



IMPORTANCE OF MODULUS OF ELASTICITY IN SURFACE REPAIR MATERIALS—TECHNOTE

Keywords: compatibility; cracking; creep; modulus of elasticity; nonstructural repair; strain; stress; structural repair; tensile strain capacity; tension.

Question

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

Answer

Modulus of elasticity is an important physical property of surface repair materials. For structural repairs, the modulus of elasticity of the repair materials should be similar to that of the substrate concrete, whereas in the case of nonstructural repairs, a lower modulus of elasticity may be beneficial.

Discussion

Concrete repairs may be broadly classified as structural (load-carrying) and nonstructural (protective and/or cosmetic). Examples of the latter are repairs in the tensile half of a beam or on the edge of a slab. Load-carrying capacity and stress distribution should be considered in the case of structural repairs where replacement of deteriorated load-bearing concrete is required. The repair materials may be subjected to tension, compression, shear forces, or a combination of these. These forces arise primarily from the superimposed loads, as dead loads will not be shared initially unless the structure is unloaded prior to repair. The repairs may become engaged over time as a result of creep in the substrate concrete, if the member is overloaded, or both. In nonstructural repairs, one of the primary design considerations is the ability of the repair materials to resist cracking for adequate protection and aesthetics. It must be emphasized, however, that a structural repair should also protect the underlying concrete from deterioration and reinforcing steel from corrosion.

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 (refer to Fig. 1). It corresponds to the slope of the straight-line portion of a graph of stress versus strain. The property, also commonly referred to as the elastic modulus or Young's modulus, is a measure of the stiffness of a material (Beer et al. 2014; Mehta and Monteiro 2014). A material with a higher modulus of elasticity is less flexible than a material with a lower modulus of elasticity. 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/C469M or ASTM C580 test methods. Additional information regarding the modulus of elasticity testing and its significance is included in ACI 546.3R.

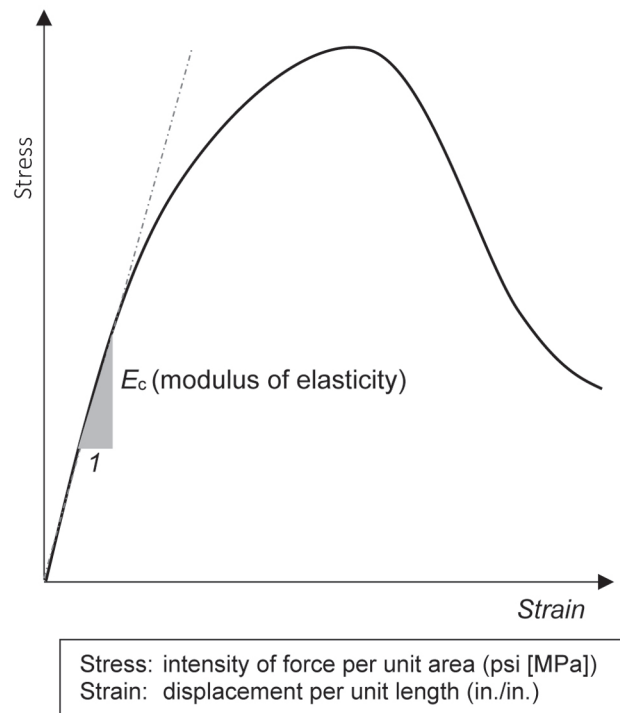


Fig. 1—Schematic stress-strain curve for concrete illustrating determination of modulus of elasticity, per ASTM C469/C469M, as slope of the line between two specific points, corresponding respectively to strain of 50×10^{-6} and a stress of 40% of the compressive strength.

One important consideration for proper repair materials selection is mechanical compatibility between the substrate and repair (ACI 562). The modulus of elasticity of a repair material with respect to that of the substrate partially determines the relative magnitude of loads resisted by the new repair and the existing substrate materials. If a material with a lower modulus of elasticity than the substrate is selected, the repair does not carry as much stress as the portion of original concrete being replaced over the element cross section; however, it is helpful in reducing stresses induced by volume changes in the material or surrounding concrete. Conversely, if a material with a higher modulus of elasticity than that of 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 materials—a situation that can lead to cracking or debonding of the repair.

The resistance to cracking of nonstructural repair materials is dependent on their deformational compatibility (Vaysburd et al. 2017), referred to as volume stability compatibility in ACI 546.3R and ACI 562. To achieve the related compatibility requirements, the materials need to have high extensibility (tensile strain capacity, which means a low modulus of elasticity and high creep), and low shrinkage. The ASTM C1581/C1581M ring test procedure captures the competition between shrinkage and extensibility in restrained movement conditions well and is thus a useful method for evaluating the cracking sensitivity of a concrete repair.

When developing materials for nonstructural repairs, it should be remembered that all composition parameters do not influence shrinkage and the tensile strain capacity in the same manner. For instance, while a lower water-cementitious materials ratio (w/cm) or stiffer aggregates will generally yield lower shrinkage, it is conversely expected to decrease creep or relaxation and increase the modulus of elasticity at the same time, offering as a result potentially limited benefits in reducing the shrinkage cracking sensitivity. Emphasis should be placed, therefore, on parameters that can produce a net positive effect upon the balance between the total strain capacity and shrinkage. One such potentially favorable parameter is the aggregate fraction. Contrary to what is generally reported in the case of compressive creep, it has been observed that increasing the amount of aggregate in the repair materials causes the tensile creep of the concrete repair to increase (Bissonnette et al. 2007). Because shrinkage is reduced when the aggregate content is increased, an optimal proper repair mixture for protective and/or cosmetic repairs should have the lowest possible cement paste content that meets the serviceability and the placement requirements.

It should be mentioned that in conjunction with the use of repair materials exhibiting lesser sensitivity to cracking, well-detailed reinforcement that is pinned into the existing substrate can ensure a satisfactory performance of the repair by distributing cracks and preventing localized wide cracks (ACI 224R; ACI 546.3R). Reinforced repair mixtures also offer a dependable alternative (ACI 544.5R).