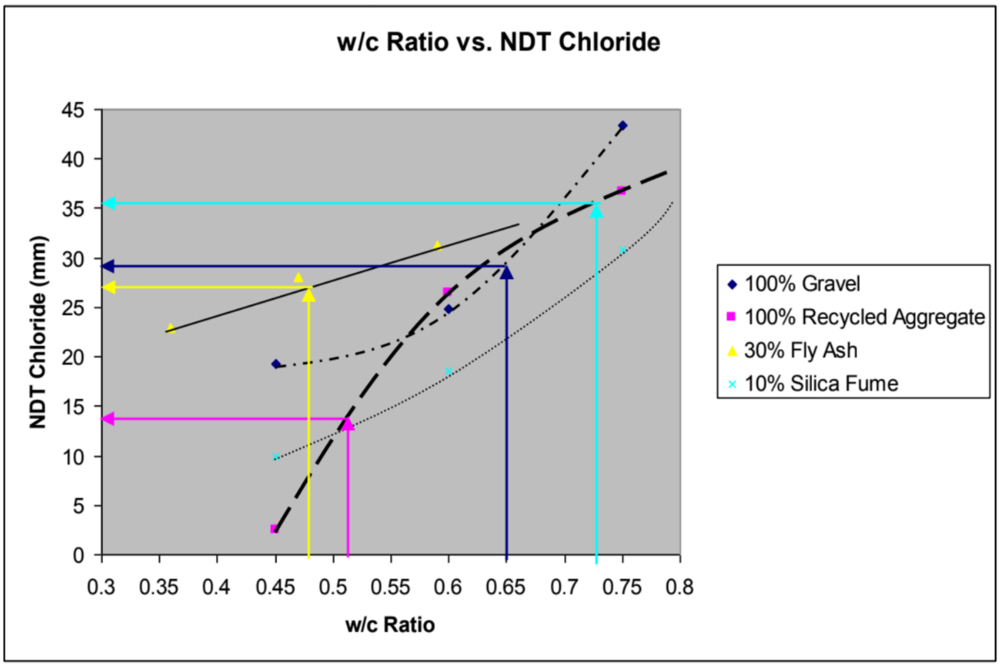
The w/c ratios for 35 N/mm^2 target strength are as follow:

- 100% Gravel = 0.65 w/c ratio
- 100% Recycled aggregate = 0.51 w/c ratio
- 30% Fly ash = 0.48 w/c ratio
- 10% Silica fume = 0.73 w/c ratio
  - Step 4 Determining the chloride results for each w/c ratio

Graph 5. w/c Ratio vs. ASTM Chloride for chloride environment.



Graph 6. w/c Ratio vs. NDT Chloride for chloride environment.



Since XD3 is more aggressive than XD4 it has been decided to choose XD3 with 30% fly ash choose the composition IIB-V with 21% Portland cement to 35% fly ash and comprises cement and combination types CEM II/B-V, CIIB-V. Moreover, for 10% silica fume choose the composition IIA with 6% to 10% fly ash and comprises cement and combination types CEM II/A-V, CIIA-V, CEM II/A-D, as shown in Graphs 4 to 6.

Table 16. A record of the concrete design results.

Test description	100% Gravel = 0.71 w/c Ratio	100% Recycled Aggregate = 0.56 w/c Ratio	30% Fly Ash = 0.52 w/c Ratio	10% Silica Fume = 0.78 w/c Ratio
Cement Content (kg/m^3)	280	355	375	245
Carbonation Depth (mm)	13	7.5	15	20
ASTM Chloride (coulombs)	6200	6500	2900	4400
NDT Chloride (mm)	29	13	26	35
ISAT – 10 (ml/m^2/s (x10^{-2})	47	50	51	32

6.3. Both

The concrete design for carbonated environment was **XC3 and XC4** (Moderate humidity or cyclic wet and dry) and minimum strength of **C28/35**. Moreover, the chosen concrete design for chloride environment was **XD1** and minimum strength of **C25/30** (from table A.1). The observed results has been demonstrated in table 17 below.

Table 17. Concrete designs under carbonation, chloride environments and both.

Description	XC3 and XC4 Carbonation	XD1 Chloride	Chosen for both (XD1)
Maximum w/c Ratio	0.65	0.60	0.60
Minimum compressive strength	C25/30	C28/35	C28/35
Minimum cement content (kg/m^3)	260	300	300

Thus, the chosen concrete design for bridge deck under both carbonation and chloride environments is XD1 (Moderate humidity) with a minimum w/c ratio of 0.60, minimum compressive strength C28/35 and minimum cement content of 300 kg/m^3.

For 30% fly ash chooses the composition IIB-V with 21% Portland cement to 35% fly ash and comprises cement and combination types CEM II/B-V, CIIB-V. Moreover, for 10% silica fume choose the composition IIA with 6% to 10% fly ash and comprises cement and combination types CEM II/A-V, CIIA-V, CEM II/A-D.

7, CONCLUSION

The concrete specification lab was set to determine the compressive strength, carbonation depth, chloride penetration and initial surface absorption values for 100% gravel, 100% recycled aggregate, 30% fly ash and 10% silica fume concrete mixes and compare them in terms of engineering and durability of concrete. It was observed that the w/c ratio had a great influence on all the test results. Hence a decrease in w/c ratio maintains a better concrete by increase the compressive strength and durability.

The results for 10% silica fume demonstrated the highest strength, lowest carbonation depth, chloride penetration and ISAT values among all other mixes. Thus, it is considered to be essential to be used for concrete design with durable property. Additionally, the best concrete mix to be considered in the concrete design for bridge deck under both carbonation and chloride atmospheres is 10% silica fume with a 0.45 w/c ratio. On the other hand, the results for 30% fly ash were the most unsatisfactory compared with other mixes. This is due to the highest carbonation depth and chloride penetration results. According to concrete specification tests results the following was concluded:

- Durability of concrete is an important aspect of good quality concrete and should be taken in to consideration when designing concrete.
- Silica fume produces denser concrete and increase compressive strength.
- Gravel is more functional in giving concrete strength than recycled aggregates.
- Recycled aggregate mix provided the concrete with more resistivity against carbonation when compared with other mixes.
- Fly ash had the greatest chloride and carbonation penetration.
- Higher compressive strength means better concrete durability.
- Lower carbonation depth indicates greater concrete durability and vies versa.
- Lower ASTM and NDT chloride results in higher concrete durability.
- Lower initial surface absorption illustrates good concrete in terms of durability.

The concrete design for bridge deck was carried out in three stages depending on the environment. The chosen concrete design was10% silica fume and the composition IIA with 6% to 10% fly ash and comprises cement and combination types CEM II/A-V, CIIA-V, CEM II/A-D.

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