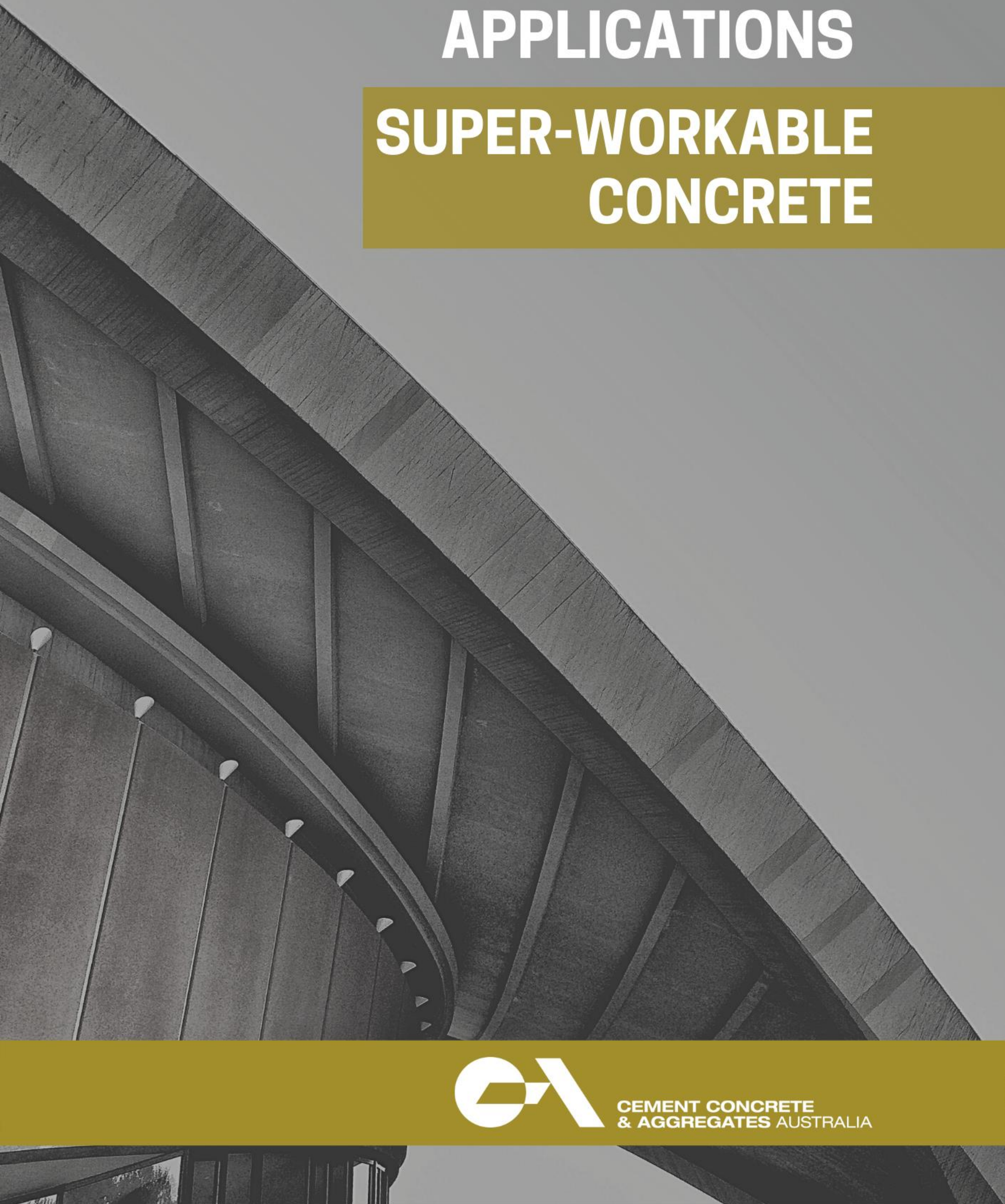

PART VI.
SPECIAL CONCRETE APPLICATIONS

SUPER-WORKABLE CONCRETE

CEMENT CONCRETE
& AGGREGATES AUSTRALIA

CONTENTS

1. OUTLINE

Traditionally concrete has always required a significant compaction effort to consolidate it to a degree that will produce optimal hardened properties. In many circumstances where concrete is to be placed it would be desirable to produce a concrete that requires little or even no compaction but still achieve all required properties.

Attempts to achieve this 'self-compacting' plastic state of concrete by using significant additions of water normally led to segregation of the concrete and poor hardened concrete properties. In the mid 1970's the availability of 'superplasticisers' (now called High Range Water Reducers) in various locations around the world (including Australia) provided a key ingredient for producing a useful form of 'Super-Workable Concrete'.

As high range water reducing admixtures and concrete mix designs have developed over the years, potential for producing non-segregating, partly or fully self-compacting concrete has become a reality and is now a more common concrete product. In Australia we have referred to this range of products as 'Super-Workable Concrete' but internationally they are also known as 'Self-Consolidating Concrete' or 'Self-Compacting Concrete'.

2. THE USES OF SUPER-WORKABLE CONCRETE

2.1 GENERAL

Super-workable concrete (SWC) is not suitable for use in every concrete application but does have certain features and benefits that will make it a suitable and efficient product to use in certain applications.

Some of the benefits of SWC are listed below:

- Reduced noise on site from equipment used to compact normal concrete;
- Possibly lower numbers of personnel used in placement of SWC with likely lower construction costs;
- Improved and more consistent compaction of concrete;
- Improved off-form finish quality.

The key reasons for this product not currently taking a majority position in the pre-mixed concrete products is the higher level of complexity in producing a consistent and reliable SWC. This complexity relates to issues like selecting suitable constituent materials, effective mix design and evaluation, control of mix water content and the level of supervision required to guarantee performance of the concrete in its plastic state.

Controlling these factors will normally lead to a more costly mix than would be the case for more easily controlled 'normal' concrete. The following sections provide a guide to designing, specifying and controlling the SWC product.

While there are many higher slump concrete products in regular use these may not meet the requirements of SWC.

3. DEFINING SUPER-WORKABLE CONCRETE

3.1 GENERAL

The name 'Super-workable Concrete' was first suggested in Australia by the committee responsible for the Concrete Institute of Australia Z40 document of the same name (see reference [4]). The committee for this guideline recommended some suitable test types and limits for this range of products. In terms of the more common consistency test, slump, SWC is taken to refer to concrete mixtures that have a slump of 250 mm or greater.

If a well-proportioned normal class concrete that is designed for an 80 mm target slump had sufficient water added to it to achieve a slump in excess of even 240 mm it is likely that it would segregate during placement [i.e. the mortar would separate from the coarse aggregate; the paste (i.e. the water + admixtures + binder) would separate from the mortar; and possibly the water would separate from the paste – i.e. heavy bleeding].

To counteract the effects noted by adding water to a standard mix, the paste viscosity needs to be increased to a level where the coarse and fine aggregate will be prevented from separating from the paste while maintaining the consistency of the concrete mix. Water/Binder ratio has a significant impact on paste viscosity as have the admixtures and additives used in the SWC mix design. The study of this behaviour of concrete is generally referred to as 'Concrete Rheology' and is discussed in the following.

3.2 CONCRETE RHEOLOGY

While Slump measurements can provide some indication of the amount of compactive effort that will be required to compact plastic concrete, they have a limited range of applicability. Concrete mixes with the same Slump value can require very different amounts of effort to fully compact them. SWC introduces additional complexities and workability measurement requires a different approach.

Work by Wallevic and others [6] has shown that the Bingham Model (**Figure 22.1**) provides a means of understanding the rheology of concrete mixes. These studies are carried out using rheometers which measure the shear rates obtained when a range of shear stresses are applied to a concrete mix. From this work, two definitive properties can be determined, namely (1) the Shear yield stress (τ_0), and (2) the Plastic Viscosity (μ).

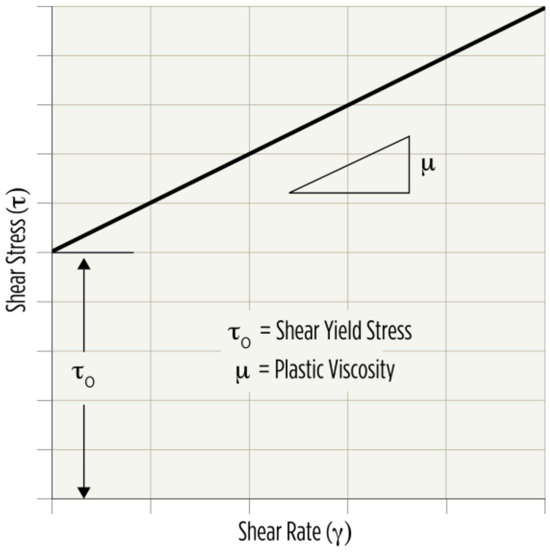

Figure 22.1 – Bingham Model of Shear Stress Vs. Shear Strain Rate

The Shear Yield Stress reflects the amount of energy that needs to be imparted to a mix to cause it to flow, while the Plastic Viscosity reflects the viscosity of the mix – that is, the ease with which it will flow.

When comparing flow characteristics of a concrete mix with a (say) 100 mm slump with those of a SWC in a rheometer, it would be seen that the low-slump concrete would have a relatively high Shear yield stress value and a steeper Plastic Viscosity curve compared to the SWC. In practical terms, it would take more effort to make the 100 mm slump concrete begin to flow and higher levels of effort to compact and finish the concrete. The SWC would have a low Shear yield stress value and a relatively flat Plastic Viscosity curve.

These characteristics of SWC help guide the development of test methods for assessing SWC and assist with providing an understanding of the behaviour of SWC in dynamic processes (such as compaction or pumping).

The factors in a concrete mix design that impact on concrete Shear Yield Stress are largely:

- Water content (higher water content = lower τ_0);
- Type of admixture and dosage;
- Quantity of paste at the same W/B ratio (higher paste volume = lower τ_0);
- Binder components (e.g. replacing GP Cement with fly ash is likely to lower τ_0).

The factors in a concrete mix design that impact on Plastic Viscosity are largely:

- Water/Binder ratio (higher W/B ratio = lower μ);
- The presence of viscosity modifying admixtures (VMA) that are designed to increase viscosity in SWC;
- Water content (lower water content = higher μ).

The impact of the proportion and properties of coarse and fine aggregates in the concrete mix design on these two rheology factors is more complex and will be discussed in *‘Materials for Super-workable concrete’* below.

4. MATERIALS FOR SUPER-WORKABLE CONCRETE

4.1 BINDERS & MINERAL ADDITIVES

When designing a SWC mix one of the most critical decisions will be that of the combination of materials to be used in the binder.

While it is possible that a Type GP or Type HE Cement may be a sole binder component, this is unlikely unless the GP or HE cements display a level of consistency, compatibility with the selected admixtures and ability to avoid segregation at the design water/binder ratio. Assessing this is discussed in 4.3 below.

Along with a Portland cement product some of the common supplementary cementitious materials (SCM’s) that are used in SWC are:

- Fly ash (generally Fine Grade but not universally);
- Ultra-Fine Fly ash;
- Ground granulated blast furnace slag;
- Amorphous silica.

These SCM’s need to be carefully selected and blended with a suitable Portland cement with particular attention being paid to their properties including particle size distribution, presence of fine carbon and quality consistency.

The European experience has been that inert mineral additives can also be used with Portland cement to improve the mix rheology and resistance to segregation by maintaining a higher paste viscosity. Some examples of these are:

- Ground limestone powder (already present to a minor degree in many Type GP cements);
- Ground silica;
- Some forms of stable clay (e.g. Attapulgite).

The focus on mineral additives is generally to achieve very small average particle size. When these are used the relative proportion in the mix will be significantly lower than that of a coarser SCM.

4.2 COARSE AND FINE AGGREGATES

Both coarse and fine aggregates will influence the SWC rheology. The individual properties of these aggregates are discussed in this section, but the blending of aggregates is more appropriately discussed in 6.2 *‘Mix Design’*.

Research has demonstrated that coarse aggregate with poor shape will lead to higher shear yield stress and when the SWC mix is corrected by water addition or admixture adjustment, it is more prone to segregation. Coarse aggregates with consistently good shape (round or cubical) will improve the flow characteristics of the concrete.

The maximum aggregate size of SWC will generally be no more than 20 mm and have a combined coarse aggregate grading that is continuous rather than single sized. In cases where higher slump flow and improved passing ability (see 5.2 *'Plastic Properties'*) are required it may be necessary to reduce the maximum aggregate size to 14 mm or 10 mm in some cases.

As the mortar density of SWC is likely to have a plastic density between 2,100 kg/m^3 and 2,200 kg/m^3 it is also important to source coarse aggregates which comply with the requirements of AS 2758.1 and useful if the aggregates also have a particle density less than 2,700 kg/m^3 to lower the risk of segregation of the coarse aggregate from the mortar.

The fine aggregate plays a major role in the resistance of the SWC mix to segregation. A single fine aggregate or blend of several fine aggregates should comply with AS 2758.1 and have a uniform grading (no single particle size range between consecutive standard sieves being greater than 30% is ideal). The average fine aggregate particle size is reflected by having a fineness modulus between 2.40 and 2.60 (see Part III of this Guide).

The use of a proportion of manufactured sand in the sand blend may be beneficial. In this case a proportion of the manufactured sand fines (passing 75-micron sieve size) can be considered as a part of the binder. Care should be exercised in the selection of sand sources in regard to maintaining consistent grading.

4.3 ADMIXTURES

As noted in the outline of this section, a key to developing SWC has been the use of 'High range water reducing admixtures' (HRWR). The early forms of these admixtures were based on sulphonated melamine formaldehyde condensates and sulphonated naphthalene formaldehyde condensates. These were moderately effective but had a short 'slump life' which meant that it was difficult to use these admixtures by adding them at the concrete plant. This did see some popularity of site added HRWR to try and overcome the issues of more rapid slump loss.

More recent innovations in HRWR admixtures has seen benefits with the introduction of poly-carboxylic ether (PCE) based admixtures to Australia in the late 1990's. Over time newer and improved versions of HRWR are becoming available.

Other types of admixtures used in SWC may include:

- Viscosity modifying admixtures (VMA);
- Slump retention admixtures;
- Standard retarding admixtures (Type Re).

Viscosity modifying admixtures aim to increase the plastic viscosity of concrete but may also increase the shear yield stress of the concrete. They can be very useful when designing a SWC mix with a total binder content at the lower end of the acceptable range (see 6.2 *'Mix Design'* following).

Slump retention admixtures are generally a combination of PCE based HRWR with modification of the molecular structure to produce a longer working life of the concrete. These become useful when SWC placement needs to be prolonged for any reason.

Retarding admixtures are based on a number of organic and inorganic chemical solutions. The aim of using these in combination with other admixture in SWC is to prolong the setting of the concrete if required.

5. TESTING OF SUPER-WORKABLE CONCRETE

5.1 GENERAL

SWC can be tested for hardened properties in much the same way as standard concrete (refer to Part VIII, Section 26 of this Guide). The key differences in test methods relate more to the SWC plastic properties where tests to determine the mix capacity to self-consolidate become critical to acceptance.

Most tests for normal concrete hardened properties apply to SWC but may require slight variations in the casting method. Both plastic and hardened property methods are discussed in the following.

5.2 PLASTIC PROPERTIES

SWC requires testing for plastic properties that is different to the test methods used for normal concrete. The key properties that help describe the rheology of a SWC mix are:

- Consistency;
- Resistance to segregation;
- Passing ability;
- Filling ability;
- Rheology.

Each of these tests has a relationship to the concrete rheology values of the mix shear yield stress and the plastic viscosity. Setting limits on the tests help with specifying the performance of the concrete during placement.

Consistency

The traditional consistency test for normal concrete is the slump test described in AS 1012.3.1. A variation of the slump test is described in AS 1012.3.5 *'Slump flow, T_{500} and J-ring test'* test method. This test differs from the slump test in that it is measuring the average diameter (mm) of the concrete moving out from the standard concrete slump test cone as the cone (filled with SWC) is lifted.

The cone is placed on a carefully levelled base plate that must be sufficiently rigid so as not to distort during testing. The plate is made of non-absorbent material and will generally be square or circular with a minimum diameter of 900 mm. A 200-mm circle is printed on the centre of the base plate for positioning the cone and a concentric 500-mm circle printed to assist with the 'T_{500}' test.

Filling of the cone is carried out by pouring SWC into the cone (that is held down to prevent leakage and with a collar fitted on the top) in one motion. The SWC has no additional compaction other than the effect of pouring the SWC into the cone. When filled, the collar is removed from the cone, the top surface of the concrete in the cone levelled and any excess concrete spilled is carefully cleaned from the outer surface of the cone and base plate. The cone is then lifted vertically in a slow action that is completed in 3±1 seconds.

The SWC concrete flows out from the base of the cone as it is lifted and two details are recorded:

- The time it takes for the concrete to reach the 500-mm diameter line. This time (to 0.1 second from starting to lift the cone) is recorded as the T_{500} result;
- The average diameter of the spread concrete once it ceases to flow. This is the 'slump flow' and is recorded in 'mm'.

These two properties are related to the mix shear yield stress and the plastic viscosity in the following ways:

- Slump flow is impacted to a minor degree by plastic viscosity, but it is more significantly related to shear yield stress (see **Figure 22.2**);
- T_{500} is largely related to the plastic viscosity of the concrete (see **Figure 22.3**).

It should also be noted that the actual value of shear yield stress required for a given slump flow will vary with the aggregates used in the mix. It is impacted by maximum aggregate size, coarse aggregate content of the mix as well as the concrete plastic density. It is unlikely that a mix with a 20-mm maximum size aggregate will be suitable for a specified slump flow of over 650 mm and also unlikely that a mix with 10-mm maximum size aggregate will be suitable for a specified slump flow of over

800 mm without risking segregation of the mortar from coarse aggregate as well as effects on some hardened concrete properties.

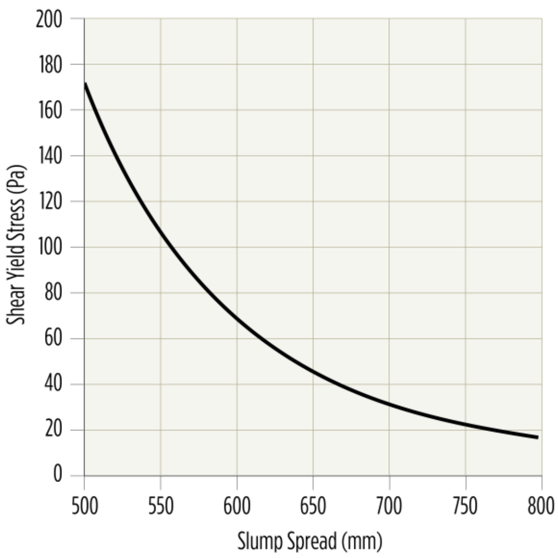

Figure 22.2 – Approximate Relationship between Slump Flow and Shear Yield Stress (based on theoretical mortar values)

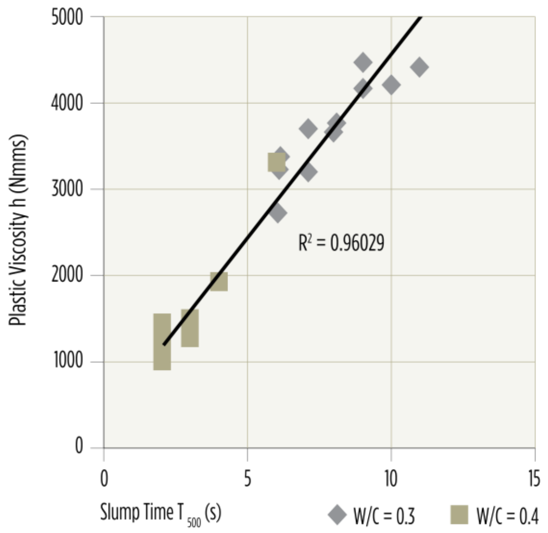

Figure 22.3- Relationship between Slump Flow T_{500} Time and Shear Plastic Viscosity (Drewnjok et al [9])

Resistance to Segregation

The resistance to segregation of SWC is typically assessed using three methods:

- J-Ring test;
- L-Box test with reinforcement bars in position;
- GTM Screen Stability test.

The J-Ring test method is detailed in AS 1012.3.5 and is an adaption of the slump flow test. In this case a ring holding a set of 12 mm diameter bars is placed on the slump flow base plate around the slump cone. When the cone is lifted the SWC flows through the bars that are set at either 40 mm, 50 mm or 66 mm spacing around the ring. Of interest in this test is the height of the concrete inside the ring and the height of the concrete immediately outside the ring after the concrete flow has ceased. The difference in these heights (expressed in mm) is an indication of the potential for the SWC to segregate during placement. The form of segregation assessed in this test is generally separation of the coarse aggregate from the mortar.

The ‘L-Box’ test method is detailed in CIA Z40 [4]. The test is largely aimed at assessing the passing ability and filling ability of a SWC mix but can be used to assess the potential for segregation by measuring the drop in height of the concrete before and after the set of bars placed in front of the ‘gate’. This value can be reported and compared to a specified maximum value. The L-Box test is more commonly used in a laboratory for mix design verification.

The GTM Screen Stability test method is detailed in CIA Z40 [4]. The principle of the method is that a 10-litre sample of SWC is allowed to stand in a covered bucket for 15 minutes thus allowing for segregation of the aggregate in the form of settlement leaving a mortar rich layer at the top of the bucket. The top two litres of SWC in the bucket is weighed, placed on a 5 mm sieve over a pan (350 mm diameter sieve and pan assembly) and left for 2 minutes during which the mortar fraction may segregate from the coarse aggregate through the sieve and into the pan. The segregated mortar is weighed and expressed as a percentage of the original weight of the SWC sample. A higher percentage of material passing the sieve indicates a higher likelihood of segregation, while too low a value suggests that the plastic viscosity of the mix is too high and may result in poor filling ability.

If the tendency of concrete to segregate is too high by each of these test methods, then the mix may need to be adjusted to increase either the plastic viscosity or increase the shear yield stress.

Passing Ability

Passing ability of SWC is the capability of the mix to flow through smaller gaps between reinforcement or other obstructions during concrete placement.

The common tests for this property of SWC are listed:

- J-Ring Passing Ability test;
- L-Box test with reinforcement bars in position.

Both tests have been discussed under the category of assessment for segregation but in both cases the measurement of the flowing characteristics when passing through the barrier of a set of steel bars provides an indication of the likely performance of the SWC mix.

The slump flow of SWC is also measured using the J-Ring as a barrier to flow. By comparison of the standard Slump Flow test with a repeat test using the J-Ring, it is possible to estimate the mix passing ability. As a guideline, the difference between Slump Flow and J-Ring Slump Flow diameters (average diameter in two perpendicular directions in both tests) is useful. If the flow diameter of the J-Ring test is more than 20 mm lower than the Slump Flow test or the J-Ring Passing Ability is more than 10 mm difference between the inner side and outer side of the ring then some blocking action is occurring that may need correction in the mix design.

The L-Box test method is discussed under the subject of segregation and it also assesses a value referred to as ‘Passing ability’. This value is not only useful as a guide to segregation but also refers to passing ability.

Passing ability is related to both plastic viscosity and shear yield strength of SWC. If the shear yield stress is too low for the plastic viscosity to control segregation, then this will be a detriment to the passing ability. Similarly, if the plastic viscosity is too high for the shear yield stress of the SWC then this will also be a detriment to passing ability.

Filling Ability

This property of SWC measures the ability of the concrete to flow into a form and fill it without compaction effort being applied to the concrete.

The two common tests to assess this ability are:

- L-Box test;
- Orimet Test Method.

The L-Box test method also measures a value referred to as the ‘filling ratio’. The filling ratio is the ratio of the height of the concrete at the front end of the L Box to the height of the concrete at the base of the filling tube. The closer the ratio is to 1.00, the better the SWC mix flowing and filling capacity is.

The Orimet test method and equipment is defined in EFNARC [5] and is a simple test that is used to assess the flow-ability of SWC. The method is simple and quick to carry out. A sample of approximately 8 litres of SWC is poured into the Orimet apparatus tube with the trap door shut (see **Figure 22.4**). The trap door is opened in less than 10 seconds from filling the tube and the time taken for the concrete to flow out under gravity is measured. The point at which the tube is emptied is considered to be when daylight can be seen through the funnel at the bottom of the tube (looking from above the tube).

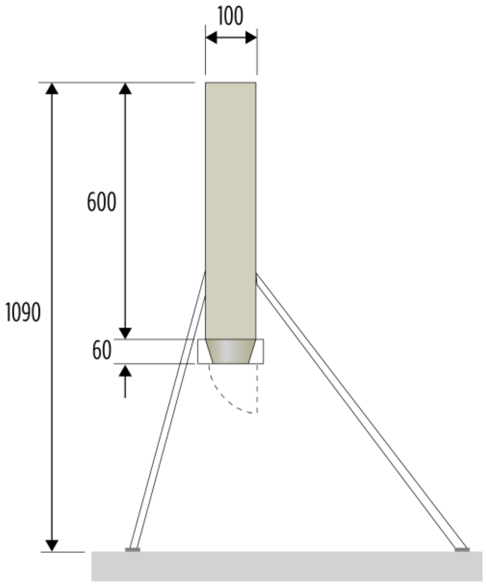

Figure 22.4 – Orimet Testing Apparatus [5] (all dimensions are in millimetres)

Typical specified flow times are less than 5 seconds using the standard 80 mm outlet of cone diameter.

Filling ability is largely impacted by the shear yield stress of the SWC. The lower the shear yield stress then the better the filling ability is – provided that the plastic viscosity is not too high.

Rheology
Testing the two rheological factors covered in sub-section 3.2 can be carried out using a rheometer. Most rheometers are only suitable as a laboratory-based aid to research and unlikely to be suitable for site quality control. There are many different commercial brands of rheometer and it is difficult to compare rheometer test results from one instrument with those from a rheometer with a different design.

A complicating factor in this is that many rheometers have rotor sizes and blade sizes that, while suitable for paste and mortar mixes, have their calibration impacted by coarse aggregate that is generally present in concrete. If a suitable rheometer is used to assess concrete it is important that the same instrument is used for all assessments of all concrete mixes on the same project. Where two or more rheometers are used on a single project or in a single laboratory, it is critical that rigorous testing comparisons of results are carried out on the same batch of concrete to assure comparable results between rheometers across a range of rheologies.

5.3 HARDENED PROPERTIES

The standard tested properties for hardened concrete also largely apply to SWC:

- Compressive strength;
- Tensile strength;
- Drying Shrinkage;
- Modulus of elasticity;
- Creep.

The only adjustments made to the test methods in each of these cases are that the normal concrete compaction methods do not apply to SWC samples. It is normal for casting test specimens that the mixed sample of SWC is placed into a suitable bucket and poured into test moulds to fill them without rodding or vibration.

For a given compressive strength and plastic density of SWC concrete the relationship of compressive strength to tensile strength, modulus of elasticity and creep are expected to be the same as for normal concrete.

Drying shrinkage of SWC is very dependent on mix design but due to lower coarse aggregate contents may be slightly higher than that in some normal concrete mixes but still conforming to AS1379 [2].

6. MIX DESIGN AND SPECIFICATION OF SUPER-WORKABLE CONCRETE

6.1 GENERAL

In Part III of this Guide the mix design of normal concrete was discussed. While the basic steps of mix design outlined in Part III of this Guide are the same for SWC as for normal concrete, the mix proportions, the testing requirements and the importance of laboratory trials are quite different.

Key differences will be:

- The hardened properties of the SWC mix may not be the most significant influence on the final mix design. Target compressive strength for the mix may be much higher than specified as an outcome from achieving required plastic properties;
- The plastic properties of SWC will be more complex to achieve. The combined effects of binder selection, admixture selection and total mix water control will be of far greater importance in designing and producing a SWC;
- The total water content of the SWC mix will most likely be higher than normal concrete of the same characteristic strength. This varies with materials and admixtures used but are controlled by the need to achieve the required plastic properties;
- The importance of assessing proposed mix designs with laboratory trial mixes

cannot be overstated. A single mix may require several adjustments after trials so as to achieve the required plastic properties;

- In the product supply phase, SWC mix ingredients will need to be monitored carefully for variation. Minor variations in materials such as binders and aggregates that would be tolerated in normal concrete have impacts on SWC that are magnified and can send a previously conforming mix out of specification.

6.2 MIX DESIGN

The key steps in preparing a preliminary mix design for trial mixing are suggested as follows:

1. Select a suitable binder combination. In general, this will contain a Type GP or HE cement, at least one SCM and some finer particle size SCM or mineral addition;
2. Obtain test data on the selected binder materials including their particle density and particle size distribution;
3. Determine maximum aggregate size and suitable aggregate sources (see 4.2 *'Coarse and Fine Aggregates'*). If a higher degree of passing ability and filling ability is required, then the maximum sized aggregate may need to be reduced to 14 mm or 10 mm;
4. Obtain test data for coarse and fine aggregates to be used. Data should include particle size distribution, particle density and water absorption for all aggregates. For coarse aggregates the particle shape (flakiness index to AS 1141.15) should be investigated before using (see **Table 22.1**). Blend the coarse aggregates to achieve a 'graded' particle size distribution as recommended in AS 2758.1 Appendix B based on the maximum aggregate size. Test data for the compacted bulk density of the blend of coarse aggregates used should be assessed using the method of AS 1141.4. The fineness modulus and grading of the blend of sands selected should meet the requirements of 4.2 *'Coarse and Fine Aggregates'*;
5. Estimate the total quantity of blended coarse aggregates used in the mix design by multiplying the compacted dry bulk density of the blend and then correcting to saturated surface dry using the aggregate water absorption values using the method detailed in Part III of this Guide;
6. Estimate the total water requirement (see **Table 22.2**);
7. Estimate the binder content needed to achieve the minimum Water/(Cement+SCM) ratio required to meet compressive strength and concrete durability requirements following the methods provided in Part III of this Guide. Check that the binder content selected has a solid volume within the recommended range given in **Table 22.2**. The solid volume is calculated using the methods detailed in Part III of this Guide. If lower than the range, then it is recommended to increase the total binder to the minimum solid volume. If higher than the range, then careful consideration is needed regarding the binder material combination;
8. Determine the solid volume of binder, coarse aggregates and water selected. It is general for SWC to assume that the air content will be 2% (0.020 m^3). Deduct the air content and solid volumes estimated for binder, coarse aggregates and water to determine the remaining volume of the sand blend. Multiply this volume by the SSD particle density of the sand blend to determine the mass of fine aggregates used in the preliminary trial mix;
9. Select suitable admixtures to produce the required mix rheology, setting characteristics and slump flow retention. Admixture supplier's advice should be sought in this regard.

This preliminary mix is only a starting point for trialling. The next steps in the mix design will focus on the same methods of assessment recommended in Part III of this Guide (assessing consistency, yield, air content and appearance) but in addition to this a preliminary assessment of the plastic SWC rheology using selected methods detailed in 5.2 *'Plastic Properties'* is recommended. For example, a starting point would be to carry out a slump flow, T_{500} and J-Ring passing ability test on the first trial mix. The values of these tests can be compared to **Table 22.4** in 6.3 *'Specification'*. Having adjusted the mix to satisfy these specified requirements then continue to test for other relevant plastic properties.

Table 22.1 – Aggregate Property Specifications

Property	Coarse Aggregate Blend	Fine Aggregate Blend
Grading	AS 2758.1 Appendix B – Graded	Maximum 30% retained between any two standard sieve sizes
Fineness Modulus	N/A	2.40 to 2.60
Flakiness Index	Max 25%	N/A
Maximum SSD Particle Density	2,700 kg/m^3	2,700 kg/m^3

Table 22.2 – SWC Mix Design Properties

Property	Recommended Range
Solid Volume of Binder	0.13 m^3/m^3 to 0.19 m^3/m^3
Water/Binder Ratio (by solid volume)	0.85 to 1.35
Total Water Content	160 L/m^3 to 200 L/m^3
Coarse Aggregate Content [10]	0.50 × Compacted Bulk Density (kg/m^3)

Having produced a mix that produces suitable plastic properties, the next step is to assess the hardened properties. The modifications available to improve hardened properties detailed in Part **III** of this Guide apply here but it must be noted that any adjustment will need another review of plastic properties until all requirements are met.

As an example, the following materials are selected to produce an SWC mix that is expected to use a blend of Type GP cement with 15% of ultra-fine fly ash in the total binder. The specified maximum W/B ratio is 0.40 to achieve the required durability:

- Type GP Cement has a particle density of 3,140 kg/m^3;
- Ultra-fine fly ash has a particle density of 2,250 kg/m^3;
- The coarse aggregate is a 14 mm maximum sized, graded aggregate with an SSD particle density of 2,660 kg/m^3, water absorption of 1.2%, a flakiness index of 14% and a Bulk density of 1,680 kg/m^3;
- The fine aggregate is a blend of two natural sands with a fineness modulus of 2.42, an SSD particle density of 2,620 kg/m^3 and water absorption of 0.9%;
- An admixture combination has been selected with a dosage set at 3.64 Litre/m^3 and an average specific gravity of 1.10.

In **Table 22.3** the resulting preliminary mix design is displayed using the methods provided in this section.

From a brief review of **Table 22.3**, the proportion of combined coarse and fine aggregates will have a grading with close to 50% passing the 4.75 mm sieve. This is a high percentage of sand when considering the binder volume of this mix, but it is characteristic of SWC concrete.

Table 22.3 – SWC Mix Design Example

Material	Mix Design (kg)	Material Volume (m^3)
GP Cement	385	0.1226
Ultra-Fine Fly ash	70	0.0311
Water	182	0.1820
Air Content	2.0%	0.0200
14 mm Coarse Aggregate	850	0.3196
Blended Fine Sand	842	0.3214
Admixtures	3.64	0.0033
TOTAL MASS & VOLUME	2,333	1.0000

6.3 SPECIFICATION

Specification of SWC is largely aimed at achieving the necessary rheology to produce concrete that can be placed with little or no compaction. The SWC should fill the forms without significant segregation.

Typical specified plastic properties will include:

- Slump flow target and acceptable range;
- T_{500} range;
- J-Ring passing ability maximum value;
- L-Box filling ratio minimum value;
- L-Box passing ability maximum value;
- Orimet flow time maximum value;
- GTM screen stability test acceptable range.

Generally, a selection of these tests may be specified along with a testing frequency. The CIA Z40 (4) document does provide some useful guidelines on specifications for these tests and has influenced the typical values provided in **Table 22.4**.

Table 22.4 – Typical SWC Plastic Property Test Specified Values

Test Method	Target Range	Max.	Min.
Slump flow (mm)	550 - 800	T+50	T-50
T_{500} (secs)	2.0 - 7.0	T+25%	T-25%
J-Ring passing ability (mm)		10	
L-Box filling ratio	0.8 - 1.0	1.0	0.8
L-Box passing ability (mm)		10	
Orimet flow time (secs)		4	
GTM screen stability (%)	5 - 15	15	5

7 REFERENCES

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