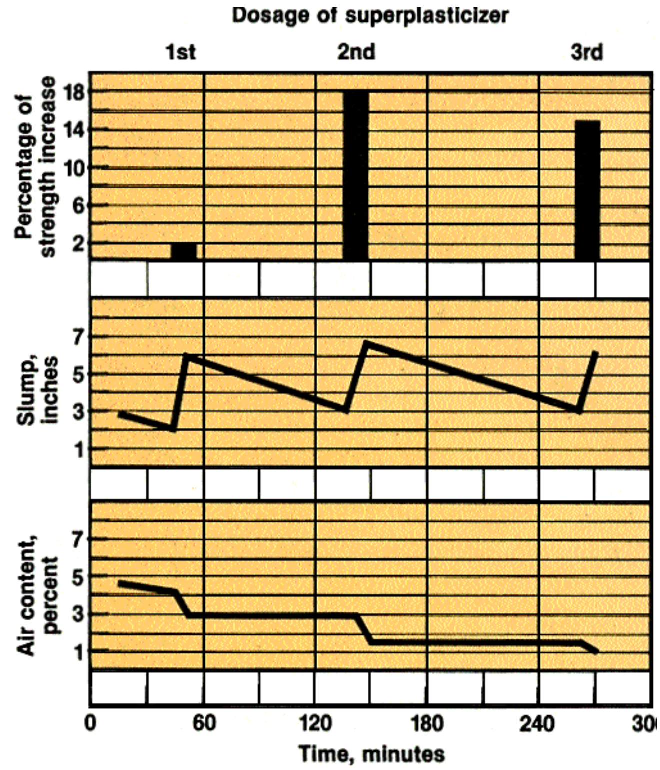
How super are superplasticizers?

Almost magically, like an alchemist turning lead into gold, superplasticizers transform stiff, low-slump concrete into flowing, pourable, easily placed concrete. Their development in Europe and Japan in the mid-sixties and their use in the United States since the late seventies have shown these relatively new admixtures to be virtual concrete wonder-drugs. They can improve workability, speed finishing, increase strength, conserve cement and help reduce shrinkage and thermal cracking. However, because of their brief history, questions and doubts about their use still exist. Just how super are superplasticizers? Are they problem-solvers or problem-makers?

How they are used

Superplasticizers can be used in three ways: (1) to create flowing, self-leveling concrete without increasing water, without reducing cement and without sacrificing strength; (2) to produce workable, high-strength concrete by reducing the water and thus the water-cement ratio; or (3) to save cement by reducing both the water and cement contents while maintaining the same water-cement ratio and the same workability. When used to produce easily placed concrete a superplasticizer can transform a 2-inch slump conventional mix into an 8-inch-slump flowing mix. When used as a water-reducing agent, the superplasticizer permits 20 to 30 percent of the water in a normal mix to be eliminated without losing slump or workability. If superplasticizers are used as cement savers, 10 to 15 percent reduction in cement is possible while maintaining the same strength concrete.



Effect of repeated dosages of one brand of superplasticizer on slump, air content and compressive strength. These results should be regarded as qualitative only since variations with concrete mixes and admixture brands can be expected. (Source: "Accelerated Strength Testing of Superplasticized Concrete and the Effect of Repeated Doses of Superplasticizers on Properties of Concrete," by V. M. Malhotra and P. T. Seabrook, published in Reference 3.)

PERCENTAGE SAVING IN LABOR TIME WITH FLOWING CONCRETE

Chute	54
Place	39
Screed	20
Jitterbug	22
Float	15
Overall	33

Flowing concrete can be placed more easily around knots of reinforcing steel, in narrow forms, around corners and in ordinary slabs. Because it is pourable—like pea soup—it spreads out faster and self-levels, thus making flat slabs flatter. All this saves labor. More work can be done in less time or the same amount of work can be done by fewer workers—either way a savings in cost.

(Source: "Use of High-Range Water-Reducing Admixtures in Residential Concrete," by Michael Zummo and Robert L. Henry, presented at ACI Convention, Washington, D.C., October 1979.)

What they are and what they cost

Made from the salts of organic sulfonates, superplasticizers can be divided into three major types: (1) sulfonated melamine formaldehyde condensates, (2) sulfonated naphthalene formaldehyde condensates and (3) modified lignosulfonates, designated here as type M, N and L, respectively.

Depending on the admixture brand, the quantity purchased, the freight cost and the dosage rate, superplasticizer costs for a typical 5-sack mix may range from about $1.70 to $6.00 per cubic yard of concrete, with a more probable range of $2.00 to $4.00 per cubic yard. This high cost can sometimes be offset by labor savings in placing and finishing (see table).

How they work

Normally, cement particles tend to cling together in little clusters. Superplasticizers act to break up these clusters and disperse the cement particles. Depending on the particular superplasticizer, this occurs in one of three ways: superplasticizer Type M forms a lubricating film on the particle surfaces; Type L decreases the surface tension of the water; and Type N electrically charges the particles so that they repel each other. Type N molecules are negatively charged. As they are adsorbed onto the cement particles, they cause the particles to be negatively charged and since all the cement particles are charged alike—negatively—the cement particles repel each other.

Well dispersed, the cement particles not only flow around each other more easily, but also coat the aggregate more completely. The result is a concrete that is both stronger and more workable. In other words, just adding a superplasticizer, even without reducing the water-cement ratio, increases the compressive strength of the concrete.

Proportioning the mix

Laboratory trial mixes may be needed to determine correct proportions, in the absence of accumulated experience with superplasticizers. Because superplasticizers function by dispersing cement particles, they function most efficiently in concretes rich in cement, fly ash or other fines. When superplasticizers are added to conventionally proportioned mixes to produce high-slump, flowing concrete, the concrete often segregates and bleeds. To prevent this, the mix must be reproportioned so that the cement-sand paste is thicker and less soupy. Adding fines inhibits bleeding by adsorbing mix water, and adding smaller size coarse aggregate (⅜- to¾-inch-diameter aggregate) inhibits segregation because smaller aggregate is less buoyant. Addition of pozzolans or about 4 to 5 percent more of the finer fractions of sand will help prevent segregation. Regardless of how high the fines content is, though, there is a maximum dosage of superplasticizer beyond which segregation is inevitable.

Superplasticized mixes proportioned to obtain high-strength concrete with more conventional workability usually have a high enough cement content (7 sacks or more per cubic yard) to supply the necessary fines. Segregation and bleeding are not significant problems. Some users have been able to improve the workability and finishability of these low-slump concretes by selecting coarse fine aggregate with a fineness modulus between 2.8 and 3.1 and increasing the proportion of coarse aggregate by 5 to 10 percent. However, in order to achieve strengths over 6000 psi most efficiently, the maximum aggregate size in cement-rich mixes should be limited. By reducing the maximum aggregate size, the total aggregate surface area is increased, the aggregate-mortar bond is increased and thus the concrete strength is increased. A decrease in maximum aggregate size has been shown to increase strengths in non-superplasticized cement-rich concrete 10 to 20 percent; adding a superplasticizer may increase strengths 20 to 40 percent more.

COMBINING ADMIXTURES TYPE F VERSUS TYPE A + TYPE E

Conventional water reducers (ASTM C 494 Type A) and high-range water reducers or superplasticizers (ASTM C 494 Type F) are chemically different. Conventional water reducers include hydroxylated-carboxylic acids, lignosulfonic acids and processed carbohydrates; superplasticizers are organic sulfonates. While some conventional water reducers can produce flowing concrete as well as do superplasticizers, the high dosages required to do so also retard the setting and strength development of the concrete, often excessively. In order to avoid this retardation a water reducer is usually used in combination with an accelerator (ASTM C 494 Type E).

Combining Type A and Type E admixtures has several benefits. By varying the dosage of the accelerator, the setting time of the concrete can be controlled. Moreover, by adding these two admixtures the strength of the concrete can be increased more than it could be by adding a superplasticizer, and the conventional admixtures can be added at the batch plant, not the site, because the rate of slump loss is slower, However, on the negative side, a combined dosage of these two conventional admixtures can cost more than a low dosage of superplasticizer, and, unlike superplasticizers, many accelerating admixtures (Type E) contain calcium chloride.

Regardless of which method is better—using a conventional water reducer with an accelerator or using a superplasticizer—a third combination of admixtures might be better than either. When a conventional water reducer is used in combination with a superplasticizer, less superplasticizer and a lower total admixture cost is required than when using a superplasticizer alone. The dosage of superplasticizer may be reduced as much as 60 percent when used in conjunction with an average dose of a conventional water reducer.

Slump and slump loss

Depending on the temperature, the humidity, the cement type, the type of superplasticizer and the other factors which normally affect slump loss, the slump change achieved by adding a superplasticizer can be completely lost within 60 to 90 minutes, sooner if the temperature is above 70° F. Higher dosages of superplasticizers have been reported in some instances to slow the rate of slump loss. However, too much superplasticizer can be added, causing the concrete to lose cohesiveness and segregate, a condition of the mix called “total collapse.”

Why superplasticized concrete loses slump relatively quickly is not clearly understood. It is not, as it is sometimes assumed, due to an acceleration of the hydration reaction of cement. The concrete does not simply set more rapidly, causing a corresponding drop in slump. Superplasticized concretes made with cements high in tricalcium aluminate (C3A), however, have been shown to lose slump faster than concretes with low C3A cements. Also, an optimum sulfate (SO3) content has been shown to minimize slump loss and maximize compressive strength.

Regardless of the reason, the effect of the superplasticizer does dissipate, and the concrete reverts back to the consistency of the original mix. If the placement of concrete is accidentally delayed, a second and possibly a third dosage of superplasticizer can be added to recreate the high slump. Although each redose reduces the amount of entrained air about 1½ percent, a second dosage generally produces a higher slump and a higher 28-day strength. In fact, both maximum strength and slump are usually achieved after the second dosage of superplasticizer. With the third dose, most if not all the entrained air is lost, and the strength declines (see figure).

Adding superplasticizer to the mix

Because the high slumps gained by adding superplasticizers are lost so quickly, superplasticizers are usually added at the site not the plant. When mixing in a ready-mix truck, the recommended procedure is to pull the concrete to the back of the drum by rotating the drum in the discharge direction, stop the drum and pour the liquid superplasticizer directly on top of the concrete. Rotating the drum in the opposite direction—the mixing direction—will then pull the concrete and the superplasticizer toward the front of the drum. Mixing for 4 to 5 minutes is usually sufficient. Failure to follow this procedure may result in unevenly mixed concrete with varying slump and strength.

The higher the initial slump of the concrete, the less superplasticizer that is needed to produce each inch of additional slump desired. For example, a 4-inch-slump mix may require only a 1½-ounce dosage per hundred pounds of cement for each inch of additional slump while a 1-inch-slump mix may require up to 2½ ounces per inch.

The dosage rate depends on the slump of the base concrete and the desired slump of the resultant superplasticized mix. For dependable results, the slump of the base concrete should be kept constant. However, the slump of the concrete delivered to the jobsite is bound to fluctuate on large jobs. To allow for this, concrete can be delivered at a slump slightly below the desired base slump, and water can be added at the site, before adding the superplasticizer, to bring the slump of the mix up to the desired base slump. This permits adding the same dosage of superplasticizer for each batch. Otherwise, the dosage of superplasticizer must be calculated individually for each batch, the amount depending on the volume of the batch and the base slump on arrival.

Setting time and finishing

Although the lignosulfonate-based superplasticizer retards the setting time about an hour when used with certain cement types, superplasticizers generally do not affect the setting time. At the most, they may retard initial set about 15 minutes. Consequently, a superplasticized mix can be finished at approximately the same time that the original base mix would have been finished had a superplasticizer not been added.

Finishing problems, however, can occur. Because superplasticized mixes, especially flowing superplasticized mixes, have a proportionately large volume of mix mortar, they tend to be sticky. The concrete pulls or drags on the trowel, the surface tears and the mix tends to move under the finisher’s weight. Using coarser fine aggregate or a higher proportion of coarse aggregate stiffens the mix and provides a less mortar-intensive appearance.

Another remedy is simply to delay finishing. Normally, with plain mixes, the concrete is troweled when most of the bleed water has evaporated and the surface appearance has changed from a wet and glossy to a dull and tacky texture. With superplasticized concrete, however, there is less mix water to bleed to the surface. Thus, the concrete appears ready to finish before it actually is ready, that is, before it has reached its initial set. Therefore, some admixture manufacturers have recommended delay of finishing about 20 minutes after the glossy sheen is gone.

Durability

Satisfactory freeze-thaw durability of concrete calls for the cement paste to be protected by minute air bubbles, purposely entrained by an air-entraining agent. Small size and close spacing of these bubbles have been shown to be important to the concrete’s durability. Superplasticized concrete which also contains entrained air in some cases has larger air bubbles and greater bubble spacing than recommended for conventional air-entrained concrete. Yet most of these concretes appear to have satisfactory durability. It appears that further study considering air voids in combination with water-cement ratio may be required for full understanding of the freeze-thaw durability of superplasticized mixes.*

When superplasticizers are used to produce flowing concrete, the water-cement ratio is usually not reduced. In this case, extra air-entraining agent may have to be added to compensate for the air loss caused by adding the superplasticizer. Exceptions, however, do exist. Some lignosulfonate-based superplasticizers increase, not decrease, the air content of the concrete. Consequently, trial mixes should always be made to check the effects and even the compatibility of a superplasticizer and an air-entraining agent; it is not guaranteed.

Although superplasticizers do not contribute to durability in flowing concrete by reducing the water-cement ratio, they do contribute to durability whenever they are used as water reducers, by increasing the tensile strength of the hardened cement paste and by strengthening the bond between the cement paste and coarse aggregate.

Other effects

On thermal cracking—Lower strength, smaller thermal diffusivity and larger thermal expansion are all conducive to cracking of concrete. Increasing the cement content strengthens the concrete, but it also decreases the thermal diffusivity and increases the thermal expansion. A point is reached where the strength gained by adding cement does not compensate for the higher thermal expansion caused by more cement. Thus, cracking results. High-range water reducers can help reduce this cracking by increasing the strength without adding cement or by reducing the cement (and thus the thermal expansion) without reducing strength.

On drying shrinkage—When used as a water reducer, a superplasticizer will produce concrete with less drying shrinkage. Since less water is in the mix initially, less water leaves the concrete over time, and there is less cracking due to drying.

On resistance to deicing salts—Superplasticized concrete has a resistance to chloride penetration similar to if not slightly higher than that of non-superplasticized concrete with the same water-cement ratio. When used to reduce the water-cement ratio, superplasticizers improve the concrete's resistance to chlorides even more.

On the steel-concrete bond—By dispersing the cement particles, superplasticizers improve the adhesion between steel and concrete.

On the corrosion of steel—No adverse effects have been reported.

Conclusion

Dramatic improvements in workability and placeability without substantially altering other desired properties of fresh and hardened concrete have become feasible with superplasticizing admixtures. Better relationships between strength and cement content are also attainable. However remarkable these accomplishments may appear at first glance, there is no magic. Superplasticized concrete is still concrete which must be properly proportioned, mixed, placed, cured and finished—or problems will arise.

A superplasticizer is not a cure-all admixture; it has its own problems, which must be taken into account. Nonetheless, dramatic transformation of stiff concrete into flowing concrete by adding superplasticizer instead of water may be the most significant breakthrough in concrete technology since the development of air-entraining agents.

References

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* According to a statement by V.M. Malhotra in Reference 1.

PUBLICATION #C820409