THE PROS AND CONS OF SPECIFYING STRENGTH AT 91 DAYS

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Abstract

The drive to produce more sustainable concrete has led to the wider use of cements with lower clinker contents. Such cements develop their strength more slowly but in the longer term give higher strengths provided water is available for continued hydration. Specifying strength at 91 days would take account of this slower strength gain and lead to more sustainable concretes due to lower Portland cement clinker content. The advantages in terms of structural performance have to be balanced against possible delays to the construction process due to a lower early strength and the technical issues and commercial risks associated with conformity at 91 days.

This paper describes the various issues associated with specifying strength at 91 days and offers solutions to the downside issues. Provided the downside issues are correctly handled, there is a strong sustainability case for specifying strength at 91 days.

Keywords: Specification, compressive strength, sustainability, conformity, production control, formwork striking times, early-age thermal cracking.

1. INTRODUCTION

The European concrete structures committee (CEN/TC250/SC2) and the concrete committee (CEN/TC104/SC1) have held initial discussions on basing the characteristic strength on the 91 day strength as the norm. This proposal is being pushed by the concrete designers [1] as they see a number of structural and environmental benefits; however, before any decision can be taken, the durability, construction and control issues need to be considered. This paper is a contribution to those discussions.

2. ENVIRONMENTAL ASPECTS

With respect to the material concrete, the Portland cement clinker content of concrete is the main contributor to global warming potential [2], see Figure 1. Consequently the cement industry is developing new cements with lower clinker contents [3] and the concrete industry is reducing the impact of concrete by selecting such cements or using additions, e.g. fly ash, directly in the concrete mixer. One impact of the secondary cementitious materials and additions (limestone excepted) is that compared with CEMI concrete they enhance strength development after 28 days provided there is water for hydration. If the characteristic strength were to be based on 91 day strength and not 28 day strength, there is the potential to reduce the proportion of Portland cement clinker in the cement or concrete and/or reduce the cement content provided the concrete retains a closed structure. This would further reduce the environmental impact of concrete structures.

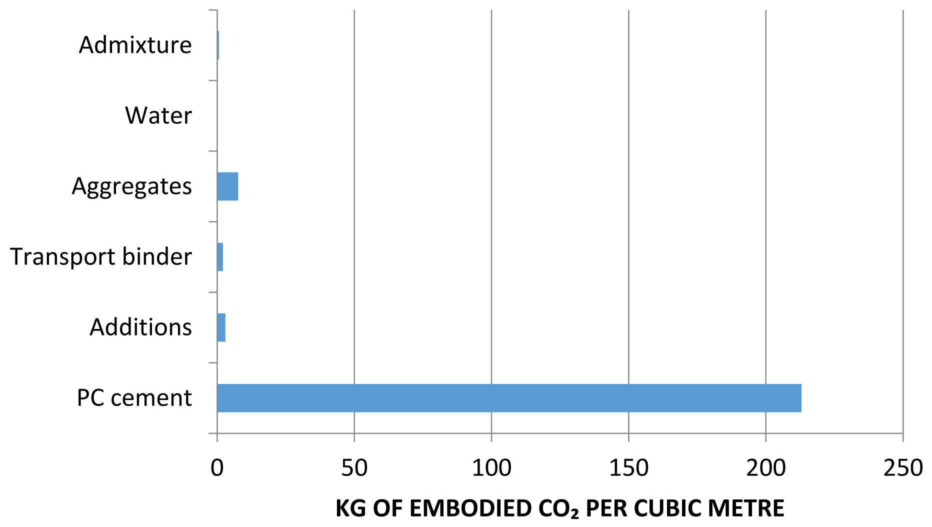

Figure 1: Embodied carbon dioxide per cubic metre of average UK concrete

3. STRUCTURAL ASPECTS

Leivestad [1] has identified a number of structural benefits resulting from basing the characteristic strength on the 91 day strength. He also questions why the full potential strength of concrete is not utilised when no account is taken of the strength development after 28 days, which may be in the order of 35 to 50% [1]. Furthermore, high early strengths lead to higher temperature rises and to a higher risk of early-age thermal cracking. In addition higher early concrete strengths lead to the need for higher proportions of crack control reinforcement. Thus, from a structural viewpoint there are several benefits and some safety issues (over-strength) are taken care of by basing characteristic strength on 91 days and no downside.

Concern will be raised as to whether concrete in rapid multi-storey construction will achieve the expected in-situ strength. These concerns might originate from data on the strength development of test specimens exposed to indoor air. Marsh and Ali [4] showed that data from test specimens over-estimate the impact on structures. CIRIA [5] showed that a 25% reduction in the outer 25mm of a section had the following impacts:

- flexural strength 93%;
- shear strength 98%;
- bond strength no change.

4. DURABILITY

There are those who argue that compressive strength has nothing to do with durability and within specific boundaries they are correct; however, it is too simplistic to ignore the impact of basing characteristic strength on 91 days and not 28 days. Assuming that the traditional method of specification of durability is applied, the concrete producer will check the concrete for conformity to the maximum w/c ratio for durability and the w/c ratio needed to achieve the target strength. If the w/c ratio needed to achieve the target strength is higher than the maximum w/c ratio specified, the producer may increase the proportion of additions so that the w/c ratio to achieve the target strength is the same as the maximum w/c ratio provided that the proportion of addition does not exceed the permitted value. As most national limiting values permit a wide range of cement/binder types, the net effect is likely to be an increase in the proportion of additions. This increase in proportions will in general:

- reduce the resistance to carbonation;
- reduce the freeze-thaw resistance;
- with GGBS and fly ash, increase the chloride resistance;
- with limestone, decrease the chloride resistance;
- increase the resistance to sulfate attack, limestone excepted.

In addition, abrasion resistance is a function of the concrete strength and so a reduction in the 28 day strength will lead to a reduction in abrasion resistance. Whether such changes in performance are significant is an open question. The author suspects that some national limiting values are based on cements that are available in the marketplace and do not take account of cements or binders at the limits of composition when combined with aggregates that are permeable to aggressive species, e.g. carbon dioxide, chloride ions, or poorly shaped. For example a cement with 40% fly ash combined with 50% of the coarse aggregate being recycled concrete gives a rate of carbonation that is significantly higher than ‘normal’ [6].

NOTE: There may be issues with respect to creep and drying shrinkage with such high proportions of recycled concrete aggregate and CEN/TC250/SC2 is currently considering the impact on design when the concrete contains recycled aggregates.

The solution is to specify durability by performance as in this case adequate durability performance will be proven.

5. CONSTRUCTION

There are several aspects of construction that need to be considered. Firstly a reduced 28 day strength also results in lower early strengths and potentially longer times before formwork may be stripped. In large sections this is unlikely to be significant but it will impact on striking times to soffit formwork of suspended slabs. Using rates of strength development data from reference [1] and assuming a compressive strength class of C30/37 and a target 2:1 cylinder strength of 38 N/mm^2, the rates of strength development is given in Figure 2 for equal 28 day strength and in Figure 3 for equal 91 day strength. The estimated time to achieve 10 N/mm^2 is given in Table 1.

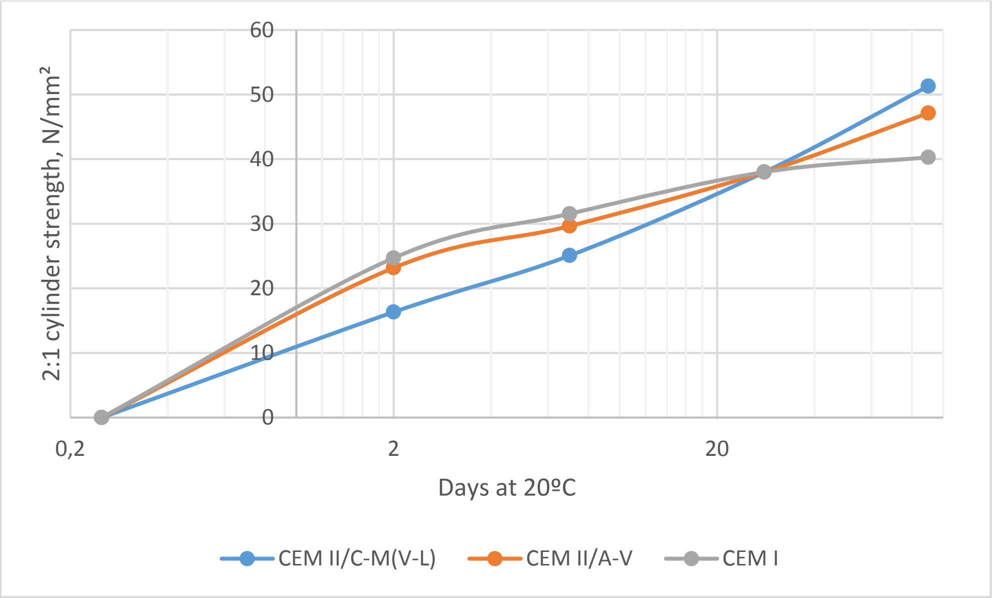

Figure 2: Rate of strength development for a C30/37 at equal 28 day strength

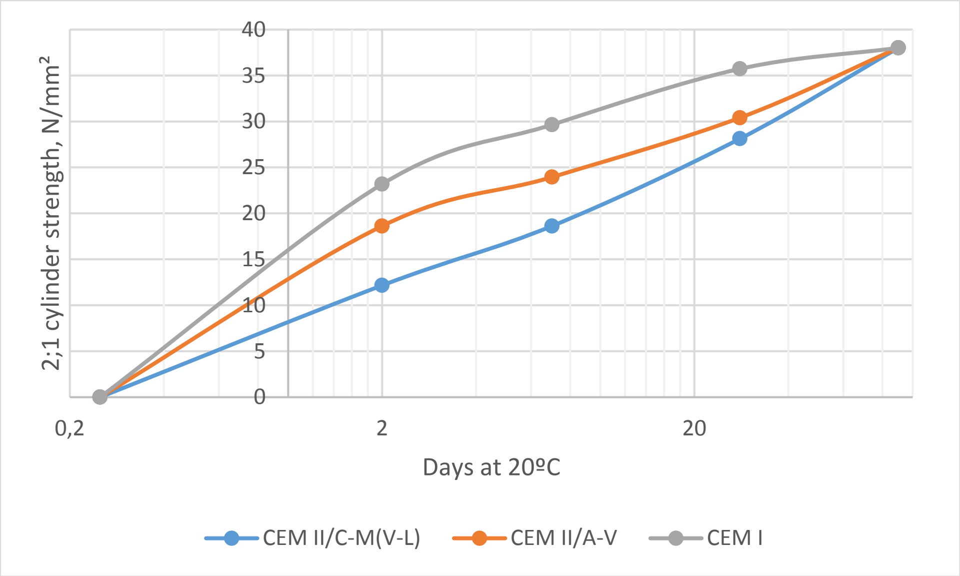

Figure 3: Rate of strength development for a C30/37 at equal 91 day strength

Table 1: Estimated time in days to 10 N/mm^2 for C30/37 concretes

Cement type	Equal 28 day strength				Equal 91 day strength			
	Average concrete temperature, ºC				Average concrete temperature, ºC			
	20	15	10	5	20	15	10	5
CEM II/C-M(V-L)	0.91	1.21	1.73	2.64	1.35	1.82	2.59	3.97
CEM II/A-V	0.61	0.82	1.17	1.79	0.75	1.01	1.44	2.20
CEM I	0.58	0.78	1.11	1.70	0.60	0.81	1.15	1.76

These estimates show that at an average concrete temperature of 10ºC, which is a reasonable value for the spring and autumn in northern Europe, the change from conformity at 28 days to conformity at 91 days using the same cement type at worse increases the formwork striking time by 1 day. A change from a CEM II/A-V cement to one of the new CEM II/C-M (V-L) cements increases the formwork striking time by about 0.5 days and, if the change in the conformity period led to the use of these new cement types, the formwork striking time are almost doubled. A slower strength gain may also impact on subsequent operations, but usually this can be resolved by re-propping, which is the process whereby as the soffit formwork is removed, props are placed to take the load.

On the other hand the use of the 91 day strength will reduce the early-age temperature rise and the risk or extent of early-age thermal cracking and also the risk of delayed ettringite formation.

In order to get a feel for the magnitude of these changes, if we take a 700mm wide section in plywood formwork and an assumed cement content of 291 kg/m^3, the temperature fall from peak temperature to mean ambient temperature is 33ºC for the CEMI, 28 to 29ºC for the CEM II/A-V and 25 to 26ºC for the CEM II/C-M [7]. This assumes that the CEM II/C-M would have a heat output that would qualify it as a very low heat cement. Even without a change in cement type, a 91 day strength would require a higher w/c ratio and a lower cement content (if permitted by the specification) and the lower cement content will give a lower temperature rise in the concrete. A reduction in the temperature fall leads to a reduction in the crack control reinforcement and a further improvement in the sustainability.

6. PRODUCTION CONTROL AND CONFORMITY

It is not a satisfactory solution to any of the parties involved to have to wait for 91 days before conformity of the concrete is proven. EN 206:2013 offers a possible solution as it permits conformity to be based on the use of control charts such as CUSUM [8]. CUSUM uses the measured 7 day strengths to predict the 28 day strength until the real 28 day strengths are available. There is no reason why this principle could not be applied to predicted 91 day strengths. Practice has shown that the ratio of 7 to 28 day strength is not constant and a second CUSUM assessment is made to detect changes in this ratio and corrections are applied when a change is detected. As it is unlikely that the ratio of 7 to 91 day strength will be constant, this procedure could be extended to the ratio of 7 to 91 day strength.

In general producers do not want to operate two control systems and they would like either 28 days or 91 days to be the norm. There would also be significant ‘education’ issues resulting from a change to the norm being 91 days. As this would be such a major change, there would be widespread publicity about the change, but there will still be some specifiers who would not be aware of this change. While ERMCO does not believe identity testing is needed for concrete from companies with third party certification, it is the reality in some places. If there is agreement to adopt 91 day strength for conformity, ERMCO needs to discuss whether they would support identity testing being based on 7-day strength only.

7. CONCLUSION

There are structural and environmental benefits for changing the basis of characteristic strength from one based on testing at 28 days to one based on testing at 91 days. From a construction viewpoint there are potential benefits (reduced temperature rise and reduced risk of early-age thermal cracking) but there is also a downside in that formwork striking times would be longer.

Concrete producers can cope with the characteristic strength being based on 91 days if they use the option in EN 206:2013 of using control charts, but having to run two control systems will result in problems.

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