Technical
Note 73

Concrete aggregates

The requirements of AS 2758.1 - 2009

1.0 Background to AS 2758

Australian Standards are prepared by committees of industry representatives who contribute their expert knowledge to ensure the information contained in a Standard reflects the best technical, scientific and system knowledge available.

In the case of AS 2758, Aggregates and rock for engineering purposes, a set of Standards has been developed to ensure uniform material compliance is identified and specified, thus minimising the risk of a failure in a project. AS 2758 comprises seven individual standards, viz:

AS 2758.0	Part 0 Definitions and classification
AS 2758.1	Part 1 Concrete aggregates
AS 2758.2	Part 2 Aggregate for sprayed bituminous surfacing
AS 2758.4	Part 4 Aggregate for gabion baskets and wire mattresses
AS 2758.5	Part 5 Coarse asphalt aggregates
AS 2758.6	Part 6 Guidelines for the specification of armourstone
AS 2758.7	Part 7 Railway ballast

This technical note provides background knowledge of the requirements for aggregates for use in concrete.

Aggregate produced from rock, gravel, metallurgical slag or suitable synthetic materials may be used provided the particular criteria set out for the aggregate is met. AS 2758.1 sets out the requirements for the quality of a material source and the properties of the coarse and fine aggregate. Although a number of requirements are nominated, there are some sections that require the use of only one set of the limits shown.

This Standard sets out the required criteria as known at the time of publishing and should not be read as a stand-alone document unless it is nominated as the only material specification in a works specification. In most circumstances, the full range of testing shown is not required to control ongoing supply of aggregates to a particular project. Separate inspection and test plans may be established for that purpose.

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2.0 Concrete Applications

Concrete is a construction material made of a mixture of glue (cement, fly ash, GGBF-slag, etc), rocks (coarse aggregate), sand (fine aggregate) and water that hardens to a stone-like mass. Chemical admixtures are frequently used to accelerate or retard set time, improve workability, reduce mixing water requirements, increase strength, or alter other properties of the concrete. The correct dosage of these is critical to achieve the required design properties. Other additives such as coloured oxides or fibres may also be added to alter the concrete's appearance or its performance.

Concrete can be designed and supplied to suit a very broad range of required properties in both the plastic and hardened states. Ranging from low-strength footpath concrete to 100 MPa high-strength concrete columns in high-rise construction, each mix is designed for a specific purpose and application.

Concrete is the most-used man-made construction material in the world. Thorough knowledge and understanding of this versatile material is essential to fully utilise its benefits. Concrete is one of the few construction materials which arrives on site not in its final form. It thus relies on the experience and understanding of the concretor to ensure it is placed, compacted, finished and cured properly to reach its full potential.

Concrete is formed by mixing measured quantities of the constituents into a plastic material which is then placed, compacted, finished and cured to become a condensed solid mass. The combining of the materials is done in a systematic way to ensure even distribution of all the particles throughout the mix, even after compaction takes place. In designing a concrete mix, knowledge of the required workability, location, application and proposed placement method (pumping, crane-and-kibble, spraying or directly from a chute), is essential as are the required hardened properties, such as 28-day compressive strength.

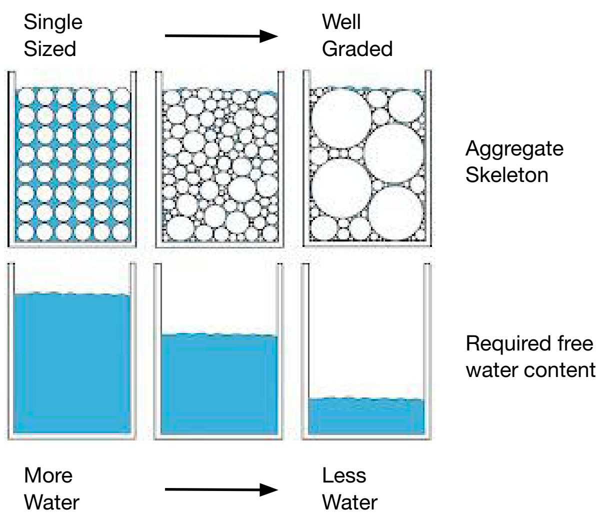

Figure 1: Impact of aggregate skeleton on water demand. Shows the influence of the void system (aggregate skeleton) on the volume of water required. The more consistent and well graded the particle distribution within the mix, the less free water is needed and the greater the strength and the lower the drying shrinkage that will be achieved

The selection of mix proportions involves a balance between economy and the requirements of placeability, strength, durability, density and appearance. For that reason, the choice of aggregates for a particular project may be heavily influenced by its source distance from the project, and specifically from the concrete batch plant. It may also be that a special aggregate is required to achieve a special design property such as a lightweight concrete, heavyweight concrete or one with low drying shrinkage due to design and construction constraints. For this reason, a clear understanding of the properties of the aggregates to be used in the concrete is essential in order that repeatable and reproducible measurable engineering properties can be achieved in the final product.

The largest single ingredient in concrete is the aggregate, both coarse and fine; it comprises 70-80% of the total mass of all constituents. The properties of these aggregates therefore needs to be well understood to enable the supplier to provide a mix that will achieve the required properties.

Some of the required aggregate properties are linked to a particular exposure classification. The exposure classifications referred to in this document are those nominated in Australian Standard AS 3600 Concrete Structures, which specifies exposure classifications based on the distance from the Australian coastline and the expected chloride and sulfate exposure the concrete is likely to experience in its service life. For example, aggregates for use in concrete in an exposure classification C environment, would be durable and able to withstand the environmental conditions likely to be experienced on site.

It is important to consider all of the definitions provided in Section 4 as they assist in understanding the terms of aggregate supply. These definitions also briefly differentiate what is known in the industry as 'fine' and 'coarse' aggregate.

3.0 Aggregate properties and the test methods specified in AS 2758.1

3.1 General

AS 2758.1 outlines the test requirements for the supply of aggregate for concrete. Each aggregate property is covered in a separate section of the standard as follows:

- Section 7 General requirements - covers Bulk Density, Particle Density and Water Absorption.
- Section 8 Dimensional requirements of the aggregate are outlined and designates them as grading for coarse and fine aggregate, material finer than 75µm, material finer than 2µm. This section also covers the requirement for shape in coarse aggregate (either by Misshapen Particle test or Flakiness Index test).
- Section 9 Requirements for durability. In this section limits are given based on the worst exposure classification. A more detailed explanation of the range of exposure classifications is shown in Appendix A of the Standard.

The requirements shown are based on the materials having the ability to withstand service conditions within a design life span of 40 to 60 years. Should a project require a longer design life then more stringent requirements may be nominated.

The tests nominated for these durability requirements are, Wet Strength and Wet/Dry Strength Variation, Los Angeles Value, Sodium Sulfate Soundness and Unsound and Marginal Stone content. Either a single test procedure or a combination of tests is needed. Only one form of the assessment methods may be required to assess the aggregate durability. This provides the user with a choice of tests to demonstrate the durability of the aggregate.

- Section 10 Requirements for alkali-reactive materials.
- Section 11 Requirements for weak particles in coarse aggregate.
- Section 12 Requirements for light particles.
- Section 13 Drying shrinkage in concrete and the influence of aggregates on that property.
- Section 14 Requirements for impurities within aggregates.
- Section 15 Requirements slag aggregates.
- Section 16 Requirements for lightweight aggregates.

Details of the tests referred to in this AS 2758.1 are provided in the AS 11411 series of Standards. Other reference methods may be from various international standards such as ASTM C295, used when performing a petrographic examination. Guidance on alkali aggregate reaction (AAR) is provided in the CCAA T47/SAA HB 79 - 2014 document.

The work specifications will usually nominate the test procedures, the test limits required and the frequency of individual tests. In general, the test procedures called for will be those cited in AS 2758.1.

3.2 Test Methods and their purpose

3.2.1 General Requirements (AS 2758.1 Section 7)

Particle Density (Clause 7.1) and Water Absorption (Clause 7.3)

The particle density test is performed by taking a sample of aggregate and determining its mass by displacing a mass of water. The result is the ratio of the density of the aggregate to the density of water.

The appropriate test method depends on the size of the aggregate being tested. For coarse aggregates the test is performed in accordance with AS 1141.6.1 or AS 1141.6.2 with aggregate that has been treated in a range of conditions such as dry and saturated surface dry (SSD) condition. Fine aggregates are tested in accordance with AS 1141.5 - the samples are similarly treated.

For the coarse aggregate sample, the weighing in water is carried out in a wire basket as shown in Figure 2. For fine aggregate, the weighing in water is performed in a pycnometer (stoppered flask) due to the fineness of the sample as shown in Figure 3.

The particle density of an aggregate is used in the mix design of concrete to calculate the mass of the final mix constituents and hence its theoretical yield (1m^3). Actual yield is measured in the field by determining the concrete wet density to AS 1012.5 and dividing the actual batch masses by this density and summing to confirm that 1m^3 has been delivered.

Figure 2: Fine aggregate in a Pycnometer and a wire basket used for coarse aggregate

AS 2758.1 designates the aggregate type as follows:

- Heavyweight aggregate has a density greater than 3.2 t/m^3.
- Normal weight aggregate has a density equal to or greater than 2.1 t/m^3 but less than 3.2 t/m^3.
- Lightweight aggregate has a density equal to or greater than 0.5 t/m^3 but less than 2.1 t/m^3.
- Ultra lightweight aggregate had a density less than 0.5 t/m^3.

Water absorption is also measured in the particle density test, both in the dry state and in the saturated surface dry condition (SSD). Water absorption for the SSD condition is obtained by measuring the increase in mass of a sample that has been soaked for 24 hours and from which all free surface water has then been removed (leaving the surface of the sample damp but not wet). The change from dry to wet (water absorption) is expressed as a percentage.

This value indicates the amount of water that is likely to be absorbed into the aggregate. Any water in excess of this amount should be available as free water in determining the total water requirements of the concrete mix. Increases in water absorption values can indicate an increase in absorptive elements in the aggregates. These in turn can have some influence on concrete strength.

As solid as aggregate may be to the naked eye, most aggregate particles have some voids (known as permeable voids and impermeable voids) which are natural pores that are filled with air or water. These voids or pores also influence the particle density and water absorption of the aggregate.

The voids within an aggregate particle should not be confused with the void system which makes up the space between particles in an aggregate mass. The voids between the particles influence the aggregate skeleton of the concrete mix design, whereas the test for water absorption is a means of calculating the water content of the particles needed to fully moisten them internally.

No absorption limits are specified in AS 2758.1 but it is noted that the average absorption of normal weight aggregate is about 2%. It is also noted that higher values may be acceptable based on local experience. Changes in water absorption may indicate potential changes in other aggregate properties. For example, weathered or soft material may have a high water absorption, and have poor long-term durability and strength characteristics.

For lightweight or vesicular aggregates the water absorption values are generally much higher and durability or other requirements are used to assess the suitability of the aggregate.

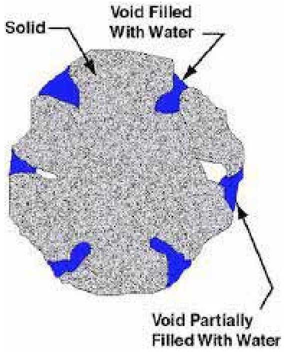

Figure 3: Shows how moisture will enter the surface particle voids, but not all voids will completely fill with water

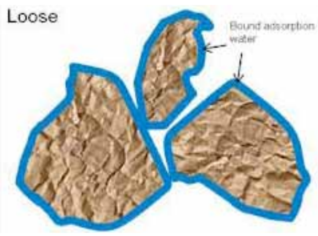

Figure 4: Shows the effect of water on the surface of the aggregate, which is over and above the void filling. The water contained outside the aggregate particles is considered free water in the concrete mix and contributes to calculations of water-cement ratio in the mix design

Bulk Density (Clause 7.2)

Bulk Density is carried out in accordance with AS 1141.4. The test gives the density (mass per unit volume) of the material when either in a stockpile or when loaded into a bulk container (such as a truck or rail wagon) for delivery.

The test is carried out in the loose density or compacted density conditions. Aggregate material may settle and compact somewhat during the loading, transport and delivery processes. This test is performed by placing a sample of aggregate into a container in layers and, if required, compacting each layer with a designated number of blows using a rod. After levelling the surface of the sample with the top of the container, the mass of the sample is taken and, using the volume of the container, the density of the aggregate is calculated.

For lightweight aggregate, AS 2758.1 specifies a maximum bulk density of 1.2 t/m^3.

3.2.2 Dimensional requirements (AS 2758.1 Section 8)

Grading (Clause 8.1)

Grading or particle size distribution is the most common test performed on aggregates for use in concrete.

The purpose of the test is to determine the breakdown of aggregate particles (in each of the standard size-segments) a given sample of the aggregate. For concrete, the individual grading of each aggregate and the combination of these is important to the plastic and hardened properties of the concrete. It contributes to the formation of the rock skeleton within the concrete mix and its ability to absorb and distribute loads in service.

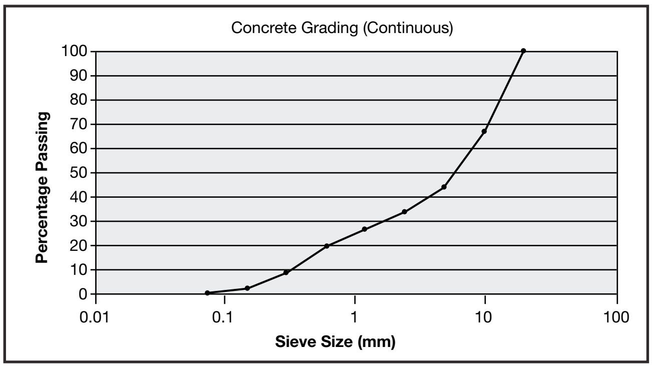

Figure 5: Typical concrete grading curve

Grading is determined by testing a sample in accordance with AS 1141.11.1, AS 1141.11.2, AS 1141.12 and AS 1141.13 (as appropriate). In AS 2758.1 the grading limits for concrete aggregate are based on the results of a "submitted grading" from the supplier and the limits of deviation from that grading. Tables 1 and 2 in the Standard give the allowable tolerances based on the "submitted grading" for each coarse or fine aggregate size supplied.

The four test methods used to determine grading are:

- AS 1141.11.1 Particle size distribution – Sieving method (dry or washed grading)
- AS 1141.11.2 Particle size distribution for vision sizing systems
- AS 1141.12 Material finer than 75µm in aggregates (by washing)
- AS 1141.13 Material finer than 2µm.

The test for grading of the larger fractions (greater than 75µm) is carried out by sieving a sample in accordance with the requirements of AS 1141.11.1. In this process, a sample of aggregate is shaken through a nest of sieves from largest down to smallest. The result is generally reported as the percentage passing each individual sieve size. The test can be performed in either a dry state (a 'dry grading') or by wetting and washing (a 'wash grading').

It is important to ensure that proof sieving is done correctly for material retained on each sieve and that no sieves are overloaded during the grading operation as this may skew the results. Given the importance of this test, it is critical that laboratory technicians receive appropriate training on how to perform it and all others in this important Standard.

If testing for grading of the coarse aggregate is performed in accordance with AS 1141.11.2 using a vision sizing system, the test is carried out only on the portion greater than 1.18mm. This test is not based on sample mass. This procedure is suitable for testing combined aggregate samples. An aggregate sample passes through a light box and falls past a high-speed camera which captures numerous images of the aggregates then uses a series of algorithms to calculate the size of each particle and determine the grading of the sample. This system is calibrated with primary and secondary procedures, including comparison with conventional grading discussed above. In this way the vision sizing system can provide fast results on an uninterrupted production run of aggregates.

Figure 6: Combined aggregate and sand sample graded into its individual sizes

General (Clause 8.1.1)

One of the main criteria when supplying aggregate for use in concrete is consistency as this assists in control of concrete production. The mixing of concrete is a batching process. Each batch requires the weighing and mixing of all coarse and fine aggregates, which can be controlled only if the aggregate supplied is consistent throughout the range of particle sizes supplied.

The AS 2758.1 Standard gives grading requirements for both coarse and fine aggregate. Table 1 shows the grading envelopes applicable for a range of coarse aggregate while Table 2 shows the deviation allowances for coarse aggregate. Table 3 shows the grading envelopes and deviation allowances for fine aggregate.

Care should be taken when using Table 1 as the values shown are the upper and lower limits. Once the deviations are applied to the submitted grading, the upper or lower limits are still required to be within the limit of the grading. For example, should a submitted sample for a single size 20mm aggregate have a value of 18% on the 6.70mm sieve, then when applying the deviation for that sieve on that aggregate size (+/-5) the net result would be 13 - 23 (18 ± 5%). The upper limit shown is 20; therefore the new grading envelope would be 13 - 20 and not 13 - 23.

Aggregates that have grading envelopes different to those shown have been found to be acceptable for concrete. It should also be noted that the gradings in Table 1 are a guide only and should not be used as a means of proving compliance or otherwise. It is more appropriate to request a nominated grading from the supplying quarry with a controlled tolerance applied to key sieve sizes. In this way the aggregate is more likely to be consistent and readily available in larger volumes.

Coarse aggregate (Clause 8.1.2)

When determined in accordance with AS 1141.11 the grading shall not deviate from the submitted sample by more than the permissible deviations shown in Table 2.

This specification is limited to aggregates of nominal size less than 40mm.

Fine aggregate (Clause 8.1.3)

When determined in accordance with AS 1141.11 the grading shall not deviate from the submitted sample by more than the permissible deviations shown in Table 3.

Material finer than 75µm (Clause 8.2)

Coarse and fine aggregate (Clause 8.2.1)

When determined in accordance with AS 1141.11 or AS 1141.12, the quantity of material finer than 75µm for each component of a blend shall not exceed the limits shown in Tables 1 and 3 for each component. For the 75-micron µm size, the test is performed in accordance with AS 1141.12 by wetting and agitating the sample to loosen and separate the very fine particles from the bulk of the material. The sample is subsequently washed over a 75µm sieve. Due to the delicate nature of the sieve cloth of a 75µm sieve, it is protected during the test by the use of a larger sized sieve (normally 1.18mm). This test can be either done as part of the AS 1141.11.1 washed test or as an individual test in accordance with AS 1141.12.

Material finer than 2µm (Clause 8.2.2)

When determined in accordance with AS 1141.13, the quantity of material finer than 2µm shall not exceed 1% for each of the coarse or fine aggregates.

The material finer than 2µm in an aggregate test is carried out on the wash water obtained from either the AS 1141.11.1 or AS 1141.12 test. This test is not generally considered applicable if being used as a control process. If the material finer than 75µm is less than 1% for coarse aggregate and less than 4% for fine aggregate the <2µm test is not required to be done.

Although a range of techniques are available to test the quantity of material less than 2µm in aggregates, the test method AS 1141.13 is specified in AS 2758.1 and may form part of a total sizing analysis or can be conducted as a separate test.

Note:

- It was initially included in the suite of tests AS 2758.1 to attempt to quantify the amount of clay fines that may be present within a natural aggregate material as these clays may shrink and swell causing increased water demand in concrete and induce potential cracking.
- In manufactured sand the quantity of fines <2µm may exceed the specified <1% limit and still perform adequately in a concrete mix. It is suggested in this case that other testing be conducted to confirm the suitability of this sand for use in concrete.

The test for material finer than 2µm, takes all the wash water from the passing 75µm method as the sample which is then reduced to a thick slurry by evaporation of the water. The resulting slurry is dried and the mass of <75µm material measured. A sub-sample is diluted in distilled water with a deflocculating agent and the suspension is allowed to settle for a controlled period. At a calculated time, a measured volume of liquid and suspended solids is collected using a pipette from the sedimentation column from a depth where the liquid would have suspended particles of 2µm size or finer. The liquid and suspended solids are dried and, by calculation, the mass of 2µm and finer material is related to the sample of <75µm material.

Particle shape in coarse aggregate (Clause 8.3)

The two methods for evaluating particle shape are:

Particle Shape by Proportional Caliper Samples are tested in accordance with AS 1141.14, the Misshapen Particle test. This test is carried out on sample fractions of material larger than 9.5mm and proportions representing fractions of greater than 10% of the sample.

The test is performed using a purpose-made caliper, or vernier calliper, that can measure the comparative width, length or thickness of a stone (Figures 8 and 9). Calculations are then carried out to determine the various relationships of the pieces. The test involves measuring the length-to-width and width-to-thickness ratio of each aggregate particle and passing it through both ends of the proportional caliper. The particles are then described as flat, elongated or flat and elongated depending on whether they can pass through the caliper or are retained.

The measure of shape is normally conducted with the caliper in the 2:1 and 3:1 positions but AS 2758.1 specifies only the 3:1 <10%. The result is normally expressed as the total percentage of misshapen particles when compared to the total normal shaped, cubical, aggregate particles.

Some specifiers will request alternative limits or test ratios and the common alternative in Australia is a 2:1 ratio. The limit set when tested at a 2:1 ratio is normally <35% but as stated earlier is not part of AS 2758.1.

Flakiness Index Samples are tested in accordance with AS 1141.15. The various fractions must represent more than 5% of the sample and the fractional sizes are between 26.0 and 4.75mm.

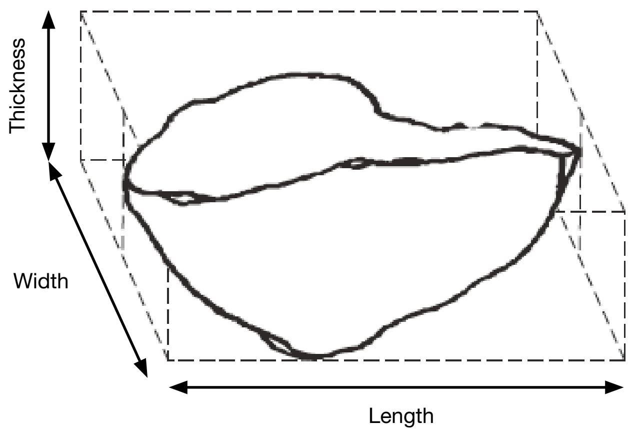

Figure 7: Standard stone dimensions

Figure 8: Proportional caliper used to perform the test

The test is performed using a measuring gauge that has standard sized slots which the sample particles either pass through or are retained (Figure 9). The result is based on a combined calculation of that which passes through the slots versus that which is retained on the gauge.

The standard sets a level of less than 35% of Flaky particles.

Figure 9: Flakiness Index test gauge and slotted sieves

3.2.3 Durability (AS 2758.1 Section 9)

General (Clause 9.1)

Concrete is commonly designed to have a life expectancy of 40 to 60 years, ie it is to remain in place and continue to perform its role for at least this length of time. Some bridges have design lives of 100+ years.

As the design life of a structure, road, bridge, etc increases so do the associated costs, due to the need for higher quality materials and more-sophisticated construction techniques. Concrete is subject to a range of atmospheric conditions (exposure) that place its design life at risk and it is this risk that needs to be taken into account in the design process. As the aggregate component of the concrete mix is in the order of 70 - 80% of the total mix volume, the aggregate plays an important role in the concrete's performance.

Exposure classification indicates the conditions to which a concrete member is likely to be exposed in service, and can be determined using the guidance notes in Appendix A in AS 2758.1. It should also be noted that there is no classification "U" in Section 9 of this Standard.

AS 2758.1 provides a range of durability tests that either singularly or in combination, provide some confidence of aggregate material integrity. The Standard notes that the three sets of tests nominated represent those most commonly used in Australia. Of special note is the requirement in the standard that only <u>one</u> of the test sets is to be included in any works specification.

It should also be noted that the chosen method should be that which most suits local experience for the particular rock source selected. It has been a common error by specifiers to select several of the test sets, which is unnecessary. It increases test costs but does not ensure durable aggregates.

Note: Different state road authorities have historically referred to different test methods from AS 2758.1 to confirm aggregate quality and durability. This does not mean one method is better than another, as all of the tests in AS 2758.1 provide valuable information on the properties of aggregates; it simply means not all tests need to be done to classify and understand the properties of an individual aggregate or its source.

Fine Aggregates (Clause 9.2)

Fine aggregates are tested in accordance with AS 1141.24 for durability. The Sodium Sulfate Soundness (SSS) test described below is the durability test used for fine aggregates.

The limits are based on exposure classification. For exposure classifications C and B2 the limit for all fine aggregate is not greater than 12% loss. For crushed fine aggregate (manufactured sand) the limit for exposure classifications A1, A2 and B1 is not greater than 15%.

Uncrushed fine aggregates that comply with the all other requirements of the standard will be suitably durable for exposure classifications A1, A2 and B1.

The durability test options in AS 2758.1 Coarse Aggregates (Clause 9.3) are:

Wet Dry Strength and Wet/Dry Strength variation (Clause 9.3.2)

This test is performed in accordance with AS 1141.22 and is a basic aggregate crushing test. It is performed by taking a measured quantity of sized aggregate and subjecting the sample to a force within a confined space. The test is performed on aggregate in both the wet and dry condition. The aim is to obtain, by crushing, 10% of produced fines in order to ascertain the strength of the aggregate in both wet and dry conditions and to determine the percentage variation between the aggregate strength in the two conditions. The equipment used is shown in Figure 10.

Figure 10: Wet/Dry strength test equipment and compression machine

The strength of the aggregate is defined as the crushing force which, when applied to a known mass of the aggregate, will produce fines of a particular sizing and amounting to 10% of the mass of the dry test portion. The wet test is performed on a sample of the same size as that for the dry test but it is soaked for 24 hours to give an understanding of the change in strength when moist.

Generally, the smaller sized aggregates produce a higher strength value due to the packing nature and void characteristics of the particles in the test mould.

For coarse aggregate, in AS 2758.1 the minimum wet strength and the maximum wet/dry strength variation are related to the exposure classification for the particular concrete. Table 4 in the Standard shows the range of requirements.

Los Angeles value and Sodium Sulfate Soundness (Clause 9.3.3)

Los Angeles value

The Los Angeles (LA) test is performed in accordance with AS 1141.23 and is a dry abrasion test. It is performed in a rotating drum container, which is loaded with steel balls (Figure 11). A bar across the inside of the drum interrupts the flow of the steel balls and ensures they perform a crushing process and do not just flow around the drum during rotation. The drum is rotated for 500 revolutions, producing fine particles by the interaction of the steel balls and the aggregate particles. The fines produced are recorded as a percentage of the initial mass. A high value means the material has poor resistance to abrasion.

Figure 11: LA machine and test sample

Table 5 in AS 2758.1 gives a range of acceptable LA test results based on grain size or rock type. Some aggregate types can lose whole crystals during the test and care is taken when interpreting results of those types of aggregate. Table B1 and B2 in the appendix can be used for guidance on grain size in aggregate types.

It is noted that aggregates that have values higher than those specified can be used depending on local experience and performance. Vesicular aggregates such as slag is an example.

Sodium Sulfate Soundness

The Sodium Sulfate Soundness (SSS) test is performed in accordance with AS 1141.24 and is used to determine the aggregate's ability to resist weathering. This test accelerates the normal weathering process by increasing the frequency and severity of the aggregates exposure to the elements.

This test is performed by placing aggregate samples in a salt water solution and then drying the sample in an oven. The process is repeated 5 times in 5 days and allows salt crystals to enter any cracks or micro-cracks present in an aggregate. As the salt crystals grow, they expand and break down the aggregate. Poor quality material will disintegrate into grain-sized particles and will show the degree of weathering that may be expected.

This test is a good indication of aggregate durability, particularly when the material is exposed to ground water or is near salt water such as areas within the coastal zone.

Table 6 in AS 2758.1 gives a range of acceptable SSS test results based on concrete exposure classification.

The maximum allowable weighted average loss is 12% for exposure A, 9% for exposure B and 6% for exposure C.

Los Angeles Value and Unsound and Marginal Stone Content (Clause 9.3.4)

Los Angeles value

The LA test is performed in accordance with AS 1141.23 as described in the previous section.

Unsound and Marginal Stone Content

This test is performed in accordance with AS 1141.30.1. It is necessary that the unsound rock has been defined and is quite distinguishable from sound rock within the same deposit. The difference may be according to colour or texture. AS 1141.30.2 gives the procedure for preparation of the reference specimens used for the comparison.

The test is performed on a sample of aggregate retained on a 4.75mm sieve. The sample is checked firstly for soft material. The remainder of material is then washed and the sample is visually examined and compared to the reference specimens and any unsound particles are separated from the rest of the sample. Their mass is expressed as a percentage of the total sample mass. Samples are generally then kept so they can be used at a quarry for visual comparison with future production.

Table 5 in AS 2758.1 gives a range of acceptable LA test results based on grain size or rock type. A maximum of 5% is specified for unsound stone content. The maximum for unsound stone and marginal stone content is 10%.

3.2.4 Alkali-reactive materials (AS 2758.1 Section 10)

General (Clause 10.1)

Alkali Aggregate Reaction (AAR) is the term used for an expansive reaction which can occur over time between the highly alkaline cement paste and reactive minerals found in some aggregates.

External moisture must also be present. Thus, AAR can occur only when the following are present:

- A potentially expansive aggregate
- Reactive alkalis
- A moisture-rich environment

This reaction can cause expansion of the altered aggregate, leading to spalling, and loss of strength of the concrete and an increased risk to the durability of any embedded reinforcing steel. As can be seen in Figure 12, cracking due to AAR can be extensive (it is commonly called map cracking due to its appearance). In most cases the embedded reinforcing steel has adequate capacity to restrain the expansive forces generated by the AAR; the biggest issue becomes sealing of the cracks to prevent ingress of further alkalis or chlorides. Additional external alkalis encourage further AAR cracking whilst chloride concentrations may accelerate the corrosion of reinforcing steel when they reach and exceed the chloride threshold level to initiate rusting.

Figure 12: AAR damage in concrete

Requirements (Clause 10.2)

AS 2758.1 requires the supplier of the aggregates to provide appropriate documentation on the potential reactivity of the aggregate to be used in concrete.

In most circumstance this is provided by having a qualified geologist perform a petrographic examination of the aggregate. The alternative is to test the aggregate in an accelerated mortar or concrete prism test. Guidance on this is given in the AAR handbook, CCAA T47/SAA HB79-2014.

Local service history also serves as a record of the likelihood of aggregate from a particular source to have AAR potential.

The works specification should stipulate the requirements for test or examination.

3.2.5 Weak Particles (AS 2758.1 Section 11)

The weak particles test is performed in accordance with AS 1141.32. The purpose of the test is to ensure the coarse aggregate integrity during the early life of the concrete, ie to minimise the risk of material breakdown during production, delivery and placing of the concrete. It involves soaking a sample of aggregate for a period of time and then by using finger pressure on each individual piece, checking for pieces that are easily broken. The test also identifies the presence of any clay lumps in an aggregate sample which may cause problems if found in concrete.

Once separated, the percentage of weak particles can be determined. AS 2758.1 specifies that there shall not be more than 0.5% of weak particles.

3.2.6 Light Particles (AS 2758.1 Section 12)

The light particle test is performed in accordance with AS 1141.31. The test is carried out by preparing a solution with a density of 2.0 t/m^3. The selected aggregate sample is soaked in the solution and the particles of a lesser density than the solution float. They are screeded off and the percentage calculated. (Particles such as wood, coal and charcoal tend to float to the surface of a dense mix such as concrete due to the vibration during placement and can produce a poor surface finish).

For normal and heavyweight aggregates, the allowable amount of light particles is less than 1%. For vesicular aggregates the limit is 3%. Lightweight and ultra-lightweight aggregates are not specified as most of their particles fail this test. These aggregates are therefore not normally used in concrete for flatwork.

3.2.7 Drying Shrinkage (AS 2758.1 Section 13)

Drying shrinkage is project and design dependant, there is therefore not a specified limit in this Standard. There are, however, some cautionary notes. Aggregate may either contribute to or assist in resisting the shrinkage of the cement paste. Water absorption can be something of an indicator of this as some aggregates with low water absorption may produce low drying shrinkage when used in well-designed concrete mixes.

Shrinkage limits will normally be included in a project works specification and are affected by more than the aggregate being used, including, but not limited to, the cementitious binder, admixtures, design slump and application used.

Due to the many factors that influence drying shrinkage, care should be taken if the materials described in Section 13 of this standard are being considered for use.

The test is performed in accordance with AS 1012.13 in a specially designated concrete testing laboratory. Concrete to be tested is cast into a rectangular mould 75 x 75 x 285mm and is specifically cured and accurately measured on a regular basis to assess the shrinkage of the mix. The shrinkage beams are normally cast as three specimens and measurements are averaged to obtain the final shrinkage measurement in accordance with AS 1012.13.

3.2.8 Impurities (AS 2758.1 Section 14)

The Standard notes that there is a range of organic or chemical substances that have been known to be present and can be detrimental to concrete at certain levels. Aggregate supply should be checked to assess their presence or influence on the final concrete mix.

Organic impurities (Clause 14.1)

This material includes vegetable matter and wood particles. The test is performed in accordance with AS 1141.34 on the fine aggregate component. It involves mixing a sample of the aggregate and a solution of sodium hydroxide which attacks the soluble materials and produces a solution whose colour is compared against a standard Tannic Acid solution or glass plate of a standardised colour (Figure 13). If the colour is darker than the reference colour, then the material fails and should not be used without further testing that validates performance in concrete. This may involve testing to AS 1289.4.1.1 to quantify organic content (max 0.5%).

Figure 13: Organic impurities assessed by the glass-plate method

Sugar (Clause 14.2)

Sugar can affect the ability of concrete to set and can also adversely affect its final strength. Cement is the "glue" of a concrete mix and sugar is known to interfere with the cement hydration process in the concrete. This test can detect many forms of sugar including that from honey, wine, fruit juices or other sources of glucose.

This test is performed in accordance with AS 1141.35. It involves mixing the sample aggregate with an acid followed by the addition of a small quantity of a solution known as "Fehling's" solution. This will show the presence of sugar by the formation of a reddish-brown precipitate.

Suitable aggregates will show a negative result to the presence of sugar.

Soluble Salts (Clause 14.3)

AS 2758.1 notes that excessive quantities of some salts may cause efflorescence on concrete, corrosion of steel or disintegration of the concrete mass. The permissible levels of the soluble salts are generally reported as a proportion of the relevant ion present in the concrete mass. AS 1379 limits both chloride and sulfate contents of concrete.

Testing for the presence of soluble salts is performed in accordance with AS 1012.20 which is a concrete testing method. As this test is normally performed in a chemical laboratory, the methodology is not described in this document.

Chlorides (Clause 14.3.1)

The chloride ion content when determined quantitatively must be reported if it exceeds 0.01%. For concrete containing embedded steel reinforcement the chloride salt content of the aggregates should not exceed 0.04%. For plain concrete, it should not exceed 0.15%.

Sulfates (Clause 14.3.2)

The Sulfate ion content when determined quantitatively must be reported if it exceeds 0.01%. Aggregate which contains sulfates in excess of 5.0% of the Portland cement mass, when calculated proportionally to the mix, should not be used.

Other salts (Clause 14.3.3)

Aggregates which contain salts other than chlorides and sulfates can have detrimental effects on concrete. A highly ionised salt such as nitrates is an example. The Standard notes this and states that, provided it can be shown that they do not adversely affect the concrete, they may be used. Any restrictions should be noted in a works specification.

3.2.9 Additional requirements for slag aggregates (AS 2758.1 Section 15)

Slag aggregates have a strong history of use in Australia and this is recognised by AS 2758.1. Slag should not be used simply as a replacement since it has its own characteristics. Differences in particle density and water absorption need to be taken into account.

Iron unsoundness (Clause 15.1)

Due to the nature of production, slag aggregate may contain ferrous oxide. Slag can disintegrate if iron sulfides come into contact with water why form hydroxides and expand.
If chemical analysis shows that the ferrous oxide content equals or exceeds 3% and the sulphur content equals or exceeds 1%, the aggregate should be tested for iron unsoundness according to AS 1141.37.

The test involves taking a sample, soaking it in water for 14 days and checking for any particles that develop cracks or disintegrate. If even one particle shows signs of change or disintegration, a second sample is tested. If there is no change, the aggregates is deemed to be free from iron unsoundness.
If the iron unsoundness of the slag exceeds 1% it shall not be used as a concrete aggregate.

It is noted that iron unsoundness has not been recorded for Australian iron blast furnace slag.

Falling or dusting unsoundness (Clause 15.2)

The characteristics of some slags change during the cooling process. If the slag inverts during cooling, normally at about 490°C, beta di-calcium silicate can change into the gamma form and disrupt the mass of the slag. Once it has changed, the resultant materials are considered kinetically stable and there will be no further disruption.

For this reason, the AS 2758.1 limits the use of fresh slag to ensure proper cooling takes place before use. The slag must be cooled to below 50°C before use as a concrete aggregate.

Stockpiling of iron blast furnace slag aggregate (Clause 15.3)

Slag is a vesicular aggregate and must therefore be cured prior to use. Vesicular aggregates generally have a higher than normal water absorption and when used as concrete aggregate must be soaked to ensure all internal voids are full before batching. If not, loss in workability may result in plastic concrete.

3.2.10 Additional requirements for lightweight aggregates (AS 2758.1 Section 16)

Weak particles (Clause 16.1)

For lightweight aggregate, the proportion of weak particles, (AS 1141.32) should not exceed 2%.

Loss on Ignition (Clause 16.2)

This test involves heating a sample of the aggregate to a temperature in the range of 800 - 1000°C and calculating the change in mass. The test is performed in accordance with AS 4489.7.1 which is a lime test method.

Some natural lightweight aggregates contain otherwise innocuous carbonates or water crystallisation, these contribute to loss on ignition and care should be used when evaluating a Loss on Ignition result.

Lightweight aggregates should not show a loss of more than 5%.

Variation in bulk density (Clause 16.3)

The ability of an aggregate to pack in a concrete mix will greatly depend on the shape, grading and mass of the aggregate particles. For this reason, it is important that lightweight aggregates, which can be susceptible to variation, are supplied on a consistent volume basis. This will assist in ensuring the aggregate mass and strength in a particular mix is maintained.

The bulk density of a lightweight aggregate should not vary from the initial sample used in the design process by more than 10%.

4.0 Conclusion

Aggregates that satisfy the requirements of AS 2758.1 are likely to be suitable for use in concrete provided they are consistently supplied and regular sampling and testing is undertaken to ensure ongoing compliance with the Standard and relevant works specifications.

5.0 References

1 AS 1141 Methods for sampling and testing aggregates Standards Australia.

2 Alkali aggregate reaction – guidelines on minimising the risk of damage to concrete structures in Australia - CCAA T47,SAA HB79-1996, ISBN 07337 04697.

3 ASTM C295 Standard guide for petrographic examination of aggregates for concrete, 2012.

4 AS 1012.5 Methods of testing concrete – Determination of mass per unit volume of freshly mixed concrete Standards Australia, 1999.

5 AS 1012.13 Methods of testing concrete - Determination of the drying shrinkage of concrete samples prepared in the field or in the laboratory, 1992.

6 AS 1379 Specification and supply of concrete Standards Australia, 2007.

7 AS 1012.20 Methods of testing concrete - Determination of chloride and sulfate in hardened concrete and concrete aggregates, 1992.

8 AS 4489.7.1 Test methods for limes and limestones - Loss on ignition - Quicklime, hydrated lime and limestone, 1997.

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