Selecting repair materials

Some important material properties that should be considered

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The concrete repair contractor can choose from a wide array of specialty and conventional repair materials. This large selection gives the contractor greater opportunity to match material properties with job demands but it can also increase his chance of selecting an inappropriate material. No matter how carefully a repair is made, using the wrong repair material will likely lead to early repair failure. Some of the material properties that should be considered when selecting a repair material are discussed in this article. While both bond and compressive strength values are frequently provided by material suppliers, characteristics such as the material's dimensional stability, stiffness and capability of transmitting fluids, vapors and electrical current can be of equal or greater importance.

Figure 1. Materials that shrink excessively won't bond well to existing concrete. Shrinkage cracking and loss of bond caused this mortar patch in a wide crack to fail.

Dimensional stability

One of the primary requirements for a successful repair is to provide good bond between the new material and the underlying concrete or substrate. The popular belief that new concrete cannot achieve a good bond to old concrete is not entirely correct. Bond failure between new and old concrete isn't usually caused by the incapability of new concrete to adhere to a properly prepared substrate. It's usually caused by shrinkage.

Virtually all concrete shrinks as it dries out after curing and most of this shrinkage occurs soon after the concrete is cast. Shrinkage of concrete in new construction is allowed for in design by providing joints that control cracking. Most repairs are made on older concretes that won't undergo much further shrinkage so the repair material must also be essentially shrinkage-free or else be able to shrink without losing bond. Figure 1 shows shrinkage cracking and debonding of a mortar used to patch wide cracks in a wall. Shrinkage of cementitious repair materials can be reduced by using mixtures with very low water content or by using construction procedures that minimize shrinkage potential. Examples include drypack, dry-mix shotcrete and preplaced aggregate concrete.

Another way to combat shrinkage problems is to use repair products that actually expand in volume once they are mixed. Caution must be exercised when using expansive materials, however, because many must be fully restrained once they are placed to prevent excessive swell which results in loss of both strength and durability. Also, when considering the use of an expansive material, it is important to determine when the expansion reaction will take place to assure that the repair can be completed before expansion occurs. When evaluating expansive repair materials, both restrained and unrestrained test specimens should be made. Strength is determined from the restrained specimens and expansion potential is determined from the unrestrained specimens.

Coefficient of thermal expansion

All materials expand and contract with changes in temperature. For a given change in temperature, the amount of expansion or contraction depends on the coefficient of thermal expansion for the material. The coefficient of thermal expansion is the change in length over a unit length divided by the temperature change. It is usually given in millionths of an inch per linear inch per degree of temperature change. Reinforced concrete has a coefficient of thermal expansion of about 6 millionths per degree Fahrenheit (0.000006 inch/inch/degree F).

When making large or thick patches or when placing an overlay, it is important to use a material with a coefficient of thermal expansion similar to that of the concrete being repaired. When a composite of two materials of widely varying thermal coefficients undergoes a significant temperature change, differences in volume changes can cause failure either at the bond line or within the section of lower strength material. While this factor is most important in environments subject to frequent, large temperature changes, it should not be overlooked in environments with infrequent temperature changes. For example, we think of a cold storage room as staying at a uniform low temperature. But when the temperature is periodically raised for routine cleaning and maintenance, an otherwise good quality overlay in the freezer could fail.

Modulus of elasticity

The modulus of elasticity of a material is a measure of its stiffness. High modulus materials don't deform under load as much as do low modulus materials. When materials with widely differing moduli are in contact with each other, the lower modulus material will tend to yield

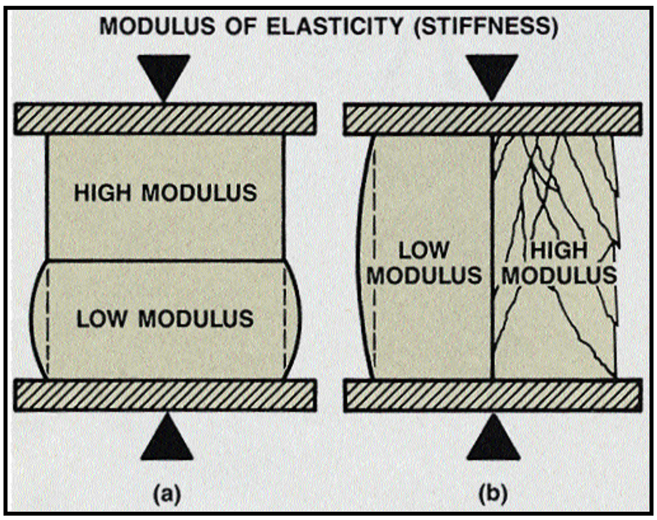

Figure 2. Materials with a low modulus of elasticity deform more under a given unit load than materials with a high modulus of elasticity. When the load is applied parallel to the bond line, as in (b), load transfer to the higher modulus material may cause failure.

or bulge under load, as illustrated in Figure 2. When the external load is perpendicular to the bond line, (Figure 2a), a difference in modulus usually doesn't cause problems. However, when the load is applied parallel to the bond line (Figure 2b), deformation of the lower modulus material transfers load to the higher modulus material which may then fracture. This type of problem can occur at the edge of a patch, and is particularly likely to happen when dynamic (impact or vibration) forces are present; for instance in pedestals under large machinery or in structures exposed to wind or earthquakes. Figure 3 illustrates this point. The lower modulus grout has deformed excessively, placing all of the load onto the stiff steel shims that were improperly left in place. As can be seen, the resulting large concentrated force has caused failure of the underlying concrete. A similar effect can occur if grout with a high modulus is used to repair a lower modulus material.

Figure 3. Lower modulus grout beneath the machinery base plate deformed excessively, placing all of the load onto the stiff steel shims that were improperly left in place. As a result, the underlying concrete failed.

A wall or section made of relatively flexible (low modulus) material should not be patched with a stiff (high modulus) material. If window openings in an unreinforced brick wall are filled with concrete, the wall could fall apart if subjected to excessive vibration or shaking because the relatively flexible brick is forced to yield around the stiff concrete.

Not all failures related to widely differing modulus materials in contact with each other are caused by external loads. Shrinkage or thermal movements, as mentioned previously, can cause loss of bond unless the modulus of the repair material is low enough to permit movement without excessive stress at the bond line. Many of the polymer repair materials such as epoxies can be formulated to achieve the low modulus needed to avoid loss of adhesion to the concrete substrate.

Permeability

Permeability refers to the capability of a material to transmit liquids or vapors. Good quality concrete is relatively impermeable to liquids but freely transmits vapors. If impermeable materials are used for large patches, overlays or coatings, moisture vapor that passes up through the base concrete can be entrapped between the concrete and topping. Entrapped moisture can cause a failure either at the bond line or within the weaker of the two materials. This can be a particularly troublesome problem with slabs on grade that are subject to freezing and thawing. Figure 4 shows the failure of an otherwise good quality but impermeable epoxy overlay which lost bond, primarily due to the pressure of mois-

Figure 4. An impermeable but otherwise good quality epoxy overlay lost bond because moisture rising through the slab on grade built up pressure under the impermeable overlay.

ture rising through the slab on grade.

Impermeable materials should also generally be avoided in patching concrete that has been damaged due to corrosion of rebar. One factor affecting the rate of corrosion is the ability of the concrete to conduct electrical current. This in turn is directly related to the permeability of the concrete. All concrete, unless it is oven dry, is conductive to some degree. However, should a portion of the concrete be replaced with a nonconductive repair material, the transmission of current through the concrete will be concentrated in a smaller section and the rate of corrosion may be accelerated.

Figure 5 shows a beam that was repaired with a nonconductive mortar less than a year before the photo was taken. When the repair mortar was knocked off, severe corrosion of the rebar was evident, even though the steel had been cleaned of all corrosion product during the previous repair. In this case, the repair was of good quality in every detail except for the use of a nonconductive material. Because of this oversight in material selection, the entire structure had to be demolished and replaced only a year after the extensive repairs were made.

Material selection

Selection of appropriate materials is an absolute requirement for obtaining durable repairs. To match properties of the base concrete as closely as possible, portland cement concrete or similar cementitious compositions are frequently the best choices for the repair material. But not always. Such factors as restricted work conditions, requirements for rapid strength gain, needed improvements in resistance to chemical attack or the need to achieve aesthetically pleasing surfaces often mandate the use of other materials.

Almost every repair job has unique conditions and special requirements. Only after these have been thoroughly examined can the final repair criteria be established. Once the criteria are known, it will often be found that more than one material can be used with equally good results. Final selection of the material or combination of materials must then take into account the ease of application, cost, and available labor skills and equipment. In general, when choosing repair materials, the true repair professional considers three things: the conditions of the repair, the properties of the repair materials, and the skill and equipment he needs to do the job.

Figure 5. The nonconductive material used to repair this beam (top) accelerated the corrosion of reinforcing steel, which led to premature repair failure (bottom).

QUESTIONS TO CONSIDER BEFORE CHOOSING A REPAIR MATERIAL

Concrete repair materials can be formulated to provide a wide variety of properties. Because the properties affect performance of the repair, choosing the right product requires careful study. Suppliers of repair materials can help repair contractors choose the right product but they need to know the anticipated service conditions and the conditions under which the product will be applied. If you haven't told the supplier the answers to the following questions, you probably haven't told him enough about the repair conditions for him to help you choose the best repair material.

Application conditions

1. *How thick is the repair section?* In thick sections, heat generated during curing of the repair material may build up and produce unacceptable thermal stresses. Some materials may shrink too much when placed in thick layers and some materials will spall if placed in thin layers. Others can be featheredged. When aggregates are used as an inexpensive filler or extender, the maximum size of aggregate that can be used will be dictated by the minimum thickness of the repair.
2. *Will the substrate be moist?* Some polymer materials will not cure properly in the presence of moisture. Others are moisture insensitive. Heat generated during initial curing of some repair materials may create steam in a moist environment and the steam may cause failure of the repair.
3. *At what temperature will the repair material be placed?* Portland cement hydration ceases at or near freezing temperatures and cement modifier emulsions won't coalesce to form films at temperatures below about 45 degrees F. Other repair materials can be used at temperatures well below freezing, although setting time may be increased. High temperatures will make many repair materials set faster, decreasing the working life or precluding their use entirely.
4. *Will repairs be carried out in poorly ventilated areas or in areas where use of flammable materials isn't permitted?* Components of some repair materials are volatile and combustible. Odor can also be a problem.
5. *Is the repair section on a vertical surface or on the underside of a horizontal member?* For unformed wall or soffit patches, repair materials must adhere to the substrate without sagging.

Service conditions

1. *How soon does the repair have to be put into service?* If repairs are subjected to early loading, rapid strength gain characteristics are essential.
2. Will the material be exposed to chemicals such as acids, sulfates, chlorides or strong solvents? Acids and sulfates will attack portland cement-based materials, and chlorides may cause corrosion of reinforcing steel. Strong solvents may soften some materials.
3. *Will the repair bear heavy traffic?* Perhaps a material with good abrasion resistance and good skid resistance is necessary.
4. *Must the material bond to steel as well as to the concrete substrate?*
5. *What are the maximum and minimum temperatures to which the material will be subjected in service?* Because thermal movements can cause stresses in the repair material or at the bond line, the range of service temperatures must be considered.
6. *Will the finished repair be exposed to vibration?* For applications such as machinery pedestals, vibration can cause distress in brittle repair materials.
7. *Is appearance of the repair important?* If color matching or duplication of original concrete texture is needed, many repair materials will be unsuitable.
8. *How long must the repair last?* If the repair is only temporary, perhaps a lower cost, less durable, or more easily applied material can be used.

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