Assessment of compressive strength class of recently supplied concrete using in-situ testing

1 Introduction

There are times when it is considered necessary to assess the compressive strength class of recently supplied concrete. Often this may be because of either one or more of the following:

- Concerns following visual inspection on delivery.
- Unauthorized addition of water on site, sometimes evident from delivery documentation.
- Incorrect supply or placement of concrete.
- Low results from testing site cube specimens.

It is important to ascertain the nature of the problem as this will help minimise the extent of the subsequent investigation and maximise the confidence in its conclusions.

This document should not be used where the supplier has a low level of quality assurance or no documented procedures. This document does not cover the estimation of compressive strength for structural assessment of an existing structure.

2 Documentation check and review of site procedures

2.1 Fresh concrete and delivery records

Concerns over concrete deliveries may be raised because the concrete is either at a significantly higher or lower consistence than expected. Higher consistence may be because either there has been water added on site or a batching error. Lower consistence may occur due to a delay in delivery whether due to traffic, waiting on site or a process error by the producer. It is also possible that the concrete supplied is as ordered by another part of the site, but not suitable for where it has been received and placed. Where site personnel have instructed the driver to add water this should be evident if the site personnel have signed for the water added on the delivery docket as required by BS EN 206. For all these reasons it is important to examine all delivery dockets and any site records to ascertain where any suspect concrete may have been placed.

The first thing to check is the ready-mixed concrete supplier's Product Conformity Certification, where the scope should be to supply concrete to BS EN 206 and BS 8500 with certification to either:

- Quality Scheme for Ready-Mixed Concrete, QSRMC, or
- BSI Kitemark Scheme for Ready-Mixed Concrete.

This should mean the supplier will have documentation linking the concrete supplied to the evidence that it should achieve the specified strength class, providing there was not an error in the ordering or production or process.

2.2 Sampling fresh concrete and test specimens

Concerns may arise due to lower-than-expected site cube strength results. Site cubes may be for specified identity testing or as prompted by a visual inspection showing something unexpected. Where site cube results are being reviewed it is important to confirm that:

- Sampling was carried out correctly, where each composite sample from a ready-mixed concrete truck comprised a minimum four increments.
- During all stages of sampling, transport and handling, the fresh concrete samples were protected against contamination, gaining or losing water and extreme variations of temperature.
- Test specimens were kept in their moulds for at least 16 hours, but not longer than 3 days, protected against shock, vibration and dehydration, and at a temperature of 20 ± 5 °C.
- After removal from their moulds the test specimens were stored correctly until immediately before testing. That is either in water at a temperature of 20 ± 2 °C, or in a chamber at 20 ± 2 °C with relative humidity ≥ 95 %.

2.3 Sampling and specimen reports

The reports from the person or persons responsible for taking, curing the sample and then testing the hardened specimen should include:

a) reference to the appropriate standard; BS EN 12350-1, BS EN 12390-2, BS EN 12390-3
b) identification of the sample;
c) description of where the sample was taken;
d) date and time of sampling;
e) confirmation that it is a composite sample;
f) any deviations from the standard method of sampling;
g) declaration by the person technically responsible for the sampling that it was carried out in accordance with BS EN 12350-1, except as noted in item f);
h) date and time of making the specimen;
i) method of compacting the concrete in the mould, including the number of strokes for hand compaction;
j) details of storage of specimens prior to de-moulding, including duration and conditions;
k) method of curing specimens after de-moulding and during any transportation, with temperature range and duration of curing;
l) any deviation from the standard method of making and curing the specimen;
m) declaration by the person technically responsible that the specimens were prepared in accordance with BS EN 12390-2 and tested in accordance with BS EN 12390-3, except as noted in item l).

3 Objective and planning

3.1 Objective

The objective of the investigation is to confirm the status of the concrete with respect to specified strength class. This will be most economically achieved if all the available information from both the site and the supplier is collated and reviewed. Although coring and their compressive strength testing is often the method whereby the client can be reassured that the in-situ concrete is of the required strength, coring without a plan or without consultation with the supplier can generate more questions than answers.

A useful first stage is to try and establish from the site and delivery documentation the areas where the concrete deliveries of concern were delivered and placed, and areas where the same concrete has been placed for which there is no concern. The next stage is to divide the total area for investigation into regions and volumes as trying to assess too large an area without a sufficient number of tests will result in an invalid assessment. It will also be useful to complete a visual survey with all parties involved to ensure that any proposed testing locations are both representative and accessible.

3.2 Planning

Having reviewed all the available data and completed a visual survey it is worth drawing up a programme of testing and including a plan on which to plot results in case there are any patterns to the results. Core testing is expensive compared to indirect testing and so it is always preferable to start with indirect testing. It is possible that indirect testing may provide the assurance required. If indirect testing does provide the assurance required it can be augmented by in-situ core testing.

4 Indirect comparative testing without coring

Where a concrete that is under investigation is one of a series of elements where there is no doubt about their strength class, then indirect testing may be used as a non-destructive method of assessing comparative strength. Indirect testing may either be by rebound hammer or ultrasonic pulse velocity (UPV). For this type of relative testing it is essential to have sufficient data for a valid comparison from both the concrete under investigation and concrete where there is no doubt about its strength class. The concrete where there is no doubt about its strength class is called the reference concrete. Ideally the reference element should have a similar maturity to the element under investigation or be more mature as the significance effects of maturity reduces significantly after 28 days. It is also preferable that for each region the formwork was removed at about the same age and that subsequent curing was similar. The BRMCA guide entitled *Assessment of compressive strength class of recently supplied concrete using comparative testing* sets out concise guidance on comparative testing.

5 In-situ assessment using cores, with or without indirect testing

5.1 Specified strength

Compressive strength to the European Concrete Design Standard, BS EN 1992-1-1 is determined from cylinder specimens where the length of cylinder is twice the diameter, i.e. 2:1 cylinder. By tradition concrete compressive strength in the UK is specified in terms of cube strength where this is still commonplace despite the introduction of the dual $f_{ck,cyl}/f_{ck,cube}$ nomenclature from the year 2000, e.g. 'C30' is specified rather than the correct term C25/30. BS EN 13791 follows BS EN 1992-1-1 so where $f_{ck,spec}$ is specified it should be remembered that the UK cube equivalent should be denoted differently, such as $f_{ck,spec,cube}$ and that mathematically $f_{ck,spec}$ is taken as 0.82 x $f_{ck,spec,cube}$.

Note: The value '0.82' is the average value of $f_{ck,cyl}$ divided by $f_{ck,cube}$ for the range of strength classes included within BS EN 206 and BS EN 1992-1-1. It is assumed to be the same as the Core Length Factor, CLF, used to express the strength ratio of a 1:1 core to a 2:1 core. CLF should not be confused with the BS EN 1992-1-1 value of '0.85' that is used to account for the difference between the design strength obtained testing specimens taken from a finished structure or element and the value based on standard test specimens.

5.2 Regions, volumes, and locations

Where more than indirect comparative testing is required then in accordance with BS EN 13791, the concrete under investigation shall be divided into regions where each region is for no more than 180 m^3 of concrete. Each region shall be further divided into 1 to 6 volumes, where each volume is no more than around 30 m^3 of concrete.

The division of a region into volumes may be done by simple division into equal volumes. It may be that after consideration of the delivery documentation and site records, including the review of site cube results, it is possible to identify areas of concrete within the region of particular concern where it would be sensible to ensure these are treated as discrete volumes. Where around 30 m^3 of concrete or less is under consideration then the region may be comprised a single volume, but where an amount of concrete is placed over more than one day then each day's concrete shall be considered a separate volume.

5.3. Indirect testing plus selected core test data

Table 1 sets out the indirect testing locations, core locations and assessment criteria for a region of concrete up to 180 m^3. Indirect testing of site concrete may be either by rebound hammer or UPV. Rebound hammer tests to be in accordance with EN 12504-2 and UPV measurements in accordance with BS EN 12504-4. The apparatus, the test procedure and the expression of test results shall be in accordance with BS EN 12504-2 or BS EN 12504-4 as appropriate. Coring is in accordance with BS EN 12504-1 and the additional requirements set out in BS EN 13791, that is cores shall be ≥ 75 mm diameter and coring not undertaken at a maturity less than 28 day at 20°C. It is also important to record the location of any reinforcement to ensure the volume of reinforcement in 1:1 cores is not more than 2.0 %, and in 2:1 cores that any reinforcement is completely within 30 mm of the ends of the core and the volume fraction of reinforcement is not more than 2.0 %.

Note: BS EN 13791 does contain requirements to cover core specimens between 50 mm diameter up to 75 mm diameter where three cores are required to achieve a test result. The use of these smaller cores is not covered in this guide.

Essentially indirect testing is used to minimise the number of cores required, but the assessment is based on the core strengths. It is important to carry out any initial assessment of the results and investigate any potential outliers. As suggested by the Standard, statistical core result outliers can be identified by checking that the spread of results is not greater than 15% of the mean value. Subject to confirmation of valid results where they satisfy the assessment criteria then the specified characteristic strength has been supplied.

The BRMCA guide entitled *Assessment of compressive strength class of recently supplied concrete using indirect testing and cores* sets out concise guidance on using indirect testing with selected core results for strength assessment.

Table 1. Summary of indirect testing locations, cores and assessment criteria for a region of concrete[A)] up to 180 m^3.

<table>
<tr><th rowspan="2">Number of volumes in test region, all < 30 m^3</th><th rowspan="2">Minimum total number indirect test locations for region</th><th rowspan="2">Minimum number of 1:1 core results and locations for coring [B)]</th><th colspan="2">Assessment criteria[C)]
Note: Both criteria need to be satisfied for the acceptance of conformity of compressive strength.</th></tr>
<tr><th>Mean of core test results at the locations closest to the to the median rebound number or the mean UPV for the test region.</th><th>Lowest core result</th></tr>
<tr><td>1[D)]</td><td>9</td><td>2 cores: One core at each of the two lowest indirect test values for the test region</td><td>–</td><td rowspan="6">$\geq 0.85(f_{ck,\ spec,\ cube} - 4^{E)})$</td></tr>
<tr><td>2</td><td rowspan="3">12</td><td rowspan="5">3 cores: One core at the lowest indirect test value for the test region, and one core at each of the test locations closest to the median rebound number or the mean UPV for the test region.</td><td rowspan="3">$\geq 0.85(f_{ck,\ spec,\ cube} + 1)$</td></tr>
<tr><td>3</td></tr>
<tr><td>4</td></tr>
<tr><td>5</td><td rowspan="2">20</td><td rowspan="2">$\geq 0.85(f_{ck,\ spec,\ cube} + 2)$</td></tr>
<tr><td>6</td></tr>
<tr><td colspan="5">A) Requirements where the concrete producer has product conformity certification.
B) Where the core diameter is ≥75 mm and the length/diameter ratio from 0.90 to 1.10.
C) $f_{ck,\ spec,\ cube}$ = specified characteristic strength in terms of cube strength. '0.85' = EN 1992-1-1 factor that accounts for the difference between the design strength obtained by testing specimens taken from a finished structure or element and the value based on standard test specimens.
D) Only where the 30 m^3 is supplied in one day. Where the concrete is supplied over two or more days then each day's volume shall be considered a different volume.
E) For specified strength C16/20 the constant is reduced to 3, for specified strength C12/15 the constant is reduced to 2, and for specified strength C8/10 the constant is reduced to 1.</td></tr>
</table>

5.4 Using core test data only.

Coring is in accordance with BS EN 12504-1 and the additional requirements as set out in 5. The minimum number of cores and assessment criteria are set out in Table 2. It is important to carry out any initial assessment of the results and investigate any potential outliers. As suggested by the Standard, statistical outliers can be identified by the application of the Grubb test where there are four or more results, or for three results by checking that the spread of results is not greater than 15% of the mean value. Subject to confirmation of valid results where they satisfy the assessment criteria then the specified characteristic strength has been supplied.

Table 2. Summary of minimum core requirements and assessment criteria for a region of concrete[A] up to 180 m^3.

Number of volumes, all < 30 m^3	Minimum number of 1:1[B] cores for each volume	Minimum total number of 1:1[B] cores for region	Assessment criteria[C] Note: Both criteria need to be satisfied for the acceptance of conformity of compressive strength.	
			Mean of all core results from the region from the volume:	Lowest core result
1[D]	3	3	–	$\geq 0.85(f_{ck,\ spec,\ cube} - 4^{E)})$
2	2	4	$\geq 0.85(f_{ck,\ spec,\ cube} + 1)$	
3	2	6		
4	2	8		
5	2	10	$\geq 0.85(f_{ck,\ spec,\ cube} + 2)$	
6	2	12		

A) Requirements where the concrete producer has product conformity certification.
B) Where the core diameter is ≥75 mm and the length/diameter ratio from 0.90 to 1.10.
C) $f_{ck,\ spec,\ cube}$ = specified characteristic cube strength. '0.85' = EN 1992-1-1 factor that accounts for the difference between the design strength obtained by testing specimens taken from a finished structure or element and the value based on standard test specimens.
D) Only where the 30 m^3 is supplied in one day. Where the concrete is supplied over two or more days then each day's volume shall be considered a different volume.
E) For specified strength C16/20 the constant is reduced to 3, for specified strength C12/15 the constant is reduced to 2, and for specified strength C8/10 the constant is reduced to 1.

The BRMCA guide entitled *Assessment of compressive strength class of recently supplied concrete using cores* sets out concise guidance on using coring for strength assessment.

6 Summary

Where there is a need to carry out an assessment of the compressive strength class of recently supplied concrete then the most important aspect is to check all available documentation and review site procedures. This is to ensure that any subsequent testing is optimised to those volumes of concrete where there is evidence of a problem. It should also be evident that the deployment of non-destructive techniques to identify volumes of concrete where there is highest concern should then enable the amount of core sampling and testing to be kept to a minimum.

Figure 1 is a flowchart covering the assessment of compressive strength of recently supplied concrete procedure covered in this document.

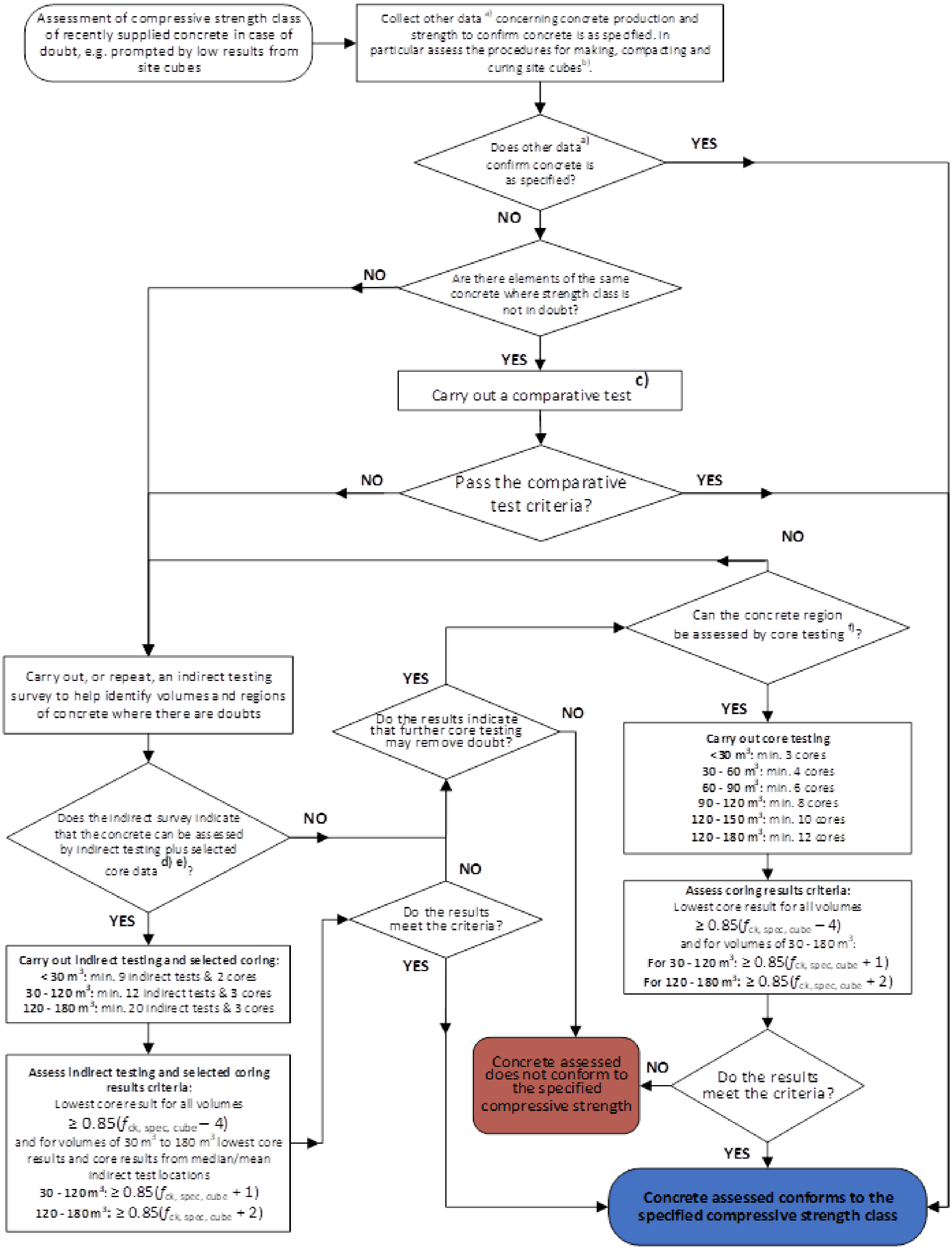

Figure 1 Flowchart for the assessment of compressive strength of recently supplied concrete.

Notes to flow chart	
a)	Other data includes the producer's results or batching records. It also includes the possibility that the doubt may be attributable to poorly sampled, compacted and cured site cubes where the doubt cannot be justified.
b)	Site cubes should be made from composite samples of concrete in accordance with BS EN 12350-1 and BS 8500-1. Concrete shall be made into compressive strength test specimens and cured in accordance with BS EN 12390-2, that is the concrete shall be compacted and then left in the moulds for at least 16 h, but not longer than 3 days, at a temperature of (20 ± 5) °C and protected against shock, vibration and dehydration. Subsequently the cubes shall be cured in water at a temperature of (20 ± 2) °C, or in chamber at (20 ± 2) °C and relative humidity ≥ 95 % until tested for compressive strength in accordance with BS EN 12390-3
c)	Comparative testing is carried out using either a rebound hammer to BS EN 12504-2 or using ultrasonic pulse velocity to EN 12504-4. Guidance on the comparative testing to PD CEN/TR 17086 is set out BRMCA Guide *Assessment of compressive strength class of recently supplied concrete using comparative testing*
d)	Coring to be in accordance with BS EN 12504-1. In particular: – BS EN 13791 requires the cores to be cured with sealed curing rather than water curing. This is primarily to ensure that the core to be tested is at a moisture condition similar to the in-situ moisture condition. Further background is given in PD CEN/TR 17086. – Cores containing reinforcing bars should be avoided wherever possible by the selection of the core diameter and the use of cover meters when deciding where to cut the cores. In general reinforcement reduces the strength of a core, the exceptions being 1:1 cores with not more than 2.0% volume fraction of reinforcement and 2:1 cores where the reinforcement is completely within 30 mm of the ends of the core and the volume fraction of reinforcement is not more than 2.0%. In these cases, the presence of reinforcement may be regarded as having no impact on the core strength. For other cases the impact of reinforcement on core strength is variable and any result is unlikely to represent the strength of the concrete and for this reason the result shall be rejected. – To be classified as a 1:1 core, where a 1:1 core is required if assessing the characteristic cube strength, the capped or ground length to diameter ratio shall be within the range between 0.90 to 1 and 1.10 to 1. – End preparation by grinding is a requirement where concrete strengths greater than 50 MPa are anticipated and highly recommended for the whole range of strengths as it is the most precise method of preparing the ends of specimens. – an estimation of the cores' excess voidage and its effect on strength shall be made by reference to BS EN 12504-1.
e)	See BRMCA Guide *Assessment of compressive strength class of recently supplied concrete using in-situ indirect testing plus selected core test data.*
f)	See BRMCA Guide *Assessment of compressive strength class of recently supplied concrete using in-situ core testing.*

STANDARDS

BS EN 206	Concrete — Specification, performance, production and conformity
BS EN 1992-1-1	Eurocode 2: Design of concrete structures — Part 1-1: General rules and rules for buildings
BS EN 12350-1	Testing fresh concrete — Part 1: Sampling and common apparatus
BS EN 12390-2	Testing hardened concrete — Part 2: Making and curing specimens for strength testing
BS EN 12390-3	Testing hardened concrete — Part 3: Compressive strength of test specimens
BS EN 12504-1	Testing concrete in structures — Part 1: Cored specimens - Taking, examining and testing in compression
BS EN 12504-2	Testing concrete in structures — Part 2: Non-destructive testing - Determination of rebound number
BS EN 12504-4	Testing concrete in structures — Part 4: Determination of ultrasonic pulse velocity
BS EN 13791	Assessment of in-situ compressive strength in structures and precast concrete components
BS 8500-1	Concrete — Complementary British Standard to EN 206. Part 1: Method of specifying and guidance for the specifier
BS 8500-2	Concrete — Complementary British Standard to EN 206. Part 2: Specification for constituent materials and concrete
PD CEN/TR 17086	Further guidance on the application of EN 13791: 2019 and background to provisions (Publication anticipated in 2020)

REFERENCES

BRMCA. DRAFT Guide to BS EN 13791. Assessment of compressive strength class of recently supplied concrete using comparative testing.

BRMCA. DRAFT Guide to BS EN 13791. Assessment of compressive strength class of recently supplied concrete using indirect testing and cores.

BRMCA. DRAFT Guide to BS EN 13791. Assessment of compressive strength class of recently supplied concrete using cores.

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