Effect of water to cement ratio on concrete

Introduction

In construction projects, concrete, along with steel, wood, glass, etc, is one of the most essential materials that are needed for a successful manufacture of a structure. It one of the most common materials on a construction site and accounts for billions of pounds everywhere across the world. Due to ever-increasing machinery and technological advancements concrete can now be made of a mixture of compound materials, nevertheless the necessary components of concrete are course or fine aggregates, Portland Cement and water. In the current times, concrete structures are manufactured every day and to sustain a safe environment for people, so it is vital that that the structures that are built are sturdy, durable and do not cause any hazards to people. It is therefore a huge task for construction companies to guarantee that the structures that are built are done so to meet all the specific safety codes, British Standards or the Euro Code Standards. The properties of concrete are very vital as they provide the necessary stability that structures are dependent on to maintain their sturdiness. As a result it is essential to research and be aware of the distinctive components of concrete and its properties, and how in this experiment these might affect the way that concrete performs when changing some variables. (Richardson, 2002).

The workability of a concrete mix gives a measure of the ease with which fresh concrete can be placed and compacted. The concrete should flow readily into the form and go around and cover the reinforcement, the mix should retain its consistency and the aggregates should not segregate.

There are four factors that can affect the workability are:

1. Consistency: The degree of consistency is depended on the nature of works and type of compaction.
2. Water/cement Ratio or Water Control of a concrete: Water/cement ratio is the ratio of water in a mix to the weight of cement. The quality of water that required for a mix is depended on the mix proportions, types and grading of aggregate.
3. Grading of Aggregate: The smooth and rounded aggregate will produce a more workable concrete than the sharp angular aggregate.
4. Cement Content: The greater workability can be obtained with the higher cement content.

Aims

The aim of this experiment was to establish the effects of water to cement ratio on the fresh properties of concrete (workability), and its effect on the hardened properties of concrete (strength). Furthermore to increase the understanding in making a concrete mixture and working out the water content that needs to be added to the mixtures. And last to expand on the understanding of the importance of fresh and hard properties of concrete.

Objectives

The objectives of the experiment were to make three concrete mixtures by altering their water/cement ratios (0. 47, 0. 55 & 0. 65) and to find out the water content to use for the three mixtures. To do a variety of tests such as the slump test, compacting factor test on fresh concrete and to carry out compressive and flexural strength tests of hardened concrete. Then finally to discuss how features such as variation in the water/cement ratio affects the workability and strength of concrete.

Theory

Concrete Production, concrete is a mixture that is made up of three components, cement, water and aggregate. The water and cement are mixed together to produce a thick paste, to which then measured out aggregates are added to. The aggregates that are added are mainly composed of usual materials such as sand, gravel and crushed rocks, however due to the latest advanced technology; it has been known that other materials such as car tyres and crushed glass to be also used as aggregates. The cement is produced by blending limestone and clay, and burning it in a rotary kiln, this results in the formation of a clinker, to which gypsum is added. The mix is then ground down to fine powder cement, in which the most common is called Portland Cement. The cement/water slurry solidifies through a chemical reaction called ‘ hydration’, the reaction produces immense heat so fresh concrete must by no means be handled with unprotected bare hands. During the winter season, temperatures drop below 2°C, so the chemical ‘ hydration’ reaction may be very slow as heat is needed as a catalyst to speed up the collision of the particles. Therefore concrete pours during these seasons are not suitable as the concrete will not set. Initially this reaction is slow to start with, so this allows for the concrete to be transported and poured before it is hardened, and the theory states that complete 100% hydration takes place after 28 days.

Properties of Concrete: There are four key properties that are desired in fresh concrete i. e. good workability, compactability, mobility and stability.

The most desired properties for hardened concrete are strength and durability. The concrete should have compressive strength (resist squeezing), tensile strength (resist stretching) and flexural strength (resist bending).

All these strengths are highly dependent on the water/cement ratio and aggregate used in the mixture, the degree of compaction and the age of the concrete. Curing concrete under water over time allows hydration to continue hence giving it strength.

The concrete used in this experiment was a C30 concrete grade and according to B. S. 5328 the compressive strength for this grade at 28 days is 30. 0 N/ sq mm which can also be written as 30 MPa which is adequate for use in beams, however this is only an estimation as there are other factors (mentioned above) that affect concrete strength. In this experiment the slump test and the compacting factor test were used to assess the workability and uniformity of concrete. The deflection/ flexural strength test was carried out to evaluate the strength of the concrete beam (mini beam sample) and find the failure load of the mini beam (100mm by 100mm by 500mm). The compressive strength was carried out to determine the maximum failure load of the cube samples (150mm by 150mm) and the cylinder samples (150mm by 300mm) (Barnes 1992).

MATERIALS AND EQUIPMENT

Casting Equipment

1. Concrete mixer
2. Bucket (average size)

3. Measuring Cylinder
4. Shovel
5. Wheel Borough
6. Scale
7. Figure 2: Shows Compaction Factor Apparatus. (used to determine workability of concrete mixture)
8. Figure 3: Slump Test Apparatus

- B. S. Slump cone (300mm high, tapering from a 100mm diameter top to a 200mm diameter bottom)
- Slump rod (or steel tamping rod) (16 mm diameter, 600mm long, with rounded ends)
- Flat metal base plate (600 sq mm)

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9. Metal Rule (300mm long)

10. Metal Scoop

11. Levelling Trowel

12. Waste rag

13. Vibrating Table

14. Moulds

- 6 no. Cube Moulds (150mm by 150mm)

- 3 no. Cylinder Moulds (150mm by 300mm)
- 3 no. Mini beam Moulds (100mm by 100mm by 500mm)

15. Materials

- Course Aggregates (Stones)
- Fine Aggregates (Sand)
- Cement
- Water (Tap)

*Note: Aggregate used was natural aggregate used was from London. Therefore no need for determining aggregate moisture content as aggregate is assumed to be laboratory dry to SSD. Hence no considerable effect on water-cemet ratio.

Striking Equipment

1. Pressure pipe (for striking cubes and cylinders)

2. Brushes (Soft and Hard metal brushes)

3. Oil, oil brush and rugs (for cleaning moulds before storing)

4. Crayon (for labelling concrete samples)

5. Curing room

Testing Equipment

1. Compressive test machinery

Figure 4: Shows the Compressive test machine used to apply loads on cubes and cylinder samples

2. Deflection test machinery (Picture shown in figure

3. Load reader/display

4. Concrete samples

5. Digital Camera

*Personal Protective Clothing was worn on all days of the experiment (Safety boots and

Coats, individuals handling concrete wore protective gloves).

METHODOLOGY

Concrete Production:

1. Aggregates were readily weighed and placed into buckets. Quantities (constants) used in all Concrete Mixes are shown below:

Material Quantitative Weight (Kg)

Cement (CEM1) 6. 50

Fine Aggregate (Sand) 16. 55

Natural Course Aggregate (Stones) 26. 00

2. The amount of water required was determined by using the formulae shown below.

- Water content = (water/cement ratio) x cement weight.

3. Water was measured into a bucket using measuring cylinders.

4. The water/cement ratio was set as the variable between 3 Concrete Mixes (to determine the effect of water/cement ratio on the strength and workability of the concrete). Water content quantities used are shown on table 1.

Table 1: Water/Cement Ratio (variable) for Concrete Mixes 1, 2 &3

Concrete Mix Water/Cement Ratio Water Content (litres)

1 0. 47 3

2 0. 55 3. 6

3 0. 65 4. 25

*See Appendix 1 for Actual Calculations Carried Out.

5. The concrete mixer paddles and pan were lightly dampened before aggregates were placed in the mixer.

6. Course and fine aggregates were placed into the mixer and mixed for 30seconds.

7. Half the water required for the mix was added to the mixture and the contents were further mixed for 1 minute.

8. The contents were covered and left for 8 minutes, to allow aggregates to absorb water, (because aggregates are porous therefore they should soak in water into voids to get a good mix and bonding with cementious (water/cement) paste).

9. Cement was spread evenly over the aggregates and mixed for 1 minute.

10. The remaining water was added and the contents were mixed for 2 minutes ensuring homogeneity of the mix.

11. Workability tests were then carried out, in the order shown below.

*Note; immediately after each test the used concrete was returned into the mixer and the

contents were remixed for 30 seconds.

FRESH CONCRETE TESTS

Compacting Factor Test:

1. Trap doors of all hoppers were shut prior to beginning the test.

2. Sample of freshly mixed concrete was scooped from the mixer into the upper hopper, the concrete sample was filled up to the brim of the upper hopper.

3. The trap-door of upper hopper was opened, to enable concrete to fall into the lower hopper.

4. After all concrete had been collected onto lower hopper, the trap-door of the lower hopper was then opened and the concrete allowed to fall into the cylinder.

5. Excess concrete remaining above the top level of the cylinder was then cut off using a plane blade.

6. The concrete collected in the cylinder was then weighed. (This weight is known as the weight of partially compacted concrete).

7. The concrete filled cylinder was vibrated to obtain full compaction, and more concrete was added to the cylinder as required to ensure the vibrated/compacted concrete was filled to the brim of the cylinder.

8. The now fully compacted concrete in the cylinder was weighed.

9. The compacting factor was then obtained using the formulae shown below.

Compacting factor = (Weight of partially compacted concrete)/(Weight of fully compacted concrete)

Figure 5: Shows steps followed during the compacting factor test.

1) Compacting factor equipment.

2) Partially compacted weight is taken on a scale,

3) The concrete is vibrated/compacted on a vibrating table and then the contents are toped up and vibrated to the rim container and the partially compacted weight was taken.

Slump Test:

1. Concrete was thoroughly mixed in the concrete mixer.
2. The slump cone was dampened to prevent concrete sticking to it.

3. The slump cone/mould was placed on the centre of the metal plate and one individual was asked to stand on the foot pieces on both sides of the mould.
4. The mould was filled in 3 equal depth layers and each layer was rod 25 times using the steel slump rod (ensuring even spread of blows covering over the whole area).
5. Concrete was heaped over the top of the cone and with a rolling motion of the rod over top of the mold the concrete was levelled thus removing the excess concrete.
6. The spillage was carefully removed from the sides of the mould and the base plate
7. The mould/cone was carefully and slowly lifted vertically upwards.
8. The slump cone was turned upside down and placed next to the molded concrete and the rod was laid across the slump cone and the distance (slump) between the underside of the rod and the highest point of the moulded concrete were read using a metal rule.
9. There are different kinds of slump a collapsed slump, sheared slump and a true slump.

The first two slump types indicate bad workability and a true slump indicates good workability.

Concrete Beam Casting & Curing:

1. Concrete was scooped out of the mixer into oiled moulds on the vibrating table (ensuring even spread).
2. Concrete was vibrated throughout the pour to eliminate voids and to enable compaction of concrete by switching on the vibrating table.

3. The vibrating motion also levelled the concrete.
4. The concrete was left to set on the mould for 24 hours
5. After which concrete was struck and placed in the curing room over 14 days.

HARDENED CONCRETE TESTS

Concrete Sample Testing:

1. Compressive Strength Tests; were carried out on cube and cylinder samples.
2. Flexural Strength Tests; were carried out in the mini beams.
3. The machines where loaded with concrete sample and load applied was set to zero before running the test.
4. Base and top plates (spacers) were used to determine to provide platforms for the concrete specimens and to also help provide even distribution of load.
5. The load was applied by the machine till maximum failure load was reached.
6. This reading was taken and the machine cleaned off concrete debris before running tests for other samples.

*Note the loading Pace Rates varied for different sample shape as shown below:

- Cylinders loading Pace Rate was set at 5. 30 KN/s
- Cubes loading Pace Rate was set at 6. 80 KN/s
- Mini Beams loading Pace Rate was set at 0. 200 KN/s

RESULTS

1. FRESH CONCRETE PROPERTIES TEST RESULTS

Compacting Factor Test Results:

Mix 1

Observations: The Concrete Mix appeared to be dry and did not pass through when the trap door of the upper hopper was opened. The concrete mix was helped through the trap door to the lower hopper by pushing it with a metal rod through the first trap door. The same was done in order to get it through the second trap door into the container. This showed that it was a bad mix with bad flowability, mobility and workability properties due to low water content.

Mix 2

Observations: The concrete mix was passed through the hopers with better ease than mix 1, however only ¼ of the contents went through, the rest was forced through both trap doors with a metal rod. Therefore the flow ability and workability properties of this mix were bad, but better than mix1, owing it to the increased water content in mix 2.

Mix 3

Observations: The obtained concrete mix was a wet mix (a bit too wet) with what would appear to be good flowability properties as all contents went through the hopers and trap doors with one sweep and much ease. Therefore the flowability and workability properties were the best observed for all 3 mixes, but too much water content is not good either.

The compacting factor test was worked out for all the 3 Concrete Mixes and results are shown in table 2 below.

*The calculations were carried out on Microsoft Excel using the formula shown below.

Compacting factor = (Weight of partially compacted concrete)/(Weight of fully compacted concrete)

BS 1881: Part 103 states that concrete is deemed unsuitable if its compacting factor is below 0. 70 or above 0. 98. For normal concretes the compacting factor normally lies between 0. 80 and 0. 92 (Jackson & Dhir 1996).

Apparent workability shown below was determined by using Compacting factor table in

There was no slump as the mix was too dry therefore indicating poor mobility, flowability and workability

Collapsed slump was obtained and the slump exceeded the allowable tolerance stated in BS 5328. The slump cone was 300mm high and the concrete mix slumped by half that value to 150mm. This indicates that the mix was too wet and this affected its cohesive properties.

Very high

*Apparent workability shown above was determined by using Slump Results Table shown in Appendix 2 (Kew 2009).

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Mix 1 Dry Mix/ Zero Slump Mix 2 Wet mix /13mm True Slump Mix3 Mix too wet/ collapsed slump

Figure 7: Shows the Slump Results Obtained for concrete mixes with varying water cement ratios. (Mix 1 w/c ratio 0. 45, Mix 2 w/c ratio 0. 55 and Mix 3 w/c ratio 0. 65).

2. HARDENEDED CONCRETE PROPERTIES TEST RESULTS

Figure 8: Shows the cube specimen being loaded into the compressing machine and on the right, the classical cube hour glass failure mode on one of the cube specimen.

Figure 9: Shows the cylinder specimen being loaded into the compressing machine and on the right, the failure mode on 3 of the cylinder specimens.

Figure 10: Shows a mini beam failing when subjected to Flexural Loads. This is the classical failure mode of beams. The beam undergoes tensile and flexural strain resulting in bending and snapping of the beam. Concrete is generally brittle and this makes it weak in tension. Hence the need for reinforcement of concrete, steel is good in tension so it lends that quality to concrete, resulting in better stronger structures.

The results above are indicative of the effects of w/c ratio on the strength of concrete. At 0. 45 w/c ratio the strength was 630. 4 < at 0. 55 N/mm2, w/c ratio strength was 646. 80 N/mm2 and at 0. 65 w/c ratio strength was 703N/mm2. The trend observed here is that as w/c ratio increases strength of concrete increases. However the concrete cubes show the opposite.

This may be down to the contact surface area to volume ratio being larger in cubes than in cylinders, hence more water being absorbed during curing such that it is excess hence starts to have reverse effect.

(Influence of test conditions. Table above show that specimen shape and size is also influential on the compressive strength. Therefore measured strength of concrete is also affected by height diameter ratio. This is to just show that test conditions can also affect the determination of concrete strength. In BS 1881: Part 116 specifies that 150mm cube test are only used for quality control purposes. Whereas BS 1881: Part 120 indicates that cylinder test specimens are used to carry out compressive strength tests for in situ concrete and precast members. A correction factories usually applied to the cylinder strength to obtain an equivalent cube strength, it takes into account the specimen height /diameter ratio (i. e. 300mm/150mm = 2.). This explains the high compressive strength results obtained in cylinder specimens than in cube specimens despite the being made off the same batch of concrete. It should also be considered that the loading Pace Rates for cubes (and cylinders were varied.

The trend obtained from the results shown above indicates that increasing w/c ratio increases flexural strength. Af hydration strengthens the bonding between the cementious material and the aggregates. However like all other factors, too much of anything is not good. If the mix has excess water it will result in reduced flexural strength and results in bleeding of concrete thus a weakened structure with pours in them. Again the normal distribution curve can me expected with extremes.

DISCUSSION

One type of test is not enough to indicate the workability of the concrete as a whole. Use of various tests bring out various properties that determine workability, for example, the compacting factor can indicate how workable in the concrete will be in terms of how easily can the concrete be vibrated and compacted. It is also a good indicator of the mobility and flowability of concrete. It Shows how easily the concrete can be pumped from a concrete skip into shutters, how easily the concrete will pass through the skip trap door when on casting real structure on site. On the other hand the slump best indicates how workable the concrete is in terms of its cohesive nature and segregation of its aggregates. It is important to carry more than one of these tests to indicate various workability factors. These tests can also be carried out at various stages between concrete production and casting. The common construction site test (In situ test) is the slump test, it serves as the last point of quality check prior to casting, and all other workability factors are normally carried out on the concrete production sites. For example, the compactability factor will be most useful on production as other mobility enhancing admixtures may be added prior to transporting concrete to site, hence saving time, money and other complications that may arise from delaying site programmes. From table 2 the results obtained from all mixes had compacting factors between 0. 70 and 0. 98 hence indicating that all the tested concrete mixes would be acceptable under the BS 1881. This certainly does not mean that all mixes had good workability properties. Jackson & Dhir (1996) state that some of the basic assumptions for the test are not correct and should not be solely relied upon extensively as they can be misleading. As concrete mixes can have same compacting factor but may not always require the same amount of work to reach full compaction as compaction cannot be justified in the true sense. From the results in table 2 it shows that changing the water/cement ratio affected the compacting factor. Increasing the water cement ratio increased the compacting factor therefore the workability of the concrete. All these tests have limits, for example placing more water would have resulted in decreasing compactability factor as increasing the water content will result in lowered compacting factors. (Compacting liquid materials do not result in changes between partially compacted weight and fully compacted weight, hence if more excess water is added the mix will have lower differences between partially compacted weight and fully compacted weight. Hence giving rise to normal distribution curves for the compressive tests. This also applies to flexural strength and durability of the concrete.

CONCLUSION

In conclusion it is clear that too little w/c ratio reduces the strength of concrete just as well as too much w/c ratio will result in porous concrete. Therefore adequate amounts need to be used to gain the best results. The best way of getting accurate assumptions on concrete is to consider various factors. Increasing the water content ratio generally increases the strength but may also result in shrinkage of the concrete hence altering durability and permeability factors.

Q1: Report all the results – fresh properties (slump value and the shape of the slump) and hardened properties (strength) of the concrete and comment on the results. See Results Section for Answers.

Q2: Why the need to measure the fresh and hardened properties of the concrete?

Fresh properties are only of much importance in the stages of the concrete mix. These help concrete producers spot problems early on the stage before structures are cast thus potentially saving money, time and preventing unstable structures form being built by spotting and correcting problems with concrete at an early stage. Also this helps prevent the need to strike down newly built structures due to instability of concrete mixes used.

Fresh properties can help indicate how much work labours will have to do on site and consequently the energy and money that will be required when casting concrete on site.

On the other hand hardened concrete properties are important in determining and the life span of the concrete in the form of s concrete structure. The hardened properties are important in observing and maintaining the strength of the structure and its durability.

Other hardened factors are permeability and shrinkage of the concrete structures after being built due to harsh weathers and conditions. The latter factors are of much importance in structures like dams which require high water retaining properties.

Therefore both properties help in the development and maintenance of a good quality structures and ensuring long life span. Whilst providing adequate safety to the habitats of those structures.

Q3: Concrete is usually tested at 28-Days for its compression strength. Why at 28-Days?

The specimens should be cured under water and for normal concrete they should have reached maximum strength at 28 Days. Concrete hardening process (Hydration) is thought to reach its final strength in 28 Days as the reaction slows to a halt and adding more water or curing concrete past that stage will sure minute or no further significant changes in concrete strength.

Q4: As for reinforced concrete beam, describe the need to place reinforced steel in concrete beam, the purpose of cover/spacing, the diameter of the steel used and why concrete beams need to be reinforced?

Concrete is good in compression meaning it has high resilience to compressive forces but is very weak in tension. As noted in the results the beams failed at much lower loads than both cubes and cylinders, although there are other factors that play a role here that is the general observation. Hence concrete reinforcement is required, it has good tensile resilience and when concrete and steel are combined they result in components strong in both tensile and compressive properties. The purpose of concrete cover is to protect steel from corrosion, due to air reacting with steel and prevent rust formation due to water.

Corrosion and rust results in weakened concrete structure as may result in loss of resilience to tensile forces. So the concrete cove4r provides protection and a neutral environment for steel. Concrete cover usually ranges around 500mm from the steel bars.

Excess cover is not good as it makes the structure more susceptible to chipping and hence weakens the cover itself and increases chances of steel corrosion taking place. The diameter of steel used can vary according to the purpose of the structure but over reinforcement can also bring about imbalances to the structural stability and may result in a weakened structure. The normal diameter used ranges between 10-30mm, this makes it easier to bend and alter on site as well as provide ease of manual handling for steel fixers.