

Concrete Technology in Focus

4x4[™] Concrete System

Very high-early-strength

Introduction

Highway and road agencies and airport authorities face major challenges from increasing traffic volumes on existing roadways, urban streets, and airports. Owners must repair or replace deteriorated pavement sections while minimizing traffic disruptions.

Traditional pavement construction, repair or replacement solutions may no longer be universally acceptable due to increasing public impatience with traffic interruption. Traditional solutions are especially inappropriate in urban areas where congestion is severe.



To help agencies meet the demands for fast-track pavement and other rapid repairs, Master Builders Solutions has developed the patented 4x4 Concrete system, a unique method for achieving high-early-strength – 400 psi (2.8 MPa) flexural strength in 4 hours or earlier.

One of the primary ways to reduce pavement closure time is to use a concrete mixture that develops strength quickly. Rapid strength gain is not limited to the use of special proprietary cements. With the 4x4 Concrete system, it is now possible to proportion such a mixture using locally available portland cements, aggregates, and selected admixtures.

A key issue with accelerated pavement construction is determining when the new pavement can be opened to traffic. The basis for this decision is made on the concrete strength and not arbitrarily on the time from placement. Strength directly relates to load-carrying

capacity and provides certainty that the pavement is ready to accept traffic. For concrete pavement, flexural strength is the most direct indicator of load carrying capacity.

Special concrete admixtures from Master Builders Solutions play a key role in producing concrete mixtures that meet strength and performance criteria. Water-reducing admixtures increase early strength by lowering the quantity of water required while increasing the workability for appropriate concrete placement and finishing techniques. Water reducers disperse the cement, providing more efficient cement hydration, thus increasing strength at later ages as well. Unique accelerating admixtures aid early strength development and reduce initial setting times by increasing the rate of hydration. A hydration-controlling admixture and/or workability-retaining admixture allows time for transportation of the concrete from the ready-mixed concrete plant to the jobsite, and provides time for adequate placement and finishing.

The Caltrans Challenge

For full depth highway pavement repairs, the California Department of Transportation (Caltrans) specifies a minimum flexural strength of 400 psi (2.8 MPa) prior to opening to highway traffic. The 400 psi (2.8 MPa) requirement is based on pavement design and the experience that if the slab is subjected to traffic prior to obtaining this strength, the durability and life expectancy of the repaired pavement may be jeopardized.

Where fast turn-around is required, Caltrans engineers have specified a proprietary high-early-strength concrete mixture. The reviews on the performance of these materials have been mixed, particularly in larger scale applications. In addition, these cements are very expensive, and are not available in all areas. These mixtures are also prone to side effects, such as insufficient control of working time, and often require a follow-up grinding process to achieve an acceptable ride. Subsequent cracking has also been a problem.

In the Spring of 2001, the Caltrans Office of Rigid Pavements & Structural Concrete issued a challenge to the concrete industry to find a less expensive, more user-friendly alternative to proprietary high-early-strength concrete mixtures. The goal was to achieve 400 psi (2.8 MPa) flexural strength within 4 hours after placement using conventional and locally available materials.

The Master Builders Solutions Solution: 4x4 Concrete

The patented 4x4 Concrete system is based on the use of selected, readily available portland cement. Using a combination of Master Builders Solutions brand MasterGlenium® high-range water-reducing (HRWR) admixtures, MasterSet® accelerating admixtures, MasterSet® DELVO hydration controlling admixtures, and/or MasterSure® Z 60 workability-retaining admixture and re-engineered mixture proportions, 4x4 Concrete meets the required engineering performance criteria while offering significant savings over proprietary high-early-strength concrete mixtures.

MasterGlenium admixtures are fourth generation high-range water reducers based on novel polycarboxylate technology. MasterGlenium products feature outstanding water reduction while providing excellent early strength characteristics. MasterGlenium admixtures provide improved dispersion due to the combined forces of electrostatic and steric repulsion (Figure 1). Improved cement dispersion at low water-cementitious materials ratios provides more complete hydration, resulting in improved strength development.

MasterSet DELVO hydration-controlling admixture is a patented technology that provides the necessary working time to adequately transport, place, consolidate, and finish the concrete. When added to concrete that is in the initial stages of hydration (Figure 2), a protective barrier is formed around cementitious particles (Figure 3) – portland cement, slag cement, fly ash, and silica fume – thereby stopping the hydration process. This essentially puts the concrete “to sleep” and prevents it from setting. This effect will eventually wear off, the concrete “awakens” (Figure 4), and hydration continues (Figure 5). Subsequent addition of an accelerator will also “awaken” the concrete and allow hydration to continue more quickly, if desired.

MasterSure Z 60 admixture is a workability-retaining admixture that provides flexible degrees of slump retention without retardation. Following its introduction, MasterSure Z 60 admixture has been used in lieu of MasterSet DELVO admixture in some 4x4 Concrete applications to maintain workability prior to the addition of the accelerating admixture at the jobsite. MasterSure Z 60 admixture has also permitted batch plant addition of the accelerating admixture, thereby providing operational efficiencies in these applications.

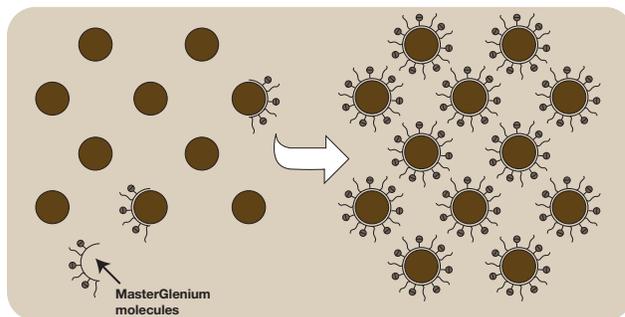


Figure 1 – Improved cement dispersion due to electrostatic and steric repulsion



Figure 2 – Initial Hydration



Figure 3 – Hydration Stopped



Figure 4 – Hydration Restarted



Figure 5 – Hydration Continues

In the past, ordinary portland cement-based mixtures were not able to achieve very high-early-strength requirements without sacrificing necessary working, placement, and finishing time. Portland cement-based concrete mixtures usually require a minimum of 24 hours, and frequently 5 to 14 days to gain sufficient strength to allow the concrete to return-to-service. With the development of technologies such as MasterGlenium, MasterSet DELVO, and MasterSure Z 60 admixtures, it is possible to utilize readily available local materials to achieve the high demands of fast-track paving repair.

Demonstration Slabs

Master Builders Solutions conducted laboratory tests to explore alternative mixture proportions and raw material combinations. Concurrently, field tests were staged in collaboration with cement producers, ready-mixed concrete suppliers, and contractors. By early September 2001, Master Builders Solutions was ready to demonstrate the 4x4 Concrete system concept to Caltrans.

The demonstration slab mixtures contained 700 to 800 lb/yd³ (415 to 475 kg/m³) of locally available Type III cement and a 1 in. (25 mm) maximum size aggregate. The water-cementitious materials ratio was held to less than 0.40. MasterGlenium HRWR, MasterSet accelerator, and MasterSet DELVO hydration-controlling admixture were incorporated into the mixture. The mixture was delivered in a ready-mixed concrete truck, had a 5 in. (125 mm) slump, and was very workable. During placement on the unusually hot day, the mixture remained workable for about 40 minutes and no finishing problems were encountered. At 4 hours, test beams showed a flexural strength of 480 psi (3.3 MPa), as against a target strength of 400 psi (2.8 MPa). To test the field strength, a fully-loaded ready-mixed concrete truck was driven onto the slab approximately 4 hours and 20 minutes after placement. No cracks were observed in the concrete slab after the truck was driven on it.

Case Study

In mid-September 2001, trial slabs conforming to Caltrans specifications for Project 07181504, were placed on I-405 during the night. The mixture proportions were essentially the same as for the demonstration slab. The concrete was placed at a 9 in. (240 mm) slump and was very workable.

Several sets of test beams were fabricated for flexural strength testing. The beams were insulated after casting. Testing was performed at 3, 4, 5, 8, and 24 hours after placement. The target strength was 400 psi (2.8 MPa) at 4 hours during nighttime temperatures. Results are shown in Table 1.

Curing Time (hours)	Flexural Strength, psi (MPa)			
	Beam 1	Beam 2	Beam 3	Average
3	420 (2.90)	465 (3.20)	390 (2.70)	430 (2.95)
4	465 (3.20)	485 (3.35)	510 (3.50)	490 (3.35)
5	535 (3.70)	545 (3.75)	510 (3.50)	530 (3.65)
8	625 (4.30)	595 (4.10)	625 (4.30)	610 (4.20)
12	655 (4.50)	640 (4.40)	655 (4.50)	645 (4.45)

Table 1 – Test Beam Results

Flexural strength gain continued, achieving 930 psi (6.4 MPa) at 7 days and 990 psi (6.8 MPa) at 28 days.

The 4x4 Concrete system was reported to be user-friendly by both the concrete producer and the construction crew placing the mixture. The 4x4 Concrete system was very workable, and again, no finishing problems were encountered.

Since all strength development criteria were met, and no problems were reported in batching, transporting, placing, or finishing the concrete, the 4x4 Concrete system was allowed to be used further on the I-405 project. For all subsequent placements, the goal of



400 psi (2.8 MPa) flexural strength was achieved 4 hours after placement. Table 2 shows average strength data for all of the I-405 placements.

Criteria	psi	MPa
4-hour flexural	480	3.3
24-hour flexural	855	5.9
28-day flexural	1250	8.6
4-hour compressive	4130	28.5
24-hour compressive	7740	53.4
28-day compressive	8250	56.9

Table 2 – I-405 Averages

When 4x4 Concrete was used on I-405, the production rates steadily increased as the crews became more familiar with the material. It was stated by the resident engineer that there was no trouble handling the material and the slabs required no grinding for smoothness.

According to Caltrans, “In production, the mixture has proven to be successful. Strength has consistently been achieved, and no cracks have been recorded. The resident engineer has repeatedly

examined the concrete slabs for cracks and found none. The crews are able to work with the concrete with no special training. The placing, texturing, and curing of the concrete have proven to be successful.”

Sustainability Benefits

The American Concrete Pavement Association, in their Surface Transportation publication, 4th Qtr, 2006, estimated that road user delays totaled over 3.7 billion hours resulting in 2.3 billion gallons (87.1 billion L) of wasted fuel. Master Builders Solutions 4x4 Concrete system facilitates the rapid repair of roads and highways by achieving strength requirements in four hours or less. This minimizes lane closure time and, more importantly, reduces fuel waste and the corresponding greenhouse gas emissions associated with traffic congestions and roadway delays due to lane closures.

In addition to the reduction in fuel waste and emissions that it provides, the sustainability benefits of the 4x4 Concrete system can be further enhanced through the use of selected supplementary cementitious materials to reduce the carbon footprint and overall embodied energy of the concrete.

In 2008, Caltrans decided to replace a three-quarter mile (1.2 km) stretch of I-5 along the Sacramento River often referred to as the “Boat Section.” One of the key goals for this project was to minimize disruption to motorists and reduce traffic congestion as much as possible while supporting California’s AB32 Sustainability Initiative. Therefore, Caltrans specified the use of a “greener” high-early-strength concrete mixture. Master Builders Solutions collaborated with CEMEX, the concrete producer, to develop a “green” 4x4 Concrete mixture that contained 50 percent slag cement for the project. This “green” 4x4 Concrete achieved a compressive strength of 3,630 psi (25 MPa) within 12 to 14 hours, and met all the requirements of the Caltrans specification.

4x4 Concrete Features and Benefits

- Very rapid strength gain and high ultimate strength
- Uses locally available portland cement and aggregates; not expensive proprietary cements
- Mixture proportioning and admixture dosage flexibility to achieve a variety of performance requirements
- Costs less than proprietary high-early-strength concrete mixtures
- Controlled hydration to allow ample time for delivery, placement and finishing
- Can be delivered in a standard ready-mixed concrete truck
- Workable and user-friendly
- Slump retention and control
- Very little (if any) grinding for smoothness
- Reduces duration of lane closure and permits faster opening to traffic
- Reduces fuel waste and emissions associated with delays due to lane closures and promotes sustainability

Applications

Present applications include full-depth repair of highway pavements, airport pavements, urban streets and intersections, and heavy equipment foundations and footings. Other applications of the 4x4 Concrete system include whitetopping, ultra-thin whitetopping, bridge deck overlays, and parking structure repair, and other applications where rapid repair is necessary.

References

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About Master Builders Solutions

Master Builders Solutions is a leading global manufacturer of concrete admixtures, as well as other sustainable solutions for the construction industry, focussed on delivering its vision: **Inspiring people to build better.** Master Builders Solutions provides value-added technology and market-leading R&D capabilities to improve the performance of construction

materials and to enable the reduction of CO2 emissions in the production of concrete. Founded in 1909, Master Builders Solutions has ca. 1600 employees operating 35 production sites globally, supporting their customers in mastering their building challenges of today – for a decarbonised future.

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