



IMPORTANCE OF MODULUS OF ELASTICITY IN SURFACE REPAIR MATERIALS

Keywords: compatibility; cracking; creep; elastic modulus; load-carrying; repair; strain; stress; tension.

Question

How important is the modulus of elasticity as a property of surface repair materials?

Answer

The modulus of elasticity is a very important property. For structural repairs, the elastic modulus should be similar to that of the substrate concrete, whereas in the case of nonstructural repairs, a lower elastic modulus may be beneficial.

Discussion

Concrete repairs may be broadly classified as structural (load-carrying) and nonstructural (protective and/or cosmetic). The load-carrying capacity and stress distribution must be considered in the case of structural repairs where replacement of deteriorated load-bearing concrete is required. The repair material may be subjected to tension, compression, and/or shear forces. Yet, even with equivalent or higher modulus repair material, permanent loads will not be shared unless the existing member is unloaded prior to repair. Different approaches may be required for the design and analysis of such repairs. It should be emphasized, however, that a structural repair must also protect the underlying concrete and reinforcing steel from deterioration and corrosion.

The modulus of elasticity is a measure of the stiffness of a material.^{1,2} A material with a higher modulus of elasticity is more rigid than a lower modulus material, which is more flexible. The modulus of elasticity is the constant of proportionality between the applied stress and the strain within the linear stress-strain range of the material. It corresponds to the slope of the straight line portion of a graph of stress* versus strain.† The term elasticity refers to the reversible character of the dimensional change (as a spring would recover if compressed or stretched). The modulus of elasticity of repair materials is typically measured using ASTM C469 or ASTM C580 test methods. Additional information regarding the modulus of elasticity testing and its significance is included in ACI 546.3R.

The modulus of elasticity of a repair material with respect to that of the substrate partially determines the relative loads resisted by the new repair and the remaining substrate materials. One important consideration for proper material selection is dimensional compatibility between the substrate and repair.^{3,5} If a material of lower modulus than the substrate is selected, the repair is unable to carry as much load as the original concrete, but it is helpful in reducing stresses induced by volume changes in the material or surrounding concrete. Conversely, if a higher modulus material than the substrate is selected, not only will the repair carry more load relative to the substrate, but the thermal- and shrinkage-induced stresses may also be concentrated in the repair material—a situation that can lead to cracking or debonding of the repair.

To have good resistance to cracking (high tensile strain capacity), the repair material for protective repairs should be “extensible.” It should have a low modulus of elasticity, low shrinkage values, and high creep. It should be remembered, however, when developing such extensible materials for protective repairs, that some factors that reduce shrinkage, such as relatively low water-cement ratio (w/c) or stiffer aggregates, have been observed to decrease creep or relaxation and increase the modulus of elasticity at the same time, thus offering little or no benefit to the tensile strain capacity (TSC). In addition, good bond strength of the repair material to the base concrete is critical to the success of the repair; however, increasing the bond strength of repair materials typically increases their modulus of elasticity and decreases their TSC. Often, a compromise must be reached between high bond strength and low modulus of elasticity.

Emphasis should be placed, therefore, on modifying these parameters that produce a net increase in TSC. One such potentially favorable parameter is the aggregate fraction. Contrary to what is generally

*Stress is intensity of force per unit area (psi [MPa]).

†Strain is displacement per unit length (in./in. [mm/mm]).

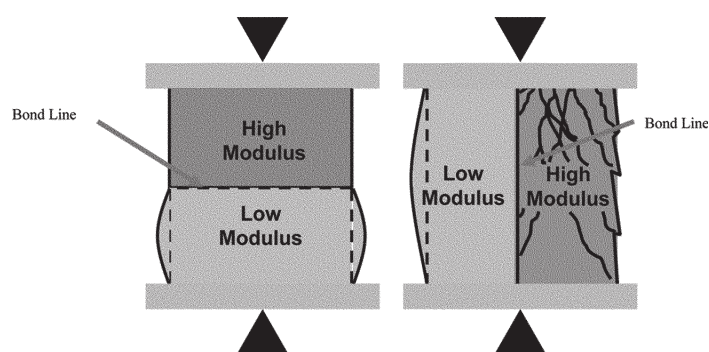


Fig. 1—Examples of repair layouts combining materials with different elastic moduli.⁵

monolithically, the difference in stiffness may lead to distress under externally applied loads, depending on the induced stress field with respect to the structure layout. For example, when the external load is essentially perpendicular to the bond line (left view in Fig. 1), as in the case of pavement overlay on a highly rigid foundation, a difference in modulus of elasticity between the repair material and the substrate does not significantly affect the overall mechanical behavior of the structure. Conversely, in repairs where the service load stresses are parallel to the bond line, the deformation of the lower modulus material causes the load to be transferred to the higher modulus material, which may then become overstressed and fracture (right view in Fig. 1).

When the moduli of the repair and of the substrate differ significantly, environmental loads (that is, drying shrinkage and thermal deformations) can also generate internal stresses such that cracking and, ultimately, debonding could occur. Moreover, shrinkage or thermal expansion and contraction can cause distress if the modulus of the repair material is too high to permit deformation without excessive stress at the bond line. It is important to consider shrinkage compatibility and thermal compatibility (coefficient of thermal expansion) when selecting repair materials. Refer to ACI 546.3R for information regarding these parameters. More compliant (lower modulus) repair material will reduce stresses due to shrinkage and thermal incompatibility, but may not be acceptable for structural repairs.

Summary

Surface repairs must be dimensionally and mechanically compatible with the existing concrete substrate to minimize cracking and ensure that the repair and existing structure act monolithically. To achieve repairs that comply with these requirements, the magnitude of the repair material modulus of elasticity with respect to that of the substrate needs to be taken into account.

Referenced standards and reports

The standards and reports listed below were the latest editions at the time this document was prepared. Because these documents are revised frequently, the reader is advised to contact the proper sponsoring group if it is desired to refer to the latest version.

American Concrete Institute

546.3R Guide for the Selection of Materials for the Repair of Concrete

ASTM International

C469 Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression

C580 Standard Test Method for Flexural Strength and Modulus of Elasticity of Chemical-Resistant Mortars, Grouts, Monolithic Surfacing, and Polymer Concretes

Cited references

1. Beer, F. P., and Johnston, E. R., *Mechanics of Materials*, third edition, McGraw-Hill, New York, 2002, 800 pp.
2. Mehta, P. K., *Concrete: Structure, Properties and Materials*, Prentice Hall, Upper Saddle River, NJ, 1986, 548 pp.
3. Vaysburd, A. M.; Emmons, P. H.; Mailvaganam, N. P.; McDonald, J. E.; and Bissonnette, B., "Concrete Repair Technology—A Revised Approach is Needed," *Concrete International*, V. 26, No. 1, Jan. 2004, pp. 59-65.
4. Pigeon, M., and Bissonnette, B., "Tensile Creep and Cracking Potential of Bonded Concrete Repairs," *Concrete International*, V. 21, No. 11, Nov. 1999, pp. 31-35.
5. Emmons, P. H., *Concrete Repair and Maintenance Illustrated*, R.S. Means Co. Inc., New York, 1993, 295 pp.