Innovative Admixture Technology Facilitates Rapid Repair of Concrete Pavements

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Abstract

Recent developments in admixture technology can dramatically modify and control both the rheological and hardened properties of concrete. Using the right combination of specific admixtures and appropriate mixture proportions are the first steps towards producing concrete with the desired performance attributes. For example, a system of innovative admixtures can now produce a novel concrete mix that facilitates the rapid repair of concrete pavements that permits opening to traffic within just 4 hours after concrete placement. This paper provides a description of the concrete system and its components, includes test data, and contains a review of successful projects, and demonstrations for local and national transportation agencies.

Introduction

With traffic volumes continuously increasing and an impatient traveling public, it is difficult to keep runways, roads and highways closed for any extended period when repairs are necessary. Traditional repair materials such as fast-setting hydraulic cement concrete have had mixed reviews, particularly in larger scale applications (Concrete Construction, 2001). In response to an industry challenge issued by CALTRANS, Degussa Admixtures in cooperation with CALTRANS and local concrete producers developed a unique and novel high-early strength concrete (NHESC) for rapid repair of concrete pavements. Successfully demonstrated for the Federal Highway Administration in a nationally covered press conference, the NHESC system has reduced the effort and time required for placement of concrete for pavement repairs and permits traffic to flow in as little as 4 hours after placement. In-place cost of the NHESC has been reported by the Western States Chapter of the American Concrete Paving Association (ACPA) to be approximately one-third that of other proprietary fast-setting concrete mixtures.

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Novel High-Early Strength Concrete

The appeal of the NHESC is that it uses locally available raw materials and follows a simple, specified methodology to achieve the desired results. NHESC is a system, not simply a mix design. It is a blend of ASTM Type III or Type I portland cement, aggregates and a unique combination of innovative admixtures resulting in workability, rheology control, and rapid strength performance for economical concrete repairs (Anderson, Daczko and Luciano, 2003).

The NHESC achieves its early strength performance, in part, by using special polycarboxylate-based high-range, water-reducing admixtures for efficient cement dispersion and lowering of the water-to-cementitious materials ratio. The use of Type III cement or alternatively, a very reactive Type I or I/II cement is required for developing the appropriate early strength. When such cement is used in traditional concrete mixes a rapid loss of workability can be expected. For the NHESC, an extended set-controlling admixture is incorporated into the mix during the initial batching. The extended set-controlling admixture enhances the workability retention in mixes containing these cements allowing the mix to be transported to the job and then easily placed into the form. A nonchloride accelerating admixture is added to facilitate early strength development, and an air-entraining admixture, if needed, is used for durability. For paving applications that contain steel reinforcement, a special corrosion-inhibiting admixture with cement hydration accelerating characteristics can be used in place of the nonchloride accelerator. The admixture system can be modified to meet many different specified strength or finishing criteria simply by adjusting the mixture proportions and admixture dosages (Bury, 2004).

Strength Performance

In one of the earlier field trials of the NHESC, CALTRANS cast test beams for flexural strength from concrete used on I-405 during a night time repair project. The slump for this concrete was 240 mm (9 ½ in.) and very workable. Results from this testing, shown in Table 1, indicate that the NHESC achieved significant early strength meeting the specified 2.8 MPa (400 psi) flexural strength requirement (CALTRANS Report, 2001).

Table 1: I-405 test beam results

Curing Time	Flexural Strength (MPa)			
	Beam 1	Beam 2	Beam 3	Average
3 h	2.90	3.20	2.70	2.95
4 h	3.20	3.35	3.50	3.35
5 h	3.70	3.75	3.50	3.65
8 h	4.30	4.10	4.30	4.20
24 h	4.50	4.40	4.50	4.45

1 MPa = 145 psi

Drying Shrinkage

The drying shrinkage of the NHESC has been investigated because of the relatively high cement contents and accelerator dosages used in the mixtures. A modified version of ASTM C 157 was used because of the rapid strength development of the NHESC mixtures. The modification required de-molding of the specimens at 5 hours of age instead of at 24 hours, and a 7-day moist cure period in lieu of the standard 28-day moist cure as specified in the test method. Average 28-day drying shrinkage values of 0.022 and 0.037 percent were obtained for NHESC mixtures having w/cm values of 0.31 and 0.34, respectively. Nominal cement and coarse aggregate contents in these mixtures were 475 kg/m^3 (800 lb/yd^3) and 1110 kg/m^3 (1875 lb/yd^3), respectively.

Similar values for drying shrinkage have been obtained in other evaluations and to date cracking has not been observed in NHESC pavement panels in the field. It should be noted, however, that plastic sheeting has been used in most of these applications as a bond-breaker between the pavement panel and the base.

Applications

Although the NHESC can be used in any concrete application requiring the rapid development of strength, one primary application segment is in the repair of deteriorated concrete pavements. The NHESC is helpful in repairing four types of concrete pavement applications.

Full-Depth Panel Replacement. Deteriorated concrete road and highway pavement panels (joint to joint sections) can be removed, the sub base prepared, and the NHESC placed, cured, and opened to traffic within 8 – 12 hours because of the early strength performance of the NHESC.

Intersections. eteriorated intersections can be replaced in as little as 4 days by using appropriate traffic control methods. Removing and replacing entire lanes one by one with the NHESC minimizes lane closures and keeps traffic flowing.

Ultra-Thin Whitetopping. The NHESC can be used as a thin, structural overlay on top of deteriorated asphalt that has been milled and cleaned to provide a durable, long-lasting surface.

Self-consolidating concrete (SCC). Whenever there is a formed pavement repair such as the entrance or exit areas of residential streets, truck stop scales, bridge decks or parking areas, the NHESC can be designed to be SCC. A SCC mix does not require the use of vibration for consolidation and will facilitate the ease of placement and reduce the in-place cost of the concrete pavement repair.

National Press Conference

On April 15, 2004, a team from Degussa Admixtures, invited by the Federal Highway Administration (FHWA), participated in a National Press Conference in Washington DC with Norman Mineta, Secretary of Transportation. The press conference, showcasing the NHESC and SCC as part of the FHWA's *Highways for Life Program*, was covered by the national TV and print media. The press conference was held at the Woodrow Wilson Bridge construction site where a local concrete producer was supplying concrete for the new bridge (Concrete Products, 2004). For the live demonstration, Secretary Mineta was given a large piece of rebar that he stuck into a conventional concrete slab to demonstrate that it was still soft 4 hours after placement. Secretary Mineta then stood next to the NHESC slab as an automobile was driven up a ramp and onto the NHESC in a choreographed display of it's strength performance as shown in Figure 1.

Figure 1: U.S. Transportation Secretary watches NHESC demonstration

Massachusetts Bay State Roads Demonstration

In a continuing effort to educate local engineers, contractors, construction officials and governmental agencies on new technology, the NHESC was further demonstrated in October, 2004 (Concrete Products, 2004). The demonstration was part of the Bay State Roads Program, a workshop organized through the FHWA, Massachusetts Highway Department, and the University of Massachusetts. Over 70 attendees from departments of transportation, public works, and highway departments in Connecticut, Rhode Island, and Massachusetts participated in the event which included batching, mixing, and placing the NHESC as shown in Figure 2.

The basic mixture proportions for the MA demonstration slab are shown in Table 2. This mix incorporated a mid-range water-reducing admixture to help enhance the finishing process. The admixture system and process for achieving the high early strength is patent-pending and therefore little information is provided with respect to dosages and specific chemistry of the admixtures.

Figure 2: NHESC education workshop and demonstration in MA.

Table 2: Mixture proportions for MA demonstration

Materials	**Quantity**
Type I Cement	475 kg/m^3
w/cm	0.31
s/a	0.38
Coarse Aggregate	~ 1100 kg/m^3
Admixtures	
Air-Entrainer	To achieve 5% air content
High-Range Water-Reducer	To achieve target slump of 200 mm
Mid-Range Water-Reducer	To improve workability and enhance finishing
Extended-Set Control Admixture	To retain workability
Accelerator	For strength acceleration

1 kg/m^3 = 1.69 lb/yd^3
25.4 mm = 1 in.

Placing

The NHESC can be placed using traditional concrete placement techniques and methods and requires no special tools. Consolidation can be achieved by internal or external vibration equipment or the mix can be designed to be SCC. At the MA demonstration, the concrete was consolidated using a pencil vibrator followed by leveling using a vibratory screed as shown in Figure 3. After consolidation and leveling, the concrete pavement can be textured using either a trowel, magnesium float, broom finish, burlap drag, tyning, or other traditional tools to obtain the desired surface.

Figure 3: NHESC is leveled using a vibratory screed

Curing and Saw Cutting

The NHESC is produced using portland cement and requires the same attention to curing as conventional concrete either by using moisture curing or curing compound methods. In addition, the use of an insulating blanket, as shown in Figure 4, is required to retain heat generated by the hydrating cement in the NHESC pavement. The retained heat will further facilitate the accelerated strength gain of the concrete which ultimately translates into the practical benefit of opening the pavement to traffic more quickly. Furthermore, the use of an insulating blanket to retain heat extends the use of the HESC technology to cooler months as well as moderate or warmer times of the year. One study (Bury, et.al., 2004) has shown that the innovative admixture technology can achieve high early strengths in ambient environments of -5, 10, 21 ^{o}C (23, 50, and 70 ^{o}F).

Because of the rapid strength development of these NHESC mixtures, saw cutting is performed much earlier than in typical pavement construction, generally between 1.5 to 3 hours after placement. The insulating blankets are temporarily pulled back at the joint location to facilitate saw cutting, and then reinstalled.

Figure 4: Curing the NHESC using an insulating blanket.

Test Results

For the MA demonstration, the slab was outfitted with two temperature probes and a data logger to measure the thermal history of the concrete. Using the maturity method, the actual strength of the concrete can be estimated. The NHESC adapts well to this technique. The maturity method involves the measurement of three key parameters; time, concrete temperature and concrete strength. Using one of two widely-used expressions, a temperature-time factor with units of **degree-hour** is calculated by multiplying concrete temperature, with respect to a datum, by the elapsed time (in hours) after the concrete was batched. In ASTM C 1074, ‘Standard Practice for Estimating Concrete Strength by the Maturity Method,’ 0 ^{o}C (32 ^{o}F) is recommended as the datum temperature for concrete containing Type I cement. A relationship between degree-hours and actual concrete strength, for a given mixture, can be determined by graphing each actual strength data and the corresponding degree-hours. The advantage of the maturity method is that once a strength-maturity relationship is established for a particular concrete, temperature histories can be used to predict the strengths of samples of the same concrete subjected to different temperature conditions.

For the MA demonstration, two temperature probes were placed approximately 150 mm (6 in.) from the slab edge and midway between the top and bottom of the slab to record the temperature history. The data, graphed in Figure 5, shows the slab temperature profile over the first six hours after concrete placement.

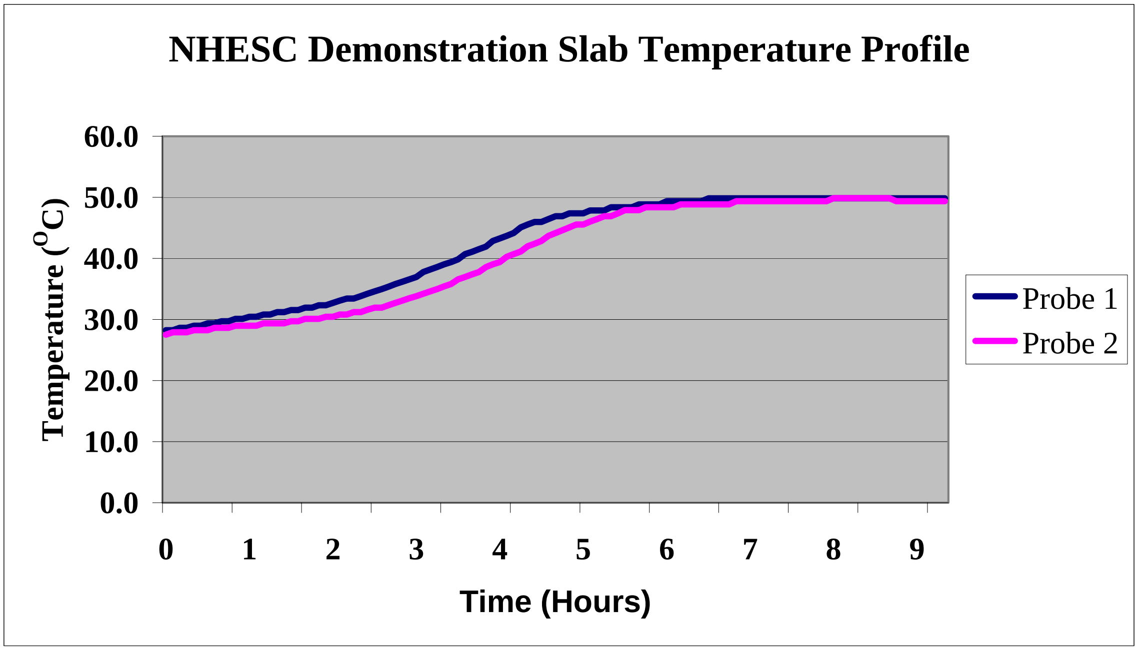

Figure 5: Temperature history of NHESC demonstration slab

As discussed, the degree-hours were calculated by multiplying the slab temperature by the elapsed time. For plotting purposes, the corresponding strength at specific time periods are shown in Table 3.

Table 3: Degree-hours and corresponding strength for the MA demonstration

Elapsed Time (h)	Temperature (^{O}C)	Degree-Hours	Compressive Strength (MPa)
3	27.8	288	5.4
4	35.6	424	10.7
5	41.1	580	19.9
6	48.9	720	25.2

1 MPa = 145 psi

The compressive strength for the MA demonstration was 63.8 MPA (9250 psi) at 24 hours indicating that the NHESC continues to gain strength beyond the first initial few hours.

The degree-hours and corresponding compressive strength for the NHESC are plotted in Figure 6. The data show that if the desired strength criteria for a project was 25 MPa (3,600 psi), the concrete would need to obtain a maturity of at least 300 degree-hours.

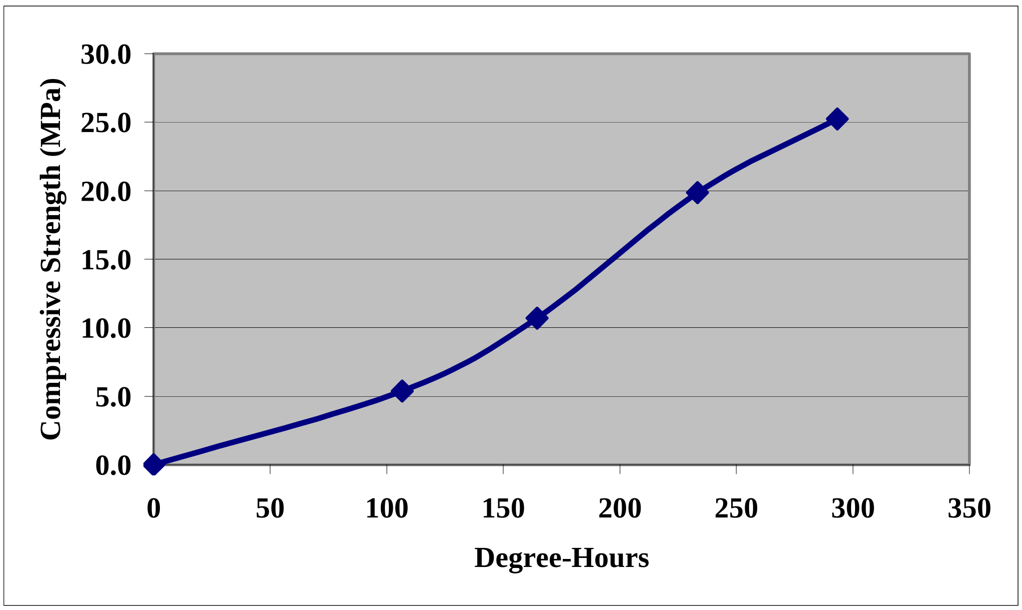

Figure 6: Flexural strength and degree-hour relationship of NHESC

The strength performance, developed by the NHESC, was demonstrated to by driving a ready mix concrete truck onto the pavement about 4 hours after the concrete placement as illustrated in Figure 7. The slab easily accepted the truck without affecting the concrete surface and did not experience any cracking.

Figure 7: NHESC supports a ready mix truck in only 4 hours after placement

Projects

Since its development, the NHESC has been successfully used in many repair scenarios for airport, road and highway pavements. The durability of this material has shown to be excellent as CALTRANS, for example, continues to use this technology every night somewhere in California two years after the first placement (Cho, 2004).

Other projects, listed in Table 4, have benefited from the use of the NHESC and many engineers, state DOTs, and airport and transportation officials are evaluating the NHESC for applications in their areas.

Table 4: The NHESC has provided benefits for many key pavement repairs.

Projects	Location	Application
Highway 140 and Applegate Road	Merced, CA	Full-Depth Intersection Replacement
Alamo Truck Stop Scale	Sparks, NV	Ultra-Thin Whitetopping at Exit
Fairplex	Pomono, CA	Ultra-Thin Whitetopping at Entrance - SCC
I-77/I-64	Beckley, WV	Ramp Sections Replacement
Poplar Street Bridge	St Loius, MO	Full Depth Bridge Deck Replacement - SCC
Philadelphia International Airport	Philadelphia, PA	Full-Depth Apron/Terminal Section Replacement
Route 10	Santa Monica, CA	Full-Depth Panel Replacement
I-5	Los Angeles, CA	Full Depth Panel Replacement
I-20/59	Birmington, AL	Emergency Highway Repair
I-405	Los Angeles, CA	Full Depth Panel Replacement
I-459 Overpass	Birmingham, AL	Emergency Highway Repair
Highway 99	Atwater, CA	Full-Depth Panel Replacement
I-80	Dixon, CA	Full-Depth Panel Replacement
Manteca Intersection	Manteca, CA	Full-Depth Intersection Replacement

Summary

The data presented in this paper and elsewhere show that very high early strength can be achieved with the NHESC technology. On average, flexural strengths of at least 2.8 MPa (400 psi) can be obtained within 4 hours after placement, depending on the specific proportions used. The NHESC mixtures have also been shown to have relatively low drying shrinkage compared to conventional concrete mixes for paving, with values lower than 0.04 percent at 28 days and as low as 0.022 percent.

The use of insulating blankets and early saw cutting is essential with the NHESC technology as is the use of maturity concepts to determine time-to-opening of pavements to traffic.

Based upon the laboratory, field testing and, more importantly, live demonstrations, the NHESC technology has proven to be a suitable material for the rapid repair of deteriorated concrete pavements.

References

Anderson, J., Daczko, J., and Luciano, J. (2003). "Producing and Evaluating Portland-Cement Based Rapid Strength Concrete", *Concrete International*, Vol. 25, No. 8, August, 77 - 82.

Bury, Nmai, and Meyers (2004). "An Innovative, High-Early Strength Concrete for Rapid Construction and Repair of Airport Pavements", *Proceedings 28th Annual International Airport Transportation Conference*, Washington DC, July 25 – 28, Copyright ASCE.

Bury, M., (2004). "Rapid Repair of Pavements Using an Innovative High-Early Strength Concrete", *Proceedings American Society of Civil Engineers - Texas Station Fall Meeting*, Houston, Texas, September 29 – October 2.

CALTRANS Report, (2001). "Portland Cement-Based Fast-Setting Concrete Demonstration", District 07, Los Angeles County, Contract Number: 07-181504, Office of Rigid Pavements and Structural Concrete, 5900 Folsom Boulevard, Sacramento, CA 95819

Cho, J., (2004). "Cementing Its Place In Concrete Industry", Cleveland Plain Dealer, 2004.

Concrete Construction (2001). "Concrete Perspectives – Four Hour Champion for Paving Repair", *Concrete Construction*, December, 69 - 70.

Concrete Products (2004), "Newington, MB Demonstrate Fast-Set Mix for U.S. DOT Chief", *Concrete Products*, May 2004, PP 9.

Concrete Products (2004). "Aggregate Industries Tests Rapid Pavement Repair", *Concrete Products*, November, 2004, PP 16.