

Use of GGBS in Concrete Construction

1. Requirements for Striking Formwork

The time requirement for striking formwork, as per BS 8110 (Structural Use of Concrete), is **4 days** for soffit formwork to slabs and **12 hours** for vertical formwork (16 degrees and above). However, shorter periods can be used, in particular for slabs or beams, if the **concrete strength is at least 10 N/mm²**, (or twice the stress to which the slab is subjected – which will normally be less than 10 N/mm² value). For vertical elements concrete is required to have a strength of 2 N/mm² or greater to prevent mechanical damage when striking vertical formwork (CIRIA report 136 Formwork Striking Times).

Experience in Ireland with concretes containing up to 50% GGBS has shown that these requirements are met. There is also some 50 years plus experience in the UK with concretes where 50% GGBS is regularly used, with no adverse affects to construction programmes.

2. In-Situ Concrete Strength Data

In-situ concrete strength data, rather than cube results, is the most accurate way to determine appropriate striking times. The most accurate way to determine in-situ concrete strength is using Temperature Matched Curing.

Temperature Matched Curing

Temperature matched curing (TMC) is curing concrete cubes in a water tank whose temperature matches the in-situ temperature in the concrete, using an electrical signal from a thermocouple placed in the concrete. TMC curing gives a far more accurate measure of the strength of the concrete element than curing cubes at 20 degrees.

It is well known that the rate of strength gain of a concrete element is affected by the temperature at which it is curing. Cold concrete gains strength more slowly than warmer concrete.

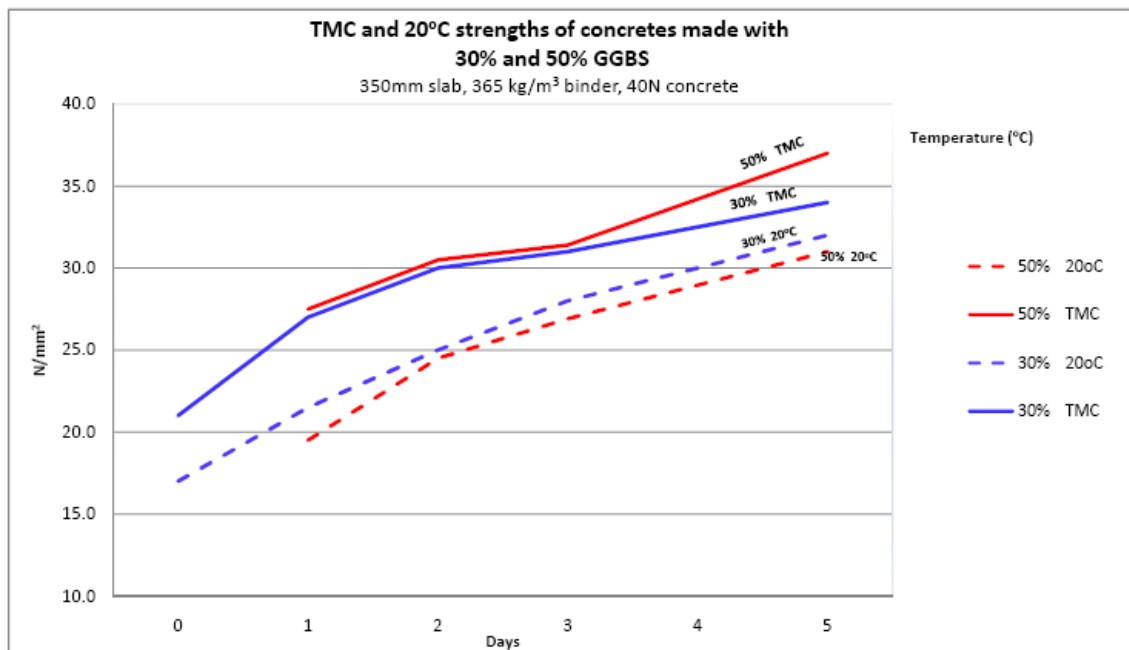
TMC gives the contractor the best possible measure of the strength in the concrete element, allowing for more accurate programming. The following few case studies demonstrate the rate of strength gain of concrete containing different % of GGBS as monitored using both TMC and standard 20 degree curing.

CASE STUDY 1

In-situ concrete strength data was obtained for flat slab construction on a recent project in Dublin city centre. The following strength data was measured for both 30% and 50% GGBS usage:

- Strength of the concrete *in the in-situ element*, using TMC
- Strength of standard site-cast cubes, lab-cured at 20°C

The results show that both the in-situ strength and the standard cube strengths of the GGBS concrete at 3 days are far greater than the minimum value of 10 N/mm² required for soffit formwork striking, as shown below:



Graph 1 – Strength versus Time – Flat slab

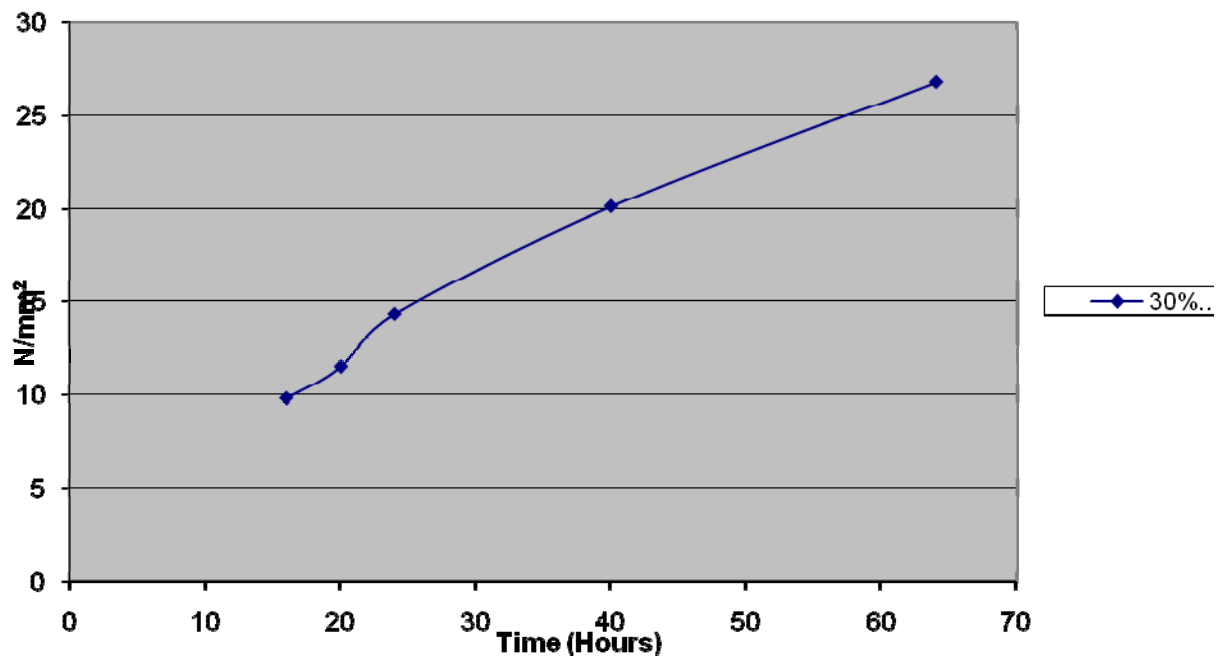
Graph 1 demonstrates that concrete containing 50% GGBS has sufficient strength to strike soffit formwork at 3 days. Based on the results here 50% GGBS was used on this job and it did not have any impact on the progress of the construction programme.

From Graph 1 it is also clear that there is little difference between the rate of strength gain for 30% and 50% replacement rates.

CASE STUDY 2

Vertical formwork to walls is generally struck the next day, often within 12-16 hours. Graph 2 shows the early age strength (measured using TMC) for a wall constructed with 30% GGBS. Only 2N/mm² is required to strike vertical formwork whereas in this case a strength of 9.7 N/mm² was achieved with 30% at 16 hours (earliest available cube result). (As noted in Graph 1, the strength for 50% replacement would not be much different to 30% GGBS).

300mm Wall with 30% GGBS - 360kg of cement



Graph 2 – Strength versus Time - for a wall

It has also been established on jobs such as Cork Civic Offices (Cleary & Doyle), Anglo Irish HQ (Royceton), Charlestown Development in Finglas (G&T Crampton) and Henry J. Lyons offices in Pearse St. (P. Elliots) that using 50% GGBS had no negative impact on the construction programme.

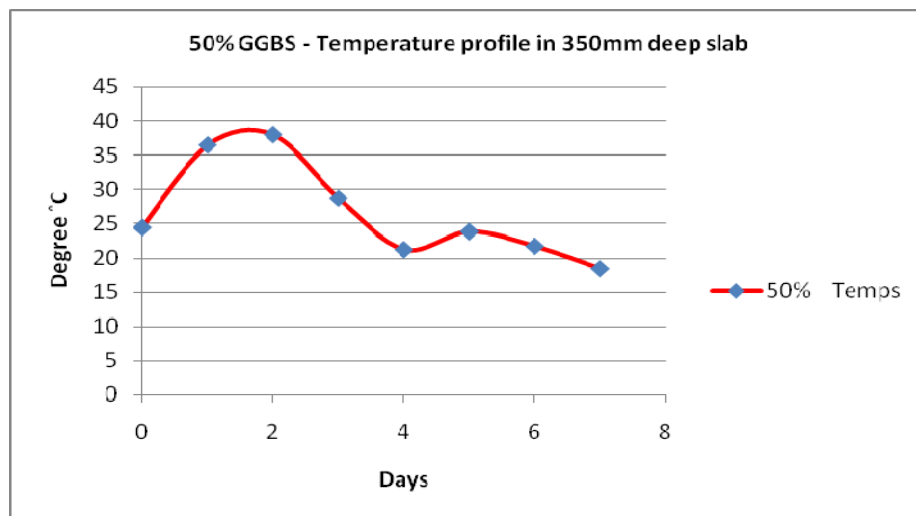
Cold Weather

Cold weather slows down the hydration of all concrete and very cold weather may impact on the normal striking programmes.

Concrete with low percentages of GGBS exhibits the same sensitivity to cold weather as ordinary concrete. Concrete with 50% GGBS may exhibit some additional retardation in very cold weather. However this effect can be mitigated by heat generated within the concrete element.

CASE STUDY 3 (same job as case study 1)

Graph 3 illustrates heat generated in a 350mm slab rising to a maximum of 36 degrees, some 15 to 20 degrees above ambient (poured in summer).

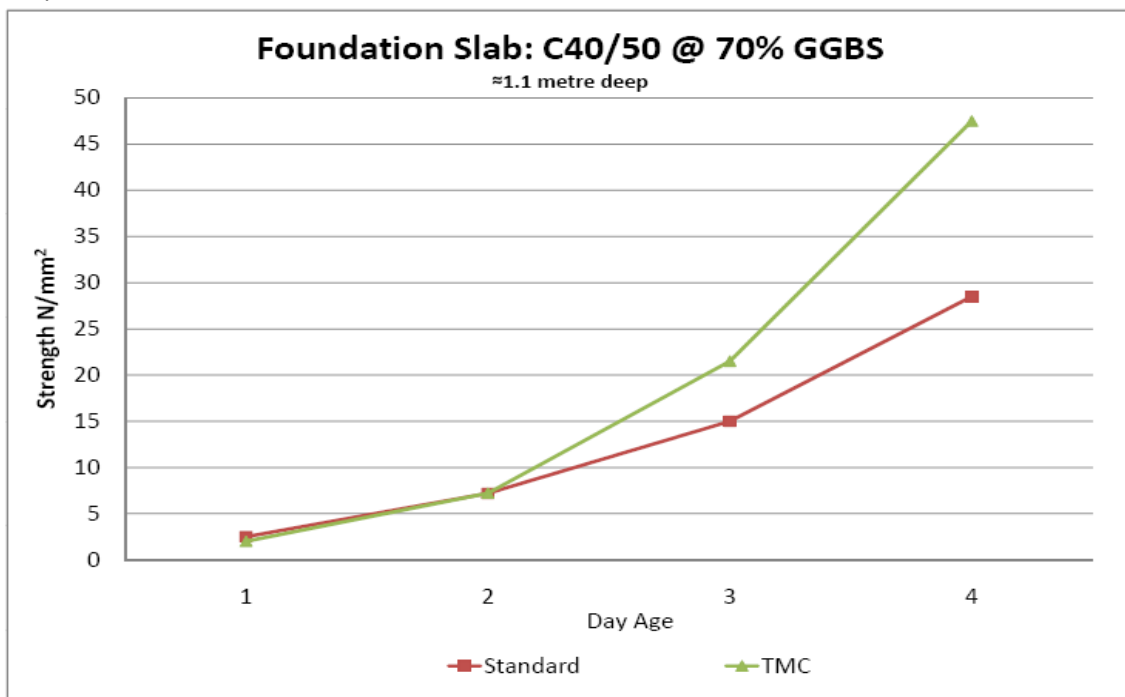


Graph 3 – Temperature profile in 350mm slab

The increase in strength that results from these elevated temperature is demonstrated in graph 1 by comparing the TMC strength data to the 20 degree strength data.

CASE STUDY 4

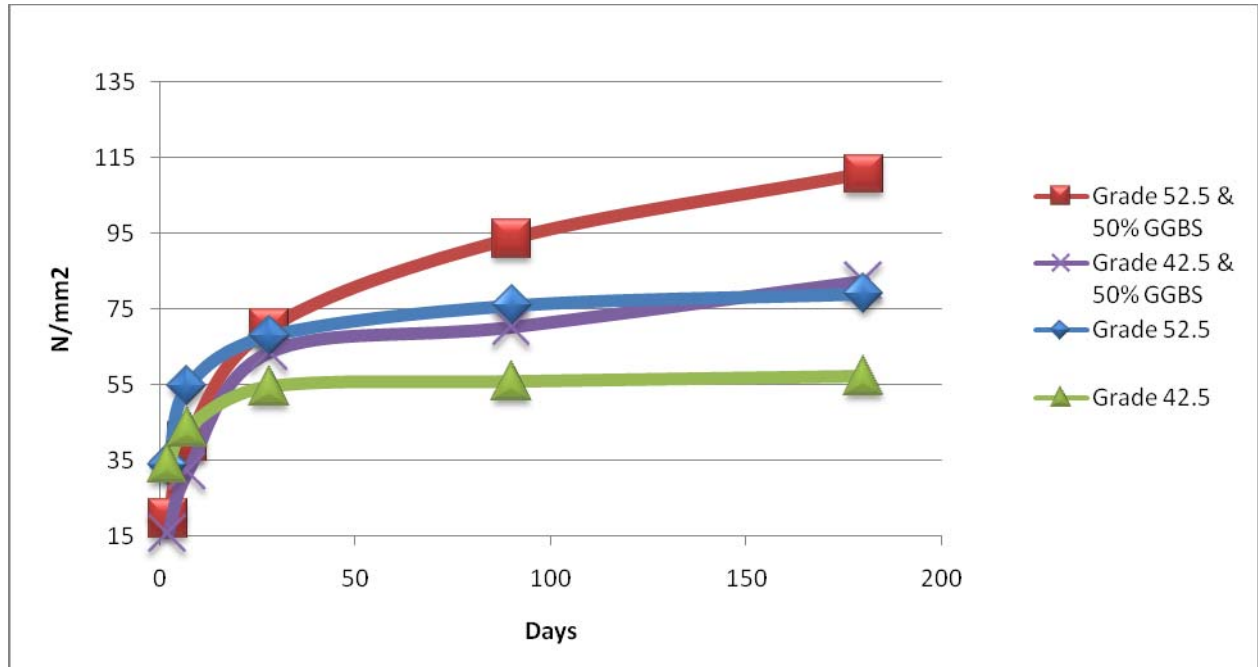
For larger concrete elements, cold weather will not have a significant impact. Since all concrete releases heat during hydration, larger elements release more heat and hence the the temperature at which the concrete cures is higher. GGBS is often specified to reduce the overall amount of heat released but even with the use of high percentages of GGBS there can still be significant temperatures in the concrete element.



Graph 4 – Increase in strength gain as a result of increased temperature (winter pour)

Graph 4 shows the strength gain data for a 1.1m deep slab poured in the winter 2009/2010. 70% GGBS was used to reduce the risk of thermal cracking and to obtain more durable concrete. High early age strengths were required. Because of the elevated concrete temperature a strength of 47N/mm² was achieved by day 4.

CASE STUDY 5



Graph 5 – Increase in strength over 6 months for blends with and without GGBS

This study shows the medium term strength development of 2 different grades of cement (namely grade 42.5 and grade 52.5) both on their own and blended with 50% GGBS. It can be noted that after 6 months the blends of 50% GGBS are substantially ahead in terms of strength development (over 40% higher in both cases).

In summary

In most circumstances, experience in Ireland and the UK has shown that using 50% GGBS has no impact on the normal programme for striking vertical or horizontal formwork. In very cold weather and for small or thin concrete elements, reducing to 30% GGBS may be required to allow formwork to be struck in accordance with traditional practice. For larger concrete elements, irrespective of replacement rates of GGBS, cold weather will not impact on the standard practice - once the standard cold weather concrete precautions are taken, such as covering with plastic sheeting and insulation where there is a danger of temperatures falling below 5 degrees, (this practice is to protect against surface frost damage). Finally, for concrete using higher percentages of GGBS it will generally be much stronger than concrete that has not used a blend of GGBS, even after just a few months. Concrete made with GGBS has been shown to continue to gain strength even a number of years later.

REFERENCE

1. On site studies
2. C.A. Clear, "Formwork striking times for ground granulated blastfurnace slag concrete: test and site results".

Extracts from the paper by C.A.Clear

"Where the proportion of ggbs is restricted to levels up to 50 % the striking times are not increased sufficiently to affect the construction programme, under normal conditions"

"Results show that for massive or medium-sized concrete construction, the use of 70% ggbs does not present a practical limitation to the striking time."

"From the examples of winter concreting described, it is evident that the in-situ early age strength development of C30 + concrete, containing up to 70% ggbs, in sections with a minimum dimension greater than 250 mm , is sufficient to achieve a striking time which does not extend the construction programme. Where only up to 50% ggbs is used, the reduction in early age development has not presented problems significant enough to prompt such field investigation, as reflected in the examples."

Table 2. Section size and striking time for TMC tests

Mix	Minimum dimension	Date cast	Average ambient temperature; °C	Minimum striking for a strength requirement of		
				2 N/mm ²	10 N/mm ²	20 N/mm ²
M1, Fig. 3(a)	1 m	9 Dec. 1992	8	21 hours	39 hours	69 hours
M2, Fig. 3(b)	1 m	20 Oct. 1992	8	21 hours	42 hours	72 hours
M3, Fig. 3(c)	1 m	3 Nov. 1992	12	18 hours	27 hours	38 hours
M4, Fig. 3(d)	250 mm	13 Mar. 1990	10	12 hours	33 hours	63 hours
M5, Fig. 3(e)	1 m	24 Nov. 1992	10	<1 day	<1 day	<1 day

The important one to note here is the data 3(d)- this is for a thin slab with 50% GGBS. It shows in March the formwork could be struck at 12 hours

See paper by C.A. Clear, "Formwork striking times for ground granulated blastfurnace slag concrete: test and site results" which looks at formwork striking times for concrete containing up to 70% GGBS [http://www.ecocem.ie/downloads/Formwork Striking Times for GGBS Concrete.pdf](http://www.ecocem.ie/downloads/Formwork_Striking_Times_for_GGBS_Concrete.pdf).