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Communication

Effect of embedded steel on the compressive damage behavior of cement mortar

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Abstract

Steel embedded in cement mortar in the uniaxial compressive stress direction was found to decrease by 80% the compressive longitudinal strain at a given stress and increase by 300% the tensile transverse strain at a given longitudinal strain. The former effect is due to longitudinal confinement of mortar by steel. The latter is due to debonding at the steel-mortar interface.

Keywords: Mechanical properties; Cement; Reinforcement; Concrete; Mortar

Steel bars commonly are embedded in concrete to reinforce concrete under tension, because concrete is weak under tension and steel has a much higher elastic modulus than concrete. However, steel often is present even in the part of a concrete structure that is under compression. When the steel bar is in the compressive stress axis, it has little effect on the elastic behavior, such as the elastic modulus, as shown by the rule of mixtures. Nevertheless, it has an effect on the damage behavior, such as the strain at failure, as reported here for the strain in the stress axis as well as that transverse to the stress axis. The strain in the stress axis (longitudinal strain) at a given stress is decreased greatly by the presence of the steel; the transverse strain at a given longitudinal strain is increased greatly by the presence of the steel. The former effect is associated with the longitudinal confinement of the concrete by the embedded steel. (This confinement is to be distinguished from the lateral confinement of a concrete column by a steel jacket [1,2].) The latter effect is associated with the weak bonding between steel and concrete causing the concrete to tend to spread laterally upon longitudinal compression.

1. Experimental methods

The cement used for mortar specimens was Portland cement (type I) from Lafarge Corp. (Southfield, MI). Natural sand was used as the fine aggregate (all passing #4 US sieve, 99.9% SiO_2). The sand-to-cement ratio was 1.0. The water-to-cement ratio was 0.45. Cement, sand, and water were mixed in a Hobart mixer for 5 min. After pouring the mix into oiled molds of size 2 inch $\times$ 2 inch $\times$ 2 inch (51 mm $\times$ 51 mm $\times$ 51 mm), a vibrator was used to decrease the amount of air bubbles. The specimens were demolded after 1 day and allowed to cure in a moist room (humidity 100%) for 28 days.

In another set of specimens, a low-carbon rimmed steel plate (2.5 mm thick) was positioned vertically at the center of the mortar in the mold, such that the plate was totally embedded (Fig. 1). The steel plate was 30 mm long in the vertical direction and 25 mm wide.

The 2 $\times$ 2 $\times$ 2 inch mortar specimens with and without embedded steel were tested up to failure under compression in the direction of the steel plate, whereas the longitudinal and transverse strains of the mortar were separately measured by resistive strain gages attached to the center of one of the vertical faces of the cube. A hydraulic mechanical testing system (MTS 810) was used at a crosshead speed of 0.029 mm/s. Three specimens of each type were tested.

2. Results

Fig. 2 shows the compressive stress-strain curves (compressive strain = −longitudinal strain) up to failure. The strain at failure was much lower when steel was present than when steel was absent. The compressive strength was

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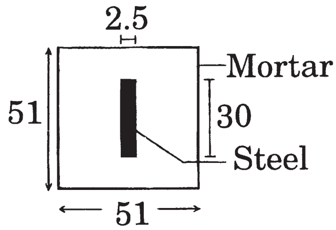

Fig. 1. Specimen configuration for mortar with embedded steel plate. All dimensions are in millimeters.

essentially the same for the two cases. At a given stress, the strain was much lower when steel was present.

Fig. 3 shows the curves of transverse strain vs. −longitudinal strain. The transverse strain was much higher for the same longitudinal strain when steel was present than when steel was absent.

Table 1 lists the strains and stress at failure. Both longitudinal strain magnitude and transverse strain at failure were much decreased by the presence of steel.

3. Discussion

The effects of embedded steel in the stress axis on the compressive damage behavior of mortar are that 1) the compressive strain at a given stress is decreased, and 2) the transverse strain at a given longitudinal strain is increased. The former effect is due to longitudinal confinement of mortar by steel. The latter effect is due to the weak interface between steel and concrete undergoing debonding, which allows the mortar to spread in the transverse direction. These effects are large, although the compressive strength is not affected by the steel.

At a given stress, the magnitude of longitudinal strain is smaller for concrete with steel than concrete without steel (Fig. 2). This means that the confining ability of the steel exists at any stress level—not just at failure.

At a given longitudinal strain, the transverse strain is higher when steel is present than when steel is absent (Fig. 3). This means that debonding at the steel-mortar interface starts to occur near the beginning of the compressive deformation.

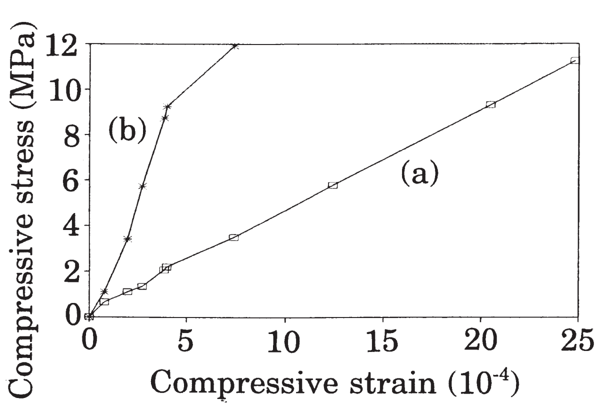

Fig. 2. Compressive stress-strain curves. *(a)* Without steel; *(b)* with steel.

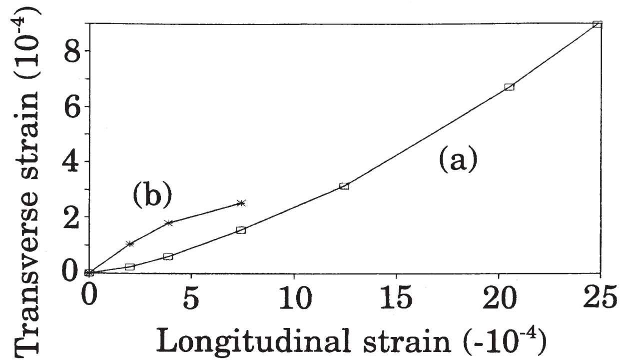

Fig. 3. Variation of transverse strain with longitudinal strain. *(a)* Without steel; *(b)* with steel.

The decrease in transverse strain at failure when steel was present (Table 1) was due to the decrease in longitudinal strain magnitude at failure. The latter is due to confinement of mortar by steel.

The confining effect of mortar by embedded steel is desirable, but the increase in transverse strain at a given longitudinal strain is not desirable. These effects of embedded steel on the compressive damage behavior should be considered in the design of steel-reinforced concrete structures.

4. Conclusion

Steel embedded in mortar in the unaxial compressive stress direction was found to decrease the compressive longitudinal strain at a given stress and increase the tensile transverse strain at a given longitudinal strain. The former effect is due to longitudinal confinement of mortar by steel. The latter effect is due to debonding at the steel-mortar interface.

References

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Table 1
Strains and stress at failure

	Without steel	With steel
Stress (MPa)	−11.2 (±0.6)	−11.3 (±1.0)
Strain (10^{-4})		
Longitudinal	−23 (±2)	−5.1 (±0.6)
Transverse	9.0 (±1.1)	3.1 (±0.5)