Reducing Co_2 Emissions of Concrete Slab Constructions with the Prime Composite Slab System

Xavier DESTRÉE[1], Brad J. PEASE, Ph.D[2]
[1]Structural Engineer, Consultant, La Hulpe, Belgium
[2]Concrete and Structural Engineer, PrimekssLabs, Riga, Latvia

INTRODUCTION

The concrete construction industry depends on environmentally demanding processes, such as mass consumption of energy, raw materials, and transit, and contributes significantly to global carbon dioxide (CO_2) emissions. Globally, portland cement production emitted 932 million metric tons of CO_2 ($MtCO_2$) in 2002, approximately 7% of all stationary CO_2 sources . Typical emission rates between 1995 and 2005 varied from 0.6 to 1.0 kg of CO_2 per kg of portland cement. While alternatives to portland cement exist, such as blended cements or low CO_2-emitting cements, demand for portland cement continues to increase. In the process of producing 1000kg of Portland cement, 125L of fossil fuel and 118kW.h of electricity are consumed.

Transport of ready-mix concrete is a secondary, yet significant, source of CO_2 emissions as illustrated in a survey of 99 ready-mix companies located throughout the US in 2006. The survey, comprising 17,080 concrete trucks that traveled an annual average of 28,760 km per truck (>491 million km total), determined the average fuel economy was 1.52 km/L. Therefore; approximately 324 million liters of diesel were consumed. According to, combustion of diesel fuel emits approximately 2.66 kg CO_2/L diesel, resulting in 0.86 $MtCO_2$ emissions due to concrete transport from the 99 companies involved. Clearly worldwide annual emissions from concrete transport are significant.

While the CO_2 emission rates associated with concrete production are far below other common building materials (e.g., steel), significant reductions in the carbon footprint of the industry are possible through the efficient and thoughtful use of portland cement. One such development, the PrimeComposite concrete slab system, seeks to reduce required concrete slab thickness (and corresponding CO_2 emissions), while improving performance and durability compared to traditional slab systems. Thickness reductions are provided using a two-pronged approach: 1) Replacement of all steel reinforcing bars with steel fibers for required tensile and flexural load capacities, and 2) Control of concrete shrinkage with proprietary admixtures. Performance and durability improvements are provided by eliminating the need for saw-cut joints and reducing the number of construction (day) joints. There are significant performance improvements and CO_2 emission reductions provided by Prime Composite slab systems compared to traditional concrete slab systems (welded wire mesh reinforced with saw-cut joints and SFRC without saw-cut joints).

Development Of The Prime Composite Concrete Slab System

Concrete floor slabs (slabs-on-grade and slabs-on-piles) are an essential, yet often overlooked, component in the function and operations of nearly all buildings. Concrete for large industrial, warehouse, retail, etc. spaces face a multitude of potential problems including cracking, curling, extensive opening of construction (day) joints, damage at saw-cut joints, among others. Shrinkage is however the central mechanism behind nearly all other issues. Shrinkage induces cracking, necessitating the inclusion of joints in an attempt to localize and control cracking, and causes slab length reductions that lead to potentially significant openings of construction (day) joints. Figure 1(a) illustrates a typical construction (day) joint opening in a SFRC slab-on-grade without saw-cut joints. Saw-cut joints, which offer only a limited level of cracking control, may reach kilometers in length for a single building, as joint spacing of 3 meters is common.


Figure.1 (a)


Figure.1 (b)

Problems are further compounded, as the optimal window of time-of-saw-cutting is finite and a function of mixture proportioning and ambient conditions. Saw-cutting too early results in raveling of the concrete surface, while cutting too late may result in uncontrolled cracking. Finally, saw-cut joints allow curling to take place and introduce a point of weakness where damage localizes and requires repair, as shown in Figure 1(b). Saw-cut joint damages commonly occur due to uneven levels of neighboring slabs leading to forklift wheel impact and/or uplift of the concrete away from the soil support system below the slab.

Prime Composite improves upon ordinary concrete by enhancing the tensile and flexural behavior and by controlling hygral (autogenous and drying) shrinkage, allowing for jointless slabs with thickness reductions up to and exceeding one half the thicknesses of other slab systems. Mechanical property improvements are realized through the controlled addition of steel fibers, while shrinkage control is accomplished by both careful mixture design and the addition of proprietary concrete additives, PrimeDC and PrimeFlow. Steel fibers, PrimeDC, and PrimeFlow are added to a simple concrete, provided by a ready-mix producer, using specialized equipment on the jobsite.

Steel Fiber Reinforced Concrete

Steel fiber reinforced concrete (SFRC) has been used for over 30 years to reinforce concrete slabs on grade and to limit the required number of shrinkage joints in concrete floors. Based on experience using SFRC, typically a continuous field size of up to 1500 m^2 are obtainable with construction (day) joints at a maximum spacing of 40 meters. Concrete for this application typically consists of a C30/37 (30 MPa cylinder strength) strength class with water-to-cement ratio (w/c) below 0.50, and a maximized aggregate content to limit drying shrinkage. Reinforcement is provided by a moderate dosage rate, typically $\geq$30 kg/m^3, of type I (cold-drawn) steel fibers. Higher dosage rates are also used depending on fiber shape and dimension, service loading, and subgrade bearing capacity.

As discussed in greater detail later on in this article, full-scale tests simulating SFRC ground-supported slabs exhibit a ductile flexural response with rotations concentrated along yield lines. Additional full-scale experiments presented in literature indicate yield line theory (i.e., flexure) controls design of both pile-supported andelevated slabs. Testing of a 20 cm thick elevated slab with 6 meter column spacing and 100-kg/m^3 dosage rate of hooked-end steel fibers indicate between 5 and 7 times the first crack loading is required to cause failure. Under typical loading conditions, punching failure around column or pile heads does not occur due to limited flexural capacity of SFRC.

Typically SFRC is cast over two layers of plastic sheet to minimize frictional restraint between the subgrade and the shrinking concrete. Steel fibers are highly effective at controlling cracks; therefore these slabs typically exhibit minimal cracking. Further, steel fibers offer a reliable control of curling at construction joints and edges are kept at an affordable level and do not affect significantly the serviceability and the durability of the slab. However as shown in Fig 1(a), joint openings in excess of 1 cm are common. Therefore, as discussed in the following section, Prime Composite includes proprietary additives to control shrinkage and further improve concrete performance.

Control of Shrinkage

As discussed above, concrete shrinkage critically affects the performance of all slabs. Restrained shrinkage results in random cracking of the slab, while unrestrained shrinkage causes substantial joint openings. Differential shrinkage caused approximately 8 mm of curling at joints and edges after only 50 days with 'optimal' concrete for slab-on-grade applications. In the authors' experience, up to 15 mm of curling has been observed with additional time.

The addition of PrimeDC, a cementitious additive, and PrimeFlow, a liquid admixture, to SFRC controls a lifetime of concrete shrinkage, as shown in Fig 2.The figure 2, using ASTMC878 test method, however shows an early expansion generated by PrimeDC reaction. This expansion has to be consistent in time and from site to site, independent of the ambient temperature, so that other admixtures and proprietary site techniques are used to regulate it in setting time, hardening and also to obtain the desired workability of the final concrete.

Figure 2 shows also that at infinite time, the concrete sample remains in compression although this is a 5 faces drying prismatic specimen in a 50% relative humidity atmosphere, thus much more demanding than a one face drying slab on ground. The shrinkage of the slab is eliminated, thus a zero shrinkage concrete, since construction joints at 60m distance apart remain closed after one year and longer.

The main advantage of the zero-shrinkage concept is to protect the slab from random cracking since it cancels the adverse effect of the drying shrinkage: crack free slabs become feasible and thanks to the steel fiber reinforcing, the tensile strength of the slab concrete becomes a viable property that the designer can rely on.

Also the cancellation of the curling along the edges makes the slab in full and permanent contact to the grade so that negative moment cracking along the joints and edges is no longer a critical loading case to consider anymore.

Construction joints that are needed to separate two consecutive pours remain closed in usual temperature conditions inside a building, so that the load transfer from one slab to the next is total.

As the drying shrinkage is cancelled, it is possible to tie the construction joints without any adverse effect like wild random cracking.

The user sees that type of floor as being like infinite so that the forklift trucks enjoy a completely smooth ride without bumps at each joint.

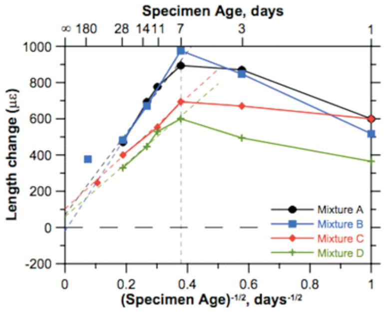

Fig.2 Zero shrinkage concrete deformations in function of age in days to infinite time

Case Studies

Since the year 2007, approximately 1.1 million m^2 of SFRC zero-shrinkage slabs have been successfully completed to the full satisfaction of the customer and the end-user.

With a normal shrinkage concrete slab as described in the introduction, a minimum thickness of 150 mm should have been needed.

When using a zero-shrinkage slab, as full continuity is obtained across the construction joints, the only loading case to verify is that of the centre point loading. The edge and corner cases of point loading do not exist anymore. Against the perimeter wall, there is indeed no traffic and the shelves are only loaded on one side thus at the half of the full intensity.

Between two adjacent buildings, the very edge of each slab is subjected to the full traffic intensity: a local thickening of the slab at 30-degree angle and without stepping, is a common solution.

REDUCTIONS IN CO2 EMISSIONS

Table 1 provides statistics on the average thicknesses (weighted by area of individual slabs) and total areas of Prime Composite and other concrete slab on grade systems cast between January and August 2012 by SIA Primekss. Other slab on grade systems included simple welded-wire mesh reinforced slabs with saw-cut joint and traditional steel fiber reinforced jointless floors. Prime Composite slabs had an average thickness of 11.8 cm, including 10,800 m2

Prime Composite slab with 18 cm thickness designed for point loads of 200 kN. Alternative slab systems were approximately 46% thicker with a weighted average thickness of 17.2 cm. Nearly twice the area of Prime Composite slabs were cast compared to other slab solutions with only approximately 31% additional concrete volume. If Prime Composite slabs were replaced with other systems (i.e., using the average thickness of other slab solutions) an additional 20,600 m^3 of concrete would be needed or 43,170 m^3 of concrete in total. CO_2-emissions related to the production of portland cement occur at rates between 0.6 and 1.0 tons CO_2/ton cement, with the weighted average in 2005 being 0.83 tons CO_2/ton cement. In the following calculations, CO_2-emissions related to PrimeDC production are assumed to be identical to portland cement, which is likely a conservative assumption as production of PrimeDC requires a lower kiln temperature and less calcium carbonate than portland cement.

On average, the total cementitious content of Prime Composite (i.e., portland cement and PrimeDC) is nearly identical to other slab systems. Current production totals presented in Table 1 result in cement-related CO2-emission rates of 28.9 kg CO_2/m^2 for PrimeComposite slabs and 42.1 kg CO2/m2 for saw-cut and traditional jointless floors. This accounts for more than 31% reduction in CO_2 per area of slab placed.

Typical reference projects:

Norwegian Post Office warehouse	42000 m2	110 mm	2×70 kN point loading
John Deere, Marsta (Sweden)	15000 m2	100 mm	2 x 50 kN
MAP high storage (Sweden)	4000 m2	150 mm	2 x 112 kN
Unil Logistic Center (Norway),	15 690 m2	120 mm	2 x 75 kN point loading

According to internal documentation a total of approximately 1,100,000 m^2 of PrimeComposite slabs on grade have been placed to date. Based on the thicknesses shown in Table 1, PrimeComposite (compared to other slab systems) has saved of approximately 15,900 tons of portland cement and reduced Primekss' carbon footprint of approximately 12,585 tons of Co_2.

Comparisons presented to this point are focused on the quantities of cement used. However, secondary sources of CO_2-emission reduction are likely considerable, for example reduced transportation and steel demand.

From January to August 2012, PrimeComposite slabs resulted in a 20,600 m^3 reduction in required concrete volume. Delivery of this volume of concrete would involve between 2060 to 3430 truckloads, depending on drum volume. As discussed in the introduction section, average fuel economy for concrete trucks was 1.52 km/L in 2006, and diesel fuel combustion emits 2.66 kg CO_2/L diesel. Assuming a one-way delivery distance of 10 km, approximately 166-277 additional tons of Co_2 would have been emitted during an 8-month period. Additionally, up to 15,450 m^3 of aggregate and CO_2 emissions related to production and transportation were saved as typically 75% of the volume of concrete consists of aggregate.

A further reduction of the carbon footprint of Prime Composite slabs is provided by the minimization of reinforcing steel. Traditional jointless slabs require a minimum reinforcement ratio of 0.5% in both directions. Assuming the average thickness of these slabs in Table 1, a total of 13.4 kg of reinforcing steel is required per square meter of slab (As = 0.5% × 172 mm × 1000 mm × 2 = 1720 mm^2/m, 1720 mm^2/m × 7800 kg/m^3 = 13.4 kg/m^2 slab). The steel fiber dosage from the full-scale results in section 3, 35 kg/m^3 and the average thickness of PrimeComposite slabs, 11.8 cm yields a steel consumption of only 4.1 kg steel per square meter of slab. As steel production typically emits in excess of 1 kg CO_2 per kg steel, a further reduction of no less than 9.3 kg CO_2/m2 of slab is realized.

The savings in CO_2 are respectively for the cement of (42.10kg/m^2-28.9kg/m^2 = 13.2kg/m^2), for the steel reinforcing of (13.40 kg/m^2- 4.10kg/m^2 = 9.3kg/m^2) so that the total saving is of 13.2kg/m^2 + 9.3kg/m^2 = 22.50kg/m^2.

Considering the reduced volumetric demand for cement and steel of Prime Composite slabs, CO_2 emissions are reduced by 22.5 kg CO_2 or 40.5% per square meter of slab.

Table 1 Statistics on Prime Composite and other slab on grade systems according to internal documentation.

Slab type	Avg. thickness	Area cast	Concrete volume
	cm	m^2	m3
Prime Composite	11.8	250,984	29,616
Other	17.2	131,220	22,570

Table.1

CONCLUSIONS

Results presented in this article conclude the following:

- Using the proprietary additives PrimeDC and PrimeFlow control shrinkage of concrete, allowing for jointless slabs sections with areas up to 6500 m^2. Shrinkage cracking, curling, and joint opening are significantly reduced or eliminated
- Full-scale testing of PrimeComposite slabs indicated a 100 mm thick slab, with sufficient quality sub-grade, supports point loads up to 115 kN.
- CO_2 emissions are reduced by no less than 40.5% by replacing traditional concrete slab systems with Prime Composite.◆

For further details:

Primekss (India)
Cell: 09899299905
Email:anant.pokharna@primekss.com
Licensed Contractor (South India):
Advanced Construction Technologies Pvt Ltd.
16, Cenotaph Road, Teynampet,Chennai.
Tel: 09840929350
Email: mohanact@gmail.com
Website:www.actind.com