

Specifying Sustainable Concrete: Using 56 day concrete strengths

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Specifying concrete strength at 56 days, rather than the traditional 28 days, can reduce embodied carbon. In appropriate situations specifying at 56 days should have little or no effect on design.

Strength gain in concrete is dependent on the type of cement. EN1992-1-1¹ considers three different types of cement which it calls Class R, Class N, and Class S. Concrete with cement Class R gains strength the quickest, Class S the slowest. Typical cements falling into these classes are given in Table 1.

EN1992-1-1 Cclass	Example cement type
R	CEM I
N	GGBS>35% or fly ash> 20%
S	GGBS>65% or fly ash> 35%

Table 1: Cement class to cement type (from CIRIA C766)².

Note: percentages relate to total cement content

Currently concrete strength is usually specified at 28 days. All concretes will gain strength after 28 days but the amount they gain will be related to the cement class with concretes with slower cements typically gaining more strength than those with faster cements. However, if the strength at 28 days is used as the design strength, for all types of cement, the additional strength gain from slower cements is not accounted for. This is shown in Figure 1 where the strengths of concretes made from different classes of cement are compared. It can be seen that by 300 days the concrete with the Class S cement is 15% stronger than that with the R cement even though the 28 day strength was the same.

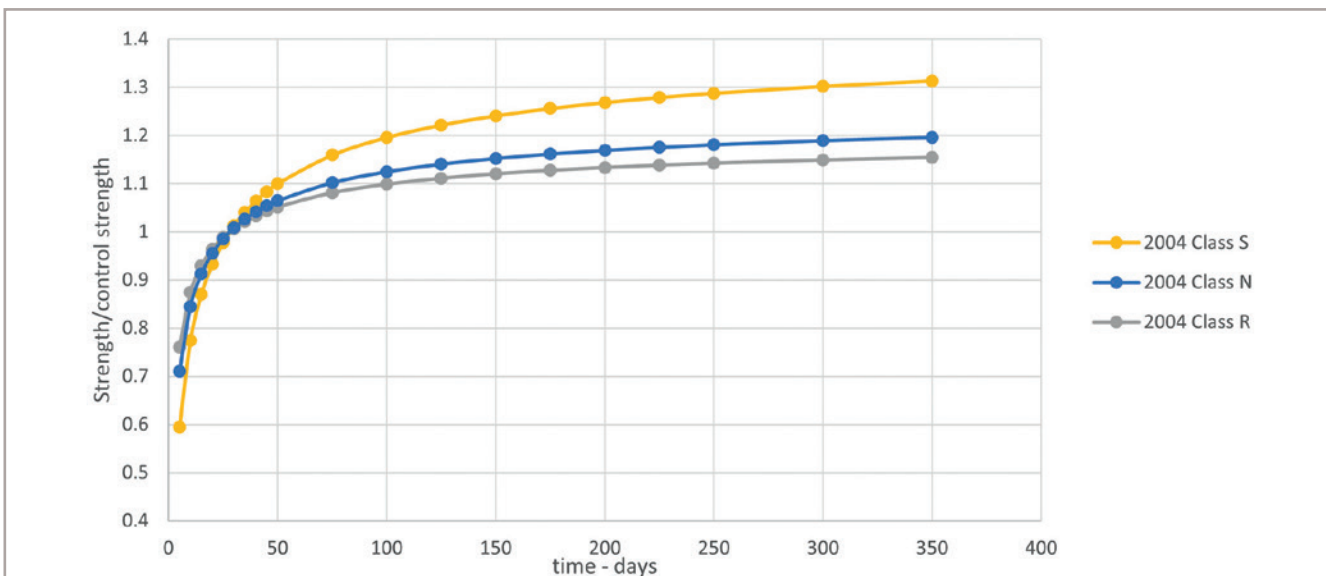
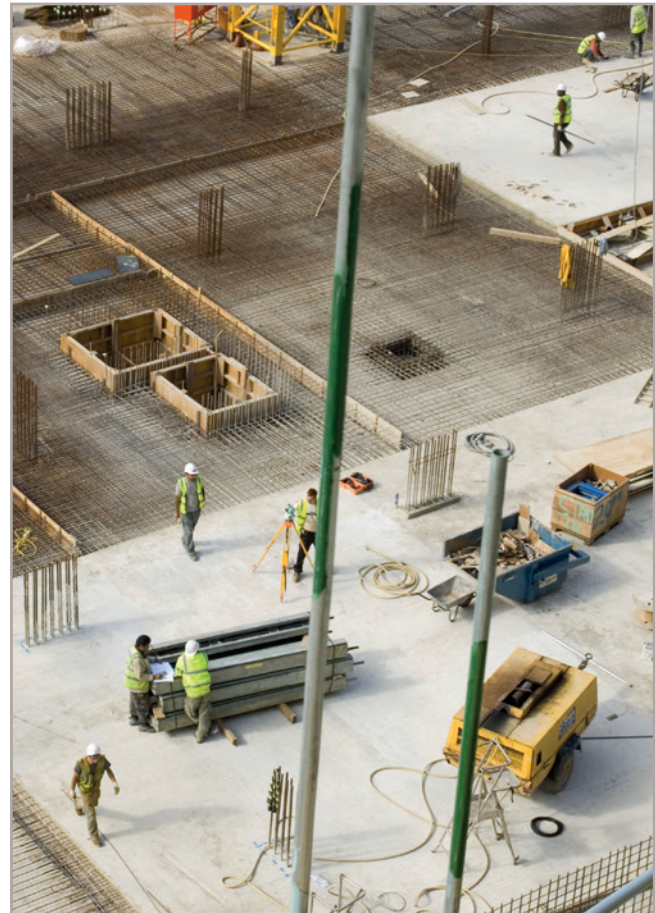


Figure 1: Strength gain of concretes made from different Class cements normalised to 28 days to EN1992-1-1:2004.

Specifying strength at later ages

Figure 2 presents the strength gain for three concretes made with class S cements. The first reaches the required strength at 28 days, the second and third concretes reach the same strength but at 56 and 90 days respectively. The concrete made with a Class R cement reaching the required strength at 28 days has been included as a comparison.

It can be seen that at 28 days the 56 day Class S concrete had a strength just under 90% of the strength of the 28 day Class S concrete. Similarly, the 90 day concrete had about 85% of the strength. By about 200 days the 56 day concrete made from the Class S cement was stronger than the 28 day concrete made with the class R cement.

Whilst exact savings will depend on the concrete mix it is estimated that saving of between 15 and 20kg/m³ of cement could be made by specifying concrete with an S class cement tested at 56 days rather than 28 days. Whilst S Class cements tend to have relatively low embodied carbon anyway this would still lead to a saving of 5 – 10 kg/m³ of embodied carbon.

Strength gain and design

Structural design codes normally allow for some increase in strength beyond the 28 days at which samples are normally tested. This is partly to offset the fact that concrete strength reduces under sustained loads. The recommended values in EN1992-1-1 take a different approach to that adopted in the UK as discussed below.

EN1992-1-1 recommended values

EN1992-1-1 includes a factor on the concrete design strength of α_{cc} which is described as “the coefficient taking account of long-term effects and unfavourable effects resulting from the way the load is applied”. This coefficient is 1.0 in the recommended values. However, if strength is specified after 28 days there is a reduction factor k_t of 0.85 on the design strength of the concrete. Therefore, indirectly, EN1992-1-1 assumes that the strength gain after 28 days is approximately 18%. It is of interest to note that PD6687³ includes a brief review of the background to the assumptions in EN1992-1-1 and concludes that the intended allowance was actually 13%.

UK National Annex values

In the UK the National Annex gives the coefficient of α_{cc} as 0.85, instead of the recommended 1.0, for bending and axial load although it is permitted to use 1.0 for shear. As the 0.85 is already included in the concrete design strength the UK National Annex takes k_t as 1.0. As the concrete design strength is a function of the product of α_{cc} and k_t the design compressive strength for concretes specified after 28 days is the same in the UK as with the recommended values in EN1992-1-1. However, the reasoning is somewhat different and PD6687 sets out the basis for the UK decision to set α_{cc} as 0.85. The discussion accepts further strength gain will occur, but it is not precise about exactly how much is assumed. The implication of the UK National Annex choices is that the design is significantly less dependent on strength gain than the recommended values in EN1992-1-1. Indeed, strict interpretation of the UK National Annex does not require a reduction in the concrete design strength when concrete strength is specified after 28 days.

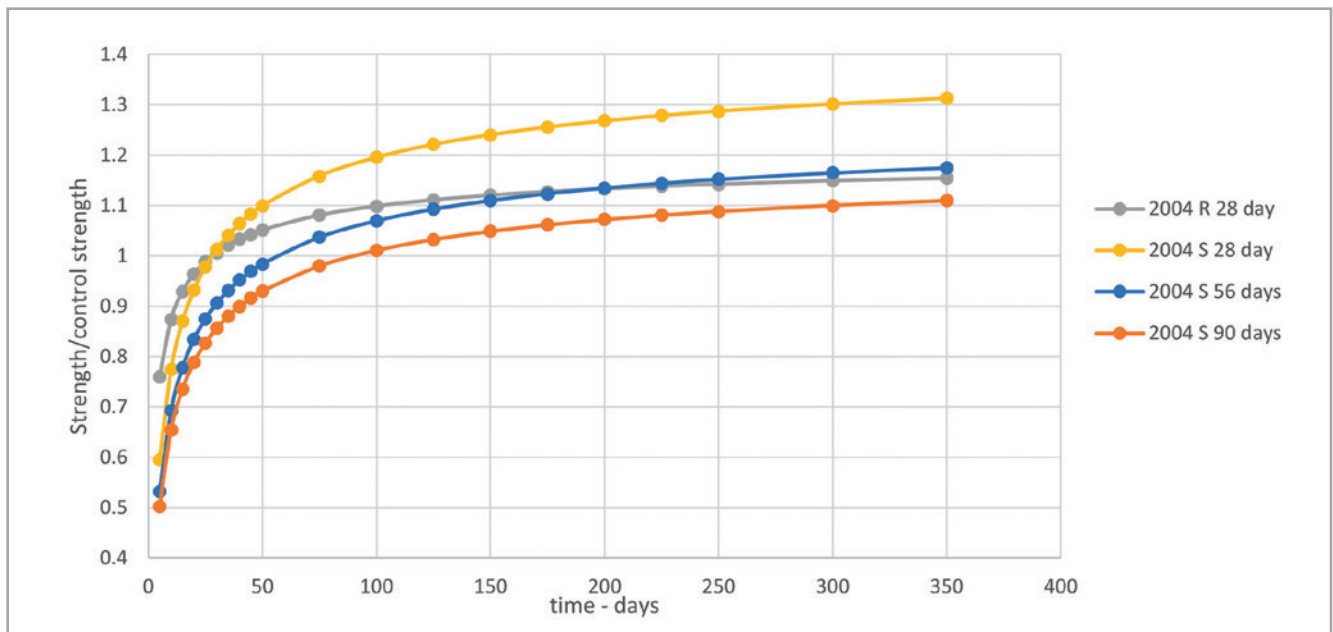


Figure 2: Strength gain of the same grade of concrete made from S and R Class cements, tested at different ages to EN1992-1-1:2004.

Research basis

Recent research has also suggested the need for a concrete strength to increase beyond that at the time of testing to offset the effects of sustained loads⁴. This work suggested that an increase in compressive strength of 18% was required to ensure the required level of safety, similar to the recommended values in EN1992-1-1. However, it also noted that some concretes did not achieve the strength increase within reasonable periods. For example, Figure 1 shows that the concrete made with the R cement has only increased its strength by 15% from the 28 day strength, after 1 year. The deficit is small, and structures built with R cements, tested at 28 days have performed adequately over many years, however basing design on 56 day strength tests for concretes with R cements would tend to reduce factors of safety.

In summary there is an assumption in Eurocode 2 that the concrete will gain strength of between 13 and 18% beyond the strength assessed at 28 days prior to being loaded with design level loads. In the UK National Annex the amount of strength gain assumed is significantly lower and the exact amount is less clear. Comparison with R cement concretes would indicate that 15% strength increase beyond the assessed strength and within a year is acceptable current practice. Therefore, if a decision is made to assess the concrete strength at a later point in time than 28 days, this would not require modification of the design rules if the strength gain between assessment of strength and the time of application of full design loads, assumed to be after one year, was 15%.

How do we specify?

There are three ways in which concrete could be specified to take account of the long-term strength gain present in some concretes:

- 1) Specify a lower strength at 28 days to acknowledge the strength gain with time. This approach carries the benefit of no change to the current practice although it is less likely to indicate longer term strength gain than 56 day conformity. The risks associated with longer term strength gain sit completely with the designer who effectively designs for a strength which is higher than the strength they specified.
- 2) Specify the strength at 56 days – it is permissible under BS 8500⁵ to specify a concrete strength at 56 days and so this should not cause specification problems. By specifying concrete at 56 days it is possible that the delay in identifying non-conforming concrete may result in greater amounts of rework. It may therefore be prudent to have earlier control specimen to confirm that the concrete is likely to reach its specified strength at 56 days. The supplier remains responsible for supplying a concrete of the strength at which the designer assumed, albeit at 56 days rather than 28 days.
- 3) Hybrids - there are various ways of combining these approaches for example option 1) could be adopted but with an additional “confirmatory” set of samples tested at 56 days. These methods would tend to be less transparent about responsibilities and if adopted care should be taken to make sure all parties are clear on what their duties are.

Option 2) would seem to be the most straightforward method to specify the concrete. However, overall, the aim is to reduce the cement content of the concretes. If the requirements on the supplier are overly onerous then they will not be incentivised to minimise the cement content. Early discussions with suppliers, including previous experience of 56 day conformity are recommended.



Other considerations

The strength v time

Concretes based on 56 days gain early age strength slower and so will not be appropriate where early strength is required for the striking of formwork or for the supporting of high construction loads. The impact of slower strength gain on programme should therefore be considered.

Curing

As the Class S cements take longer to gain strength, curing should be considered. The relationships given in the Eurocode and used to produce Figures 1 and 2 are based on concrete cured at 20 degrees at >95% humidity.

Temperature will affect the rate of strength gain, but over longer periods in the UK environment the effects of variations from 20 degrees are likely to be minor. However, if the concrete dries out this will stop further hydration and therefore prevent further strength gain. Whilst curing agents are typically applied to finished concrete surfaces it is not normal to treat the struck surfaces and the effectiveness of the curing agent over the longer term is limited. Drying occurs through a diffusion process and fortunately that occurs slowly in concrete and is associated with drying shrinkage. Nonetheless for a 300mm slab exposed top and bottom 60% of the drying shrinkage occurs within the first year. In contrast for a 500 deep raft only exposed on its top surface only about 20% of the shrinkage will have occurred. Whilst there is no direct link between the percentage of shrinkage and continued strength gain, thin slabs could dry out before sufficient strength gain has occurred.

Specified curing times are important to the surface properties of the concrete to avoid dusting, plastic shrinkage cracking and improve durability. As the durability requirements are primarily defined by the concrete constituents and proportions, providing these conform to BS 8500⁵ there should be no need to enhance curing requirements due to changing the time when the strength is specified. However, as BS EN 13670⁶ tends to specify curing times as a time to reach a proportion of the 28 day strength it could be argued that an equivalent 28 day strength should be specified. For the typical Curing Class 2, which requires curing until 35% of the 28 day strength is reached, the rate of strength gain at this point is so steep it is unlikely to make a meaningful difference to construction if this is specified as 35% of the 56 day strength.

Heat of hydration

In deeper pours the heat of hydration causes a significant temperature rise in the first few days after casting. The increase in temperature increases the strength gain during this period. However, there is also evidence that it reduces the longer-term strengths. The issue is discussed further in CIRIA C766². The temperature rise for equivalent concretes made from S class cements will be lower than that for other classes of cement. In addition, it has been found that at a given peak temperature the effect on long term strength is less for concretes with high replacement levels of fly ash or GGBS than for CEM I cements. Therefore, whilst control of early thermal temperature rise is important for S class cements, the overall impact of early age rises in temperature on long term strengths is significantly less than for R class cements.

Summary

The use of a concrete made from a S class cement with the strength specified at 56 days should give long term strengths similar to a concrete made from an R class cement with strength specified at 28 days. Specifying the concrete at 56 days should reduce the cement content by 15-20kg/m³ leading reductions of 5 to 10 kg/m³ embodied carbon. There should be no difficulties with specifying such a concrete under BS8500 although discussion with the concrete supplier is recommended. These concretes will not be appropriate when early striking times are required and should not be used in thin elements subject to rapid drying. Concretes with S class cements are normally suited to use in foundations, retaining walls, larger columns, and transfer slabs and in these cases the specification of strength at 56 days should be considered.

References

- 1) *BS EN 1992-1-1:2004+A1 2014. Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings.* BSI, 2015.
- 2) *CIRIA 766. Control of cracking caused by restrained deformation in concrete.* CIRIA, 2018.
- 3) *PD6687-1:2020. Background paper to the National Annexes to BS EN1992-1, BS EN1992-1 and BS EN 1992-4.* BSI, 2020.
- 4) Tasevski et al, "Assessing the compressive strength of concrete under sustained actions: From refined models to simple design expressions", Structural Concrete, 2019.
- 5) *BS 8500-1:2015+A2:2019. Concrete – Complementary British Standard to BS EN 206, Part 1: Method of specifying and guidance for the specifier.* BSI, 2019.
- 6) *BS EN13670:2009. Execution of concrete structures,* BSI, 2015.

Further reading

This paper is a companion guide to *Specifying Sustainable Concrete*, a 24-page document which looks at all of the constituents of concrete and the decisions/choices that can be made in their specification to achieve the most sustainable solution.

Specifying Sustainable Concrete can be downloaded free from www.concretecentre.com/publications



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