THE EFFECTIVE USE OF A NOVEL WORKABILITY-RETAINING ADMIXTURE IN PRECAST/PRESTRESSED CONCRETE PRODUCTION

Joseph A Daczko, BASF Construction Chemicals - Admixture Systems, Beachwood, Ohio

ABSTRACT

A hidden variable, which can influence the overall quality of a precast/prestress element, exists in many plants around the world. This variable is workability retention and, if ignored, can result in surface imperfections, such as pour lines and, in extreme cases, cold joints and honeycombing. All of these lead to higher production costs. In most plants a batch of production concrete is placed within 15-30 minutes from the time that Portland cement comes into contact with water in the mixer. This leads precast/prestressed producers to think that workability retention in their concrete mixtures is unimportant. This is not the case. The workability retention requirements of a concrete mixture vary based on the element being cast, the method of placement, batching cycle and other variables, while the workability retention time of the mixture is influenced by factors such as mixture proportions, materials, and environmental conditions. This paper will discuss the variables that influence workability retention requirements and how they have been managed historically. It will then present how the use of a novel Workability-Retaining Admixture has improved the final quality of precast/prestressed elements using real world examples.

Keywords: consistency, production, slump loss, workability retaining admixture

Introduction

The basic goal of every precast/prestressed concrete producer is to satisfy customer demands while profitably producing precast elements on a predictable schedule. In order to achieve this goal, a producer is required to monitor and control multiple variables. For example, the surface finish of architectural precast elements must meet certain quality standards. The producer must pay special attention to all variables affecting surface finish and will sometimes incorporate mixture adjustments to ensure an acceptable surface finish is obtained. He must do this however, without losing sight of how those changes may impact compressive strength development which governs de-molding time. Some examples of the variables to be monitored include; the concrete mixture's rheological characteristics, ambient and concrete temperatures, placement and consolidation techniques, form cleanliness, raw material fluctuations, etc. In this example, if an element is de-molded and does not have an acceptable surface finish the producer will likely employ some technique for refinishing the unacceptable sections costing him both time and money. Additionally, if the production schedule is delayed due to delayed compressive strength gain, this can also cost the producer time and money. Most producers have a highly trained quality control department responsible for managing these many interactions and most variables are understood and reasonably controlled. One variable that is often overlooked however, is the workability retention characteristics of the concrete mixture.

Slump, Consolidation and Surface Finish

It is well known that the slump level of a concrete mixture directly influences the effort required to achieve the desired level of consolidation (1). This relates not only to its impact on compressive strength, density etc. but also to the final surface finish. Figure 1 shows the surface finish over time of two concrete samples subjected to the same level of consolidation effort. The concrete in each tube was taken from the same laboratory batch, but the concrete in the left tube had a slump of 1.5 inches (40 mm) before the addition of high range water reducer (HRWR) and the concrete in the right tube had a slump of 7.5 inches (185 mm) after the addition of HRWR. Both samples were placed on a vibrating table and pictures were taken at 0, 5 and 10 seconds of vibration. Notice the difference in surface appearance. It is clear that lower slump concrete requires greater consolidation effort in order to achieve an acceptable surface finish. The addition of HRWR significantly improves the handling properties of concrete both initially and then for some period of time depending on the variables mentioned earlier.

Fig. 1. Surface finish of low and high slump concrete after vibration

Producers must recognize however, that concrete fresh properties are finite in duration. As soon as Portland cement and water come into contact, chemical reactions initiate that drive the concrete mixture towards stiffening and the development of hardened properties. This means that a mixture proportioned to be highly fluid and castable (even with HRWR) is transitioning to a stiffer, less workable consistency. If a mixture stiffens more rapidly than expected and the consolidation effort is not adjusted, an increase in surface blemishes such as bug holes may be seen resulting in a greater need for surface patching or in severe situations pour lines and honeycombing may result.

The Costs of Inadequate Consolidation

In some cases, patching of surface blemishes is an acceptable practice. Figure 2 shows a picture of a partially patched surface from a structural concrete element. The right side has been patched while the left side has not. The acceptance of this practice, as well as the patching cost differs depending on the nature of the element being cast. One reference suggests a cost of approximately $\$2.30/yd^3$ ($\$3.07/m^3$) in labor for patching surface blemishes of double tees cast with conventional slump concrete (2). On the other hand, an architectural element using integrally colored concrete will likely be more difficult, time consuming and costly to patch versus a standard grey structural mixture. In the most extreme case, a mixture may stiffen so rapidly that it cannot be adequately consolidated resulting in large voids or honeycombing in the final piece. In a structural element this will result in either very expensive repair or complete rejection of the element.

Inadequate consolidation results in higher production costs for the producer, therefore it is in the producer's best interest, whether producing architectural or structural elements, to ensure adequate workability throughout the placement and consolidation processes.

Fig. 2 Partially patched surface of a structural element

Time Dependency of Fresh Properties

Concrete's versatility as a construction material results from its ability to be transformed, through hydration, from a plastic castable material to a hardened mass. This transition time is variable and has an impact on the final quality of the element. Many precast/prestressed producers require 15-30 minutes of workability time from the start of batching to the completion of placement. This may seem like a short time, and therefore, one may make the assumption that workability retention characteristics are not critical. It has been the author's experience that most producers however, do not regularly generate and maintain slump retention data for their mixtures. Knowing the slump loss profile of the mixture in use is a key component to controlling quality. Table 1 presents workability retention data of production self-consolidating concrete (SCC) from six different precast/prestressed plants across North America. This data represents a range of "typical" performance that can be seen at locations across the United States and Canada. The workability retained at 30 minutes ranges from 55%-86%.

Table 1. Workability retention data from production SCC at 6 precast plants

	1	2	3	4	5	6
Cement, lb/yd^3 (kg/m^3)	699 (415)	597 (354)	700 (415)	698 (414)	517 (307)	720 (427)
Fly Ash, lb/yd^3 (kg/m^3)	133 (79)	173 (103)	120 (71)	120 (71)	169.5 (101)	0
Fine Aggregate, lb/yd^3 (kg/m^3)	1365 (809)	1303 (773)	1100 (652)	1127 (668)	1385 (821)	1422 (843)
Coarse Aggregate, lb/yd^3 (kg/m^3)	1530 (907)	1510 (895)	1635 (970)	1644 (975)	1511 (896)	1575 (934)
Water, lb/yd^3 (kg/m^3)	299 (177)	285 (169)	290 (172)	281 (167)	289 (172)	258 (153)
HRWR, fl oz/cwt (ml/100kg)	6.5 (423)	7.4 (481)	4.4 (286)	4.2 (273)	10.6 (689)	8.75 (569)
Initial slump flow, in. (mm)	28.75 (730)	27 (686)	18.75 (476)	20 (508)	26.5 (673)	25.5 (648)
30 minute slump flow, in. (mm)	18 (457)	21.5 (546)	14.25 (362)	17.25 (438)	14.5 (368)	20 (508)
% maintained at 30 minutes	63%	80%	76%	86%	55%	78%

Although it is expected that changes to proportions and materials will result in different performance, one should note the wide range of workability retention values presented in this table. Review of this data should lead a precast/prestressed concrete producer to evaluate the workability retention of his mixtures in light of his production processes and determine the probability of a problem occurring. For example, the rapid slump flow loss of mixture 5 creates a very "unforgiving" production environment. If production or placement were delayed when using this mixture, it is quite possible that a noticeable pour line or cold joint could easily occur, especially since it is an SCC mixture and will not be vibrated. This producer should take immediate steps to improve the workability retention of his mixture and make it more "forgiving" with respect to production use. He should also have an appreciation for how this performance will change as concrete and ambient temperatures change.

Another characteristic that is sometimes overlooked is the continued slump loss of the concrete which has already been placed and consolidated in the form. Whether this concrete is conventional slump or self-consolidating concrete it must maintain the necessary consistency to allow the following deliveries to mesh and blend with the already placed concrete and not create a pour line.

One must also consider the influence of raw material changes when mixture proportions are held constant. The following set of data demonstrates this influence by evaluating workability retention at 30 minutes for seven mixtures. This data is the result of a national evaluation of materials where testing was conducted in seven varied geographic locations across the United States. The cement composition (Portland cement only) and content, the water content, air content and the initial slump target were kept constant. No. 67 coarse aggregate or larger was used and all mixtures were run in a controlled laboratory environment. Table 2 shows the basic proportions.

Table 2. 30 minute workability retention proportions

Portland Cement, lb/yd^3 (kg/m^3)	705 (418)
Water Content, lb/yd^3 (kg/m^3)	290 (172)
Air content, %	2%
Slump Target, in (mm)	8 (200)

The HRWR used in each region varied and aggregates were proportioned following local expertise. Figure 3 shows the 30 minute slump loss data from the mixtures run in the 7 regions.

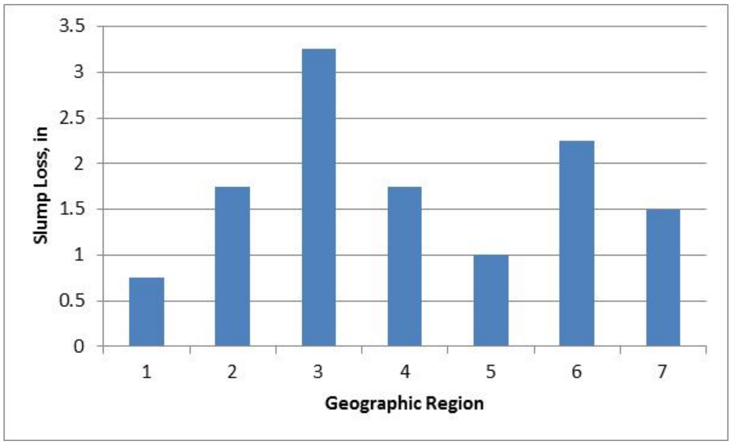

Fig. 3 30 minute slump loss from 7 regions (1 inch = 25.4 mm)

Notice in Figure 3 that after only 30 minutes in laboratory conditions, slump loss can be over 3 inches (75 mm), while with a different set of materials it can be as low as 0.75 inches (20 mm). The practical importance of this for the precast producer is not simply the magnitude of the slump loss and knowing whether the mixture in use loses 0.75 or 3 inches of slump, but additionally realizing the range of possible slump loss values based on which materials are used. A change in materials can result in quite different workability retention time which can then impact the quality of consolidation and the resulting surface finish.

Note that these slump loss values can change as concrete and ambient temperatures change throughout the seasons. They can also be influenced by form temperatures. The author has been involved in precast production plants where all casting was performed outside using steel forms. These forms can have temperatures greater than 140^o F (60^o C). Placing concrete onto hot forms can result in even faster stiffening.

Historical Methods for Control of Slump Loss

Although in recent years a number of precast producers have started to use mixer trucks to deliver concrete to the casting site, most producers still use a bucket or auger conveyor equipment. The use of this non-mixing equipment eliminates the possibility of re-dosing HRWR at the casting site if slump loss is too high. Therefore, other methods for managing slump loss have historically been employed by precast/prestressed concrete producers such as the addition of retarding admixtures. Retarding admixtures function by delaying the onset of or slowing the rate of cement hydration, with cement hydration being one of the variables influencing workability time. The paradox here is that producers want the efficiency of an easy to place and consolidate concrete mixture while achieving high early compressive strength. If dosed too high, the use of a retarding admixture to extend workability retention time may result in retarded or delayed compressive strength development. However, if the dosage is reduced so as not to affect the compressive strength development, then insufficient workability retention may occur, and a less- than-optimal placeability and final surface finish may result. This current method therefore does not maximize the performance attributes a precast producer is looking for, nor does it maximize efficiency and profitability.

New Admixture Technology for Control of Slump Loss

A novel admixture technology developed specifically to provide concrete producers the ability to adjust workability retention based on materials, conditions and project needs has been reported on and fully described earlier (3,4). This new technology is not a retarding or hydration controlling admixture. Rather, it falls into the new admixture category of workability retaining admixtures. The dosage of this admixture can be adjusted to provide varying levels of workability retention without retarding the setting and strength developing characteristics of the concrete mixture. Data confirming this performance has been previously published (2, 3, 4). This is a very important feature for the precast/prestressed concrete producer who needs an easily castable mixture that develops high early compressive strength. Workability-retaining admixtures are currently being used in numerous precast/prestressed factories across North America in applications ranging from architectural to structural concrete.

The following data table provides an example of field performance typical of this new admixture technology. The concrete data presented was developed for use in an architectural application. The project required the use of white cement, a 7-10 inch (175-250 mm) slump, 4.5 -7.0 percent air and 3500 psi (24.1 MPa) release strength. Concrete temperatures ranged from 82-85^{o} F (28-30^{o} C).

Table 3. Production batch data with and without workability retaining admixture

	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6
White Cement, lb/yd^3 (kg/m^3)	750 (445)	750 (445)	750 (445)	750 (445)	750 (445)	750 (445)
Coarse Aggregate, lb/yd^3 (kg/m^3)	1820 (1080)	1820 (1080)	1820 (1080)	1820 (1080)	1820 (1080)	1820 (1080)
Fine Aggregate, lb/yd^3 (kg/m^3)	1150 (680)	1150 (680)	1150 (680)	1150 (680)	1150 (680)	1150 (680)
Water, lb/yd^3 (kg/m^3)	300 (178)	295 (175)	290 (172)	290 (172)	295 (175)	300 (178)
HRWR, fl oz/cwt (ml/100kg)	12 (780)	12 (780)	12 (780)	12 (780)	12 (780)	12 (780)
Workability Retaining Admixture, fl oz/cwt (ml/100kg)	0	0	0	6 (390)	6 (390)	6 (390)
Initial Slump, inches	9.5 (240)	9.5 (240)	9.25 (235)	10 (255)	9.5 (240)	9.5 (240)
30-Min. Slump, inches	6 (150)	5.5 (140)	5.5 (140)	9.0 (230)	9.25 (235)	9.0 (230)
Initial Air, %	5.7	5.20	5.50	5.00	5.60	6.80
30-Min. Air, %	5	4.50	4.50	4.70	5.10	6.20
1 day - compressive strength, psi (MPa)	4380 (30.2)	4500 (31)	5650 (39)	5320 (36.7)	5323 (36.7)	5010 (34.5)
28 day - compressive strength, psi (Mpa)	7130 (49.2)	9330 (64.3)	9645 (66.5)	9160 (63.2)	9712 (67)	9000 (62.1)

Notice first that the reference mixture consistently lost 3.5-4 inches (80-100 mm) of slump within 30 minutes. After this time all of the reference mixtures were outside of the specified slump range. In addition to the slump loss, air loss over 30 minutes for the reference mixture ranged from 0.7-1.0%. The mixtures containing the workability-retaining admixture lost 0.25-1.0 inch (10-25 mm) of slump and 0.3-0.6% air without retarding early compressive strength development. The mixtures containing the workability-retaining admixture meets all of the performance specification requirements, both initially and at 30 minutes. These mixtures would be easier to handle and would eliminate many of the placement and consolidation-related defects that can occur in precast production.

Architectural Concrete Application

This novel workability retaining admixture has been used in a number of precast/prestressed concrete applications with varied performance requirements. The first example is in the production of precast architectural wall panels. The exposed section of the wall incorporated a thin brick veneer backed with a structural, white concrete mixture using white portland cement (see Fig. 4). White cement mixtures tend to have a relatively shorter workability retention time than comparative mixtures using standard gray portland cement. Because of the brick veneer and the architectural nature of the panels the placement and consolidation techniques where very controlled and deliberate in order to produce a consistent and high quality. This resulted in a somewhat slower placement time, which, in combination with the white cement mixture made workability retention time a critical concrete performance attribute. The producer had experienced rapid slump loss problems on similar jobs in the past resulting in a significant number of pieces needing recast. On this particular project the product was used from the beginning at an average dosage rate of 2 fl oz/cwt (130 mL/100kg) holding the concrete workability constant for 60-90 minutes without retardation of setting or compressive strength development.

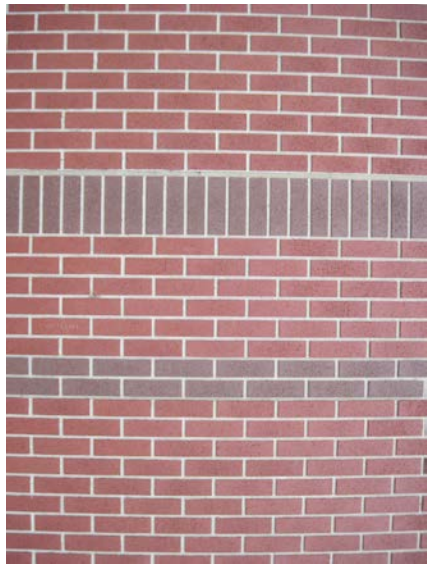

Fig. 4 Precast Wall Panel with Brick Veneer and White Concrete Backing.

Structural Concrete Application

Workability-retaining admixtures are also used in structural concrete applications. One example is the case of a large precast/prestressed concrete producer casting high performance, 84-in (2.1-m) tall, bridge girders. The high performance nature of the concrete required the use of a low water to cementitious materials ratio, silica fume and a calcium nitrite corrosion inhibitor. To meet scheduling and specification requirements, the concrete was required to reach 8500 psi (58.6 MPa) compressive strength in 34 hours and 10,100 psi (70 MPa) at 28 days.

Ambient temperatures during placement were in the low 90^{o} F (low 30^{o} C), with concrete temperatures in the mid 80^{o} F (mid 20^{o} C). With these temperatures, mixture proportions and performance requirements, controlling slump loss and achieving proper consolidation was a major concern. In addition, the preset time (time delay until steam is applied) could not be affected. Since the time to release the prestressing tendons was fixed, any delay in preset would result in a reduced time of steam cure and a lower strength at release. Test results at 34 hours less than 8500 psi (58.6 MPa) would require the beam to stay in cure longer and delay the production schedule.

Prior to using the workability-retaining admixture, the producer experienced consolidation problems resulting in a rejected beam (see Fig. 5). These beams are very expensive and re-casting is never a desirable option. The beams that were acceptable still required significant patching of bugholes and other surface blemishes. Some of these beams required as many as 2 men, patching for 8 hours which is a considerable cost for the producer.

Fig. 5 Rejected Bridge Girder with Consolidation Voids

After the workability-retaining admixture was incorporated into the mixture at a dosage rate of 3-5 fl oz/cwt (195-325 mL/100kg) workability was maintained making placement and consolidation much easier and more efficient. No more honeycombing was experienced and surface blemishes (bugholes) were reduced. In addition, because the workability retaining admixture does not retard, the preset time was not impacted and stripping times were not delayed. This allowed the producer to meet his pour schedule.

Conclusions

The workability retention of concrete is critical to ensure that placement and consolidation activities are completed efficiently thereby avoiding issues such as honeycombing or excessive surface blemishes. Avoiding these issues can significantly improve a precast/prestressed producer's profitability by minimizing re-work and reducing labor costs. A number of variables influence workability retention including: ambient and concrete temperatures, mixture proportions, admixtures and raw material characteristics. Historical methods for minimizing workability loss, such as the use of retarding admixtures, although effective, are not flexible enough to allow for the proper dosage adjustments. The reason for this is that producers also need high early compressive strength development. If a retarding admixture is dosed too high it will retard the cement hydration, lowering early age compressive strength and possibly delaying the de-molding time.

A novel workability retaining admixture has been developed to provide precast/prestressed concrete producers with the ability to manage workability retention time without negatively influencing early compressive strength development. This admixture is being used in architectural concrete applications as well as in structural applications. It has saved producers significant dollars by eliminating rejected pieces and by reducing any need for patching when conventional slump concrete is used.

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