Unconfined Compressive Strength (UCS)

Industry Guidance for Cement Bound Aggregates

Scope

This document is intended to ensure that mix design and quality assurance testing utilising compacted moulded samples to determine Unconfined Compressive Strength utilise the same mould configuration and compaction, curing and testing laboratory protocol.

Industry position

NZTA and industry have developed *NZTA T/19 specification for indirect tensile strength testing of modified and bound pavement materials* as the guide to determining the pavement aggregate strength when mixed with cementitious and/or bituminous binders. This specification has been approved and ratified by both NZTA and the National Pavement Technical Group (NPTG) as the preferred methodology of determining the appropriate cementitious and/or bituminous stabilising agent to achieve either modified or fully bound pavement layer materials. The decision to move away from Unconfined Compressive Strength (UCS) is the result of research suggesting that tensile properties (as derived from the Indirect Tensile Strength (ITS) testing) is more appropriate for determining materials characteristics and design parameters than compressive strength properties.

Nonetheless, UCS is still specified in standards and specifications that relate to these materials and is the choice of some practitioners, especially in Local Authority applications. This document provides guidance on the application of the UCS test within the New Zealand context to enable consistency across the industry.

Experience in New Zealand shows the UCS result variability can be high due to variations in mould size, compaction, curing and aspect ratio. A fine grading in an aggregate material when mixed with low cement contents (1%) can still give high UCS results. If the UCS test is to be used to help the designer estimate the design modulus, it should always be used in conjunction with the ITS.

Introduction

Despite the release of the NZTA T/19 Indirect Tensile Strength standard, UCS is continuing to be specified or used as a benchmark test. It is often used as a test for determining the threshold for when a cement treated material becomes bound and a generally 4.0MPa is targeted, and other times it is used as a means of inferring modulus. For those specifying UCS as a means of determining the modulus of modified materials there is the need to have a common alignment to ensure that when specified all involved are aware of the performance requirements.

At times when UCS is being specified, the specifier and those undertaking the testing are not referencing the same methods. It should also be noted that the AGPT UCS values used to define modified and bound aggregates are not transferable to the UCS values determined in this guide. This has led, on occasion, to under reporting of the pavement material strength required and therefore has led to unnecessary rework. This document is intended to ensure that mix design and quality assurance testing all utilise the same protocol.

Ratified New Zealand Approach

Typically, the maximum aggregate sizes used in New Zealand are 40mm for basecourse and 65mm for subbase. The Austroads UCS test method, developed for 20mm topsize aggregate, which specifies a 105mm diameter mould, is not appropriate for these larger aggregates. Therefore, the decision was made to adopt a 150mm diameter and 300mm height sample to provide an appropriate mould size for the 37.5mm topsize and also an aspect ratio to permit full development of the failure plane to the side of the sample.

It has been proposed that New Zealand adopt a ratified national standard for testing of UCS.

The UCS test involves compacting a material into a mould, extruding (or removing from split mould) that sample and then applying a steadily increasing axial load until the sample fails. The maximum value of the compressive force per unit area which the sample achieves is referred to as the UCS.

The following testing parameters shall be followed:

i. **Sampling**
   Sampling shall be carried out in accordance with NZS4407 Part 2. Samples shall be transported in a sealed container to prevent evaporation. The number of test blocks per sample shall be directed by the Engineer, but is recommended to be 2. The recommended frequency of field sampling shall be 1 to 2 samples for 2500m2 or one days' production, 2 to 3 samples for 2500m2 to 5000m2 and 3 to 4 samples for more than 5000m2. Note that the lower sampling frequency is to be adopted if materials are found to be consistent and the higher number to be used on projects / sections of pavement that have > 20 million DESAs or for pavements that have higher then road legal commercial vehicles loading such as Port / Airport applications.

ii. **Curing prior to compaction**
   Test samples shall be cured in accordance with the requirements of the project specification. Where no project specific curing time is specified, samples containing GP cement shall be compacted within 2 hours from cement mixing.

iii. **Sample dimensions**
   The mould size shall be 150mm diameter and 300mm in height. To ensure aspect ratio of 2Height/1Diameter the height of specimen shall be 300mm +/-10mm. Preference is to use hinged moulds (such as RLT moulds).

iv. **Compaction**
   Sample to be compacted to NZS 4402: 1986 test 4.1.3. Vibrating Hammer, with the exception of taking the thoroughly mixed sample and compacting into the mould in 5 equal layers of approximately 60mm compacted thickness each. Vertical static downward force shall be 350 +/-50 N and applied for 180 +/- 10 seconds for each layer. A light scarification shall be undertaken at the top of the first 4 layers. Samples to be compacted at or near optimum moisture content for the aggregate and cement blend. Moisture content to be calculated and reported for sample at time of compaction.
   Note –Site Quality Assurance samples shall be compacted at field moisture content. Where QA samples cannot be returned to laboratory in a sealed container and fully compacted within two hours site compaction is required on an adequate anvil, such as a concrete slab, to simulate laboratory conditions.

v. **Maximum Particle Size**
   The maximum particle size of the test sample shall be 37.5mm. Any material that is greater than 37.5mm shall be screened out, weighed and the percentage oversize shall be reported with the UCS result

vi. Curing conditions

Samples shall be moist cured (with damp hessian cloth over mould) at 21°C +/- 2°C for 7 days. Curing commences immediately after compaction. Samples shall be demoulded no longer than 24 hours after preparation and stored in an airtight container following demoulding. Where end caps are required, they shall follow the requirements of NZS 3112 Part 2 Test 4 Capping.

vii. Apparatus / Rate of loading

To accommodate a strongly bound 150mm diameter test sample a loading apparatus capable of applying 100kN may be required. Breaking head is to be swivel-type to ensure top face is non-eccentrically loaded. The test duration is intended to be between 5 to 10 minutes and the recommended rate of loading is 10kN/min. In some situations the sample may not be tested to failure due to strongly bound and apparatus capacity. In these instances the threshold for demonstrating strongly bound condition will be to achieve 4MPa minimum capacity.

viii. Calculations

Wet density, dry density and the unconfined compressive strength shall be calculated as follows;

(a) The wet density (ρw) of the test specimen(s) as compacted from the following equation:

$$\rho w = \frac{m_2 - m_1}{V}$$

where

ρw = wet density, in tonnes per cubic metre

m_2 = mass of the mould plus compacted specimen, in grams

m_1 = mass of the mould, in grams

V = volume of the specimen ($v = \pi r^2 h$), in cubic centimetres

(b) The dry density (ρd) of the test specimen(s) as compacted from the following equation:

$$\rho d = \frac{\rho w \times 100}{100 + w}$$

where

ρd = dry density of the specimen, in tonnes per cubic metre

ρw = wet density, in tonnes per cubic metre

w = moisture content of the specimen, in percent

(c) The unconfined compressive strength (*UCS*) of the specimen(s) from the following equation:

$$UCS = \frac{F \times 1273}{(D_{av})^2}$$

where

UCS = unconfined compressive strength, in megapascals

F = load at failure, in kilonewtons

D_{av} = average diameter, in millimetres.

Note: 1273 = $\pi/4 \times 1000$.

$\pi/4$ is the constant in the formula for the surface area of the specimen(s) and

1 kN/mm² = 1000 MPa.

Note 1: A UCS test result of 4.0MPa or more for a 7-day moist cure reflects a strongly bound material

Note 2: UCS testing for Foamed Bitumen samples shall be done as follows:

- Sample preparation and curing as per NZTA T/19 (Sample preparation and curing);
- Compaction in accordance with NZS4402: 1986: Test 4.1.3 (NZ Vibe hammer) modified to 2 layers in a mould with sample 150mm Diam.x125mm Height sample, or Servopac (AS2891.2.2) with sample 150mm Diam. and single layer 125mm high with 3 degrees and 240kPa pressure for 125 gyrations.
- UCS crushing in accordance with NZS4402:1986 Test 6.3.1 with sufficient number of simultaneous readings of the load measuring device and axial compression gauge to define the stress strain curve well past the peak axial load.

Reporting

The following data for the test specimen(s) shall be reported:

a) Description of the aggregate to be tested;
b) Description of where, when, how and by whom the aggregate was sampled;
c) If applicable, the amount of material retained on the 37.5mm test sieve as a percentage of the mass used in the original sample;
d) Binder type (i.e. GP Cement) and application rate as a percentage of the dry weight of aggregate;
e) Report mould type (i.e. hinged or solid);
f) The elapsed time between addition of the binder and compaction of the test sample;
g) Curing time, in days, taken from the time of compaction to time of testing;
h) Moisture content of the specimen at compaction, in percent to nearest 0.1; also noting any water added to the sample before compaction in percent to nearest 0.1;
i) Compactive effort applied;
j) Loading rate and load apparatus maximum capacity;
k) Unconfined compressive strength to the nearest 0.05MPa;
l) Clarification of sample failing at peak load, or peak load reached without sample failing (in case of sample strength exceeding machine apparatus load capacity);
m) Moisture content of the specimen on completion of testing, in percent to nearest 0.1;
n) Sample dimensions of each specimen to nearest 1mm. Dry density of each specimen as compacted, to the nearest 0.01 t/m3;

Related Documents

NZS4402: 1986, Test 4.1.3 New Zealand vibrating hammer compaction test.

NZS 4402: 1986, Test 6.3.1 Unconfined Compressive Strength

NZS 3112 Part 2: 1986, Test 4. Methods of test for concrete

NZS 4407, 2015 Part2. Methods of sampling and testing road aggregates

NZTA T/19. 2020. Procedures for design and indirect tensile strength testing of modified and bound pavement materials.