IMPORTANT ASPECTS OF CEMENTITIOUS MATERIALS USED IN REPAIR & RETROFIT

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SUMMARY

Replacement of damaged cementitious material is a frequent requirement in repair and retrofit of concrete and masonry structures. Additionally, the augmentation of existing members as well as provision of new elements such as infill shear walls, is often performed. All of these items require a repair material similar to the substrait, but of high bond strength. In order to obtain maximum bond from new cementitious compositions, the elimination of shrinkage is requisite. Control of shrinkage through proper design of new cementitious mixtures and the use of a variety of construction procedures is discussed.

INTRODUCTION

Concrete and masonry materials are normally subject to shrinkage as they cure and dry out. It is not unusual for such reduction in volume to continue for a number of years following construction (Ref. 1). In new construction, the shrinkage is anticipated in design, and provisions are made for it to occur without adverse results. In repair and retrofit of existing structures, consideration must be given to the fact that the existing structural members have already reached their final volume. Accordingly, compositions used to patch or add to such members must possess very low shrinkage potential. Whereas engineers commonly direct much concern to obtaining good bond, often specifying adhesive bonding agents, in most cases such is not necessary, and good bond strength will be automatically provided if the newly placed material is reasonably free of shrinkage. Thus, use of material compositions or construction procedures, either alone or in combination, which eliminate shrinkage is mandatory if optimal results are to be achieved.

FUNDAMENTAL CONSIDERATIONS

Cementitious materials such as concrete and mortar are made by combining cement, water, and aggregate together into a uniformly mixed substance. The cement and water when combined are referred to as the cement paste and it is this paste that binds the aggregate together. The binding action results from a chemical reaction between the cement and water known as hydration. Enough water must be provided to permit a sufficient amount of the cement to hydrate. Any water in excess of that chemically required is "surplus" and will increase the shrinkage potential of the mixture, precluding good bond development. Additionally, such surplus water will adversely affect other important properties of the composition such as strength, durability, impermeability, resistance to abrasion, and resistance to freezing and thawing damage. It is virtually impossible to provide too little water in most conventional concrete and mortar mixtures, as the amount of water required to obtain the necessary plasticity

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and workability usually greatly exceeds that required for proper hydration. In repair and retrofit work, however, it is mandatory to keep the water-cement ratio as low as possible, subject to provision of enough water to provide sufficient hydration.

When a unit of cement hydrates, the resulting hydration product or gel occupies a space approximately 2.4 times its original volume. Thus, a water-cement ratio of 0.44 (by weight) is required if 100% hydration is to occur (Ref. 2). Such complete hydration will consume an amount of water by chemical reaction equal to about 22% of the weight of the cement (Ref. 3). Thus, whereas a water-cement ratio of .22 by weight will provide enough water for 100% hydration, such could not occur, as it would be physically impossible for all of the cement to hydrate due to insufficient room for the resulting hydration product. The resulting mixture will harden, however, regardless of whether there is complete hydration of all of the cement or not (Ref. 2, 4). Well documented research has established that it is neither necessary nor desirable for 100% hydration to occur. In fact, one of the strongest materials ever made with portland cement possessed a water-cement ratio of only 0.08, and yet developed a strength of some 40,000 psi (2812 kgf/cm^2) in spite of the fact that very little of the cement could hydrate due to insufficient water available (Ref. 2). Because all water in excess of 22% is surplus water which can adversely affect the quality of the final composition, and 100% hydration of all of the cement is not required, it follows that the amount of such surplus water should be limited to the greatest degree possible.

MIX DESIGN

It is desirable to maintain uniform structural properties within individual members to be repaired. Therefore, where an existing member is being patched, it is advisable to match new materials to the original as closely as possible. Use of aggregates and other composition ingredients obtained from the source used when the original structure was constructed is desirable. If that source is not known or unavailable, an effort should be made to locate materials that match the original as closely as practicable. Likewise, it is advisable to match the original mix proportions as closely as possible, with exception of a reduction in the water content as previously discussed.

Where new members are being constructed, design of a mix which contains the minimum feasible amount of water should be considered. Many well established methods for such mix design are described in Ref. 1. Concrete mixtures designed for minimal shrinkage should have a low total water content, and contain the largest possible amount of aggregate consistent with the required workability. Also, the largest size aggregate that can be handled and placed should be used, as mixes containing large-size aggregates have more total aggregate and thus less pore space requiring cement paste than those containing small-size aggregates. Shrinkage is also influenced by the type of aggregate. Hard aggregates are difficult to compress and therefore provide more restraint regardless of shrinkage of the cement paste.

Water Reducing Admixtures

A variety of water reducing admixtures are available commercially and such materials have been in use for many years. These admixtures are used to reduce the quantity of mixing water required to produce concrete of a given consistency, without changing the amounts of any of the other constituents. Water reducing admixtures can be divided into four basic types (Ref. 5), as follows:

1. Lignosulfonic acids and their salts.

2. Modifications and derivatives of lignosulfonic acids and their salts.

3. Hydroxylated carboxylic acids and their salts.

4. Modifications and derivatives of hydroxylated carboxylic acids and their salts.

Some water-reducing compounds also retard the set of the concrete. In order to offset such retardation, many water reducing admixtures are treated to destroy set-retarding properties or to promote accelerated set. Two compounds frequently used in this regard are calcium chloride and triethanolamine. Research (Ref. 6) has shown that these compounds actually cause an increase in drying shrinkage even though the admixtures of which they are a part permit the use of less total water. Thus, water-reducing admixtures containing such accelerators, although permitting substantial lowering of the water requirement, can actually increase the amount of drying shrinkage, and should thus be avoided.

In contrast, many, though not all, of the water-reducing admixtures of the set-retarding type reduce shrinkage or increase it only slightly. Most water-reducing admixtures also entrain air in the concrete, although in the amounts commonly found this is usually beneficial. Because of the increased plasticity of the cement paste resulting from use of such admixtures, it is usually possible to increase the aggregate content, which is also beneficial as previously discussed. The effectiveness of such admixtures varies, and they are usually more effective in reducing water in rich mixtures than in lean ones. At their normally used dosages, these admixtures result in a water reduction on the order of five to thirteen percent. Recent work by Thorpe and Cordon (Ref. 7) demonstrates, however, that the water reduction potential can be substantially increased when the admixtures are used at double their normal dosage. In fact, one lignin type admixture reported therein resulted in a reduction of up to twenty-seven percent. In such use, caution must be exercised, in that there is wide variation in the quality of lignin materials, the most significant being content of residual sugar in varying amounts. Sugar acts as a retarder and special attention should be given to this factor when evaluating such admixtures for any particular usage. Because the shrinkage reduction (or increase) potential of mixtures containing water-reducing admixtures varies widely, regardless of the actual water reduction produced, careful evaluation and consideration must be given to selection of such materials intended for use.

Superplasticizers

Superplasticizers are a relatively new development and are only now coming into common usage. First developed in Germany and Japan, these compounds have been available in the United States since the mid 1960s. Their use permits twenty to thirty percent less water in a given concrete mixture without any loss in the plasticity or workability. Because of the significantly lower amount of water required for a given mix, a reduction in cement content of ten to fifteen percent is possible without any loss of strength. Because of the large reduction in required mix water, drying shrinkage is reduced, especially when the water-cement ratio is reduced to the area of .30 by weight, which is possible with very stiff mixtures. In contrast to their extraordinary advantages as outlined above, these chemicals do have the disadvantage that large losses in workability occur within one half to one hour after they are introduced into the mixer. For this reason, they should not be added until immediately prior to use of the resulting concrete. In projects utilizing ready-mix trucks, the admixture is usually added at the job site rather than at the batch plant.

Superplasticizers are made from the salts of organic sulfonates, and can be divided into three dominant types as follows:

1. Sulfonated melamine formaldehyde condensates.

2. Sulfonated naphthalene formaldehyde condensates.

3. Modified lignosulfonates.

Type 1 acts to reduce coagulation of the cement particules by forming a lubricating film on their surfaces. Type 2 electrically charges the particles negatively, so that they repel each other. Type 3 acts as a strong surfactant and thus decreases the surface tension of the mix water. The ultimate result is better dispersal of the cement particles, which facilitates coating of the aggregate more completely, and improved plasticity. For these reasons, the use of a superplasticizer provides important benefits, while overcoming the limitations of some of the more common water-reducing admixtures.

Latex Modification

Latex compositions can be added to any cementitious mixture. The addition of such compounds can promote many desirable properties, including low shrinkage and high bond strength. Commonly used compounds include SBR (styrene butadiene rubber) and acrylic latex emulsions. Typical modified cementitious compositions contain about ten to fifteen percent latex modifier by weight of the cement. In place, the emulsion bonds chemically to the aggregate as well as the substrait to be repaired. Because it remains in the interparticulate voids as they form, internal microstresses are relieved, and the formation of microcracks or more significant cracks is impeded. Latex modified compositions require special mixing and handling as initial set occurs in as little as thirty minutes. For this reason, special equipment and knowledge is required in their use, except in the case of small patches. As they have the advantage of requiring only one day of wet curing, they are particularly well suited for use where many small patches are required, over a large expanse of relatively inaccessible area, such as on the walls of a highrise building.

Fiber Reinforcing

The ability of a cementitious composition to yield in either volume or configuration can be greatly reduced by the inclusion of fiber reinforcing in the mixture. Such limitation of yield obviously limits shrinkage and thus provides for improved bond. In addition, the inclusion of fibers in the mixture usually results in a cured mass possessing a substantial increase in ductility. A wide variety of fibers are in common usage, including fibers made from glass, plastic, and steel. They vary from less than an inch to about two inches in length, and are usually deformed or provided with enlarged ends in order to reduce slip within the final mass. Although a considerable amount of work has been performed with fiber reinforcement, relatively little information as to actual field behavior in repair applications has been well documented, although the extent of their use is ever expanding. Thus, while valid standards are currently lacking, the benefits of use of these materials should not be ignored.

CONSTRUCTION TECHNIQUES

The principal limitation, in the use of cementitious compositions with water contents sufficiently low to preclude damaging shrinkage, is the inability to compound such mixtures with enough plasticity and workability to provide for proper placement. Thus, a number of construction techniques have been developed which enable placement of such compositions regardless of their lack of plasticity. In addition, there are methods available to reduce shrinkage through removal of some of the mix water immediately upon placement of the composition and prior to its initial set (Ref. 8).

Drypack Mortar or Concrete

Drypack mortar and concrete are compositions possessing the same constituents as regular concrete or mortar, except that the water content has been reduced to the minimum quantity required to provide a cohesive mass when compressed or rammed into place. Thus, while drypack materials cannot be placed, utilizing normal procedures, they do have a near optimal water content for sufficient hydration and are virtually shrinkage free. They are usually hand placed in small amounts at any given time, being tamped or rammed into place to the maximum obtainable density. Because such placing requirements are labor intensive, the procedure is not economical for large volumes; however, it is well suited for small patches and repairs in remote locations, or in areas where inexpensive labor is available. Also, since such work does not require extensive use of skilled labor, it is particularly applicable for use in areas where skilled labor is lacking and available labor is relatively inexpensive. Because minimal water is required, repairs made with drypack compositions are stable and extremely durable.

Preplaced Aggregate Concrete

Preplaced aggregate concrete is cast by pumping mortar into the pore spaces of previously placed large aggregate. There is virtually no limitation to the maximum size aggregate, although the smallest size is usually on the order of 1 cm (3/8 in.). The intrusion mortars most commonly used are composed of portland cement, fine sand (Minus No. 8 mesh), and an expansion promoting additive. Because each piece of large aggregate in preplaced aggregate concrete is in intimate contact with the adjoining pieces, and the intruded mortar expands after placement, the material is to some degree self stressing and thus provides high bond strength. It is therefore well suited for repair and restoration type work, especially where access is difficult or an unusually large congestion of reinforcing or other inserts exist.

Drymix Shotcrete

The drymix shotcrete process involves premixing of the cement and sand and transfer to the work site through a hose in a stream of compressed air. The end of the hose is equipped with a suitable nozzle at which point water is injected and mixed with the material as it exits at high velocity. The water content can be adjusted at the nozzle and is restricted to approximately that required for proper hydration of the cement. Because shrinkage is virtually eliminated due to the low water content together with the high impact force at which it is applied, properly installed drymix shotcrete possesses very high bond strength. Compressive strength of 27,600 kN/m^2 (4000 psi) is commonly obtained. The process is particularly suited to restoration work, as the material is transported to the work site through hose, making its placement virtually unlimited by access restrictions.

Low Slump Concrete

Normal concrete mixtures designed to contain the least possible amount of water, and based upon the minimum slump that can be reasonably placed, are useful in making repairs where architectural finishes or color must be maintained, or where large masses of new material are required. In order to hold the water content of these mixtures to the lowest possible amount, superplasticizers, as previously discussed, are frequently utilized. Where very low slump compositions are to be used, special consideration must be directed to the placing and consolidation methods. For structural applications, the use of external form vibrators is a frequent expedient. Where the new concrete is used for slabs or other flatwork, mechanical placing equipment and vibrating screeds enable efficient placement of essentially zero slump material.

Vacuum Water Removal

Although not frequently used in structural applications, vacuum water removal is a fairly well established method of removing surplus water from normal concretes, prior to their initial set. In practice, immediately following normal placing of the concrete, special filter pads are placed over the area to be treated. A suction mat is then placed over the filter pad and the edges are completely sealed. A vacuum is then created under the mats through use of a suction pump connected to the mat with a hose. The process can be applied to vertical and other formed surfaces by adaption of the filter and suction pads as required, and their subsequent placement in the forms, prior to concrete placing. The use of vacuum dewatering in structural applications has been limited, however, it has proven practical in actual applications and is worthy of consideration in repair and retrofit work, where the use of normal concrete is otherwise desirable (Ref. 9).

CONCLUSIONS

A variety of different methods, relating to design of specific mixtures, as well as placing techniques, are available to offset the deleterious effect of shrinkage and thus lack of bond normally experienced with cementitious compositions. Shrinkage of new cementitious mixtures can be minimized through careful proportioning of the individual mix constituents, and use of the least possible amount of water in the mixture. Water reduction can be facilitated through the use of normal water-reducing admixtures or superplasticizers. Composition shrinkage can be reduced through inclusion of latex modifiers, fiber reinforcing, or both. Shrinkage of the final composition can be minimized or completely eliminated by use of drypack mortar or concrete, preplaced aggregate concrete, or drymix shotcrete. Low slump concrete can be used with appropriate application considerations, and surplus water can be removed from any cementitious composition prior to initial set, by means of vacuum water removal.

APPENDIX - REFERENCES

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