Technical note

Degradation of the bond between old and new mortar under cyclic shear loading, monitored by contact electrical resistance measurement

Jingyao Cao, D.D.L. Chung*

Composite Materials Research Laboratory, Department of Mechanical and Aerospace Engineering, University at Buffalo,
The State University of New York, Buffalo, NY 14260-4400, USA

Abstract

Degradation of the bond between old and new mortar under cyclic shear loading was observed nondestructively by measuring the contact electrical resistance of the joint. Degradation, which was due to fatigue and caused a decrease in bond strength but no visual damage, was indicated by an abrupt increase in the resistance at a small fraction of the fatigue life. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Bond strength; Electrical properties; Mortar; Degradation; Fatigue

1. Introduction

The repair of a concrete structure commonly involves the bonding of new concrete to the old concrete [1–7]. Partly due to the drying shrinkage of the new concrete, the quality of the bond is limited. Destructive measurement of the shear bond strength has been previously used to assess the quality of the bond [8]. However, the bond may degrade at stresses below the shear bond strength, even though the degradation may not be visible. This degradation may occur during static or cyclic loading. In particular, cyclic loading may lead to fatigue. Such degradation is revealed in this work through measurement of the contact electrical resistance of the bond interface during cyclic shear loading, as degradation causes the contact resistance to increase.

Measurement of the contact electrical resistance between old and new mortar has been previously used to assess the performance of carbon-fiber-reinforced mortar as an electrical contact material for cathodic protection [9]. However, the measurement was not carried out during mechanical loading.
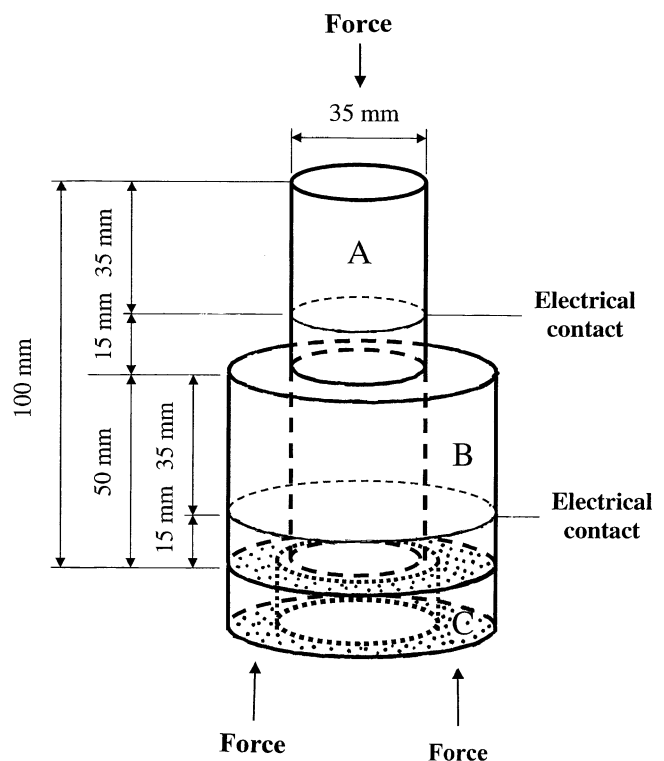

Fig. 1. Configuration for measuring contact electrical resistance during shear loading of joint between old mortar (A) and new mortar (B). C was the steel support.

* Corresponding author. Tel.: +1-716-645-2593x2243; fax: +1-716-645-3875.
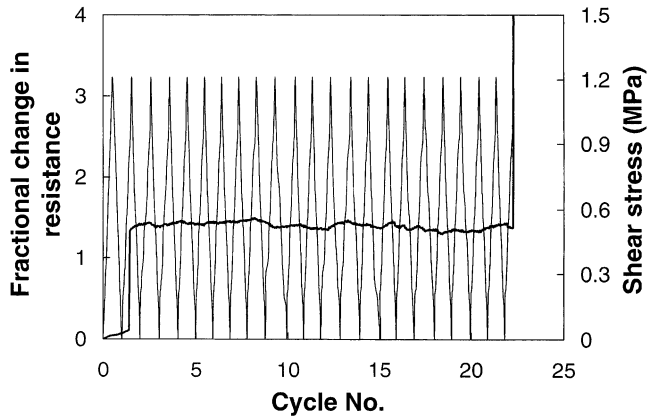*E-mail address*: ddlchung@acsu.buffalo.edu (D.D.L. Chung).

Fig. 2. Variation of the fractional contact resistance change with cycle No. during cyclic shear loading at a shear stress amplitude of 1.21 MPa up to bond failure. Thick curve: fractional change in contact resistance. Thin curve: shear stress.

The objective of this paper is to study the damage evolution of the bond between old and new mortars during cyclic loading. Contact electrical resistance measurement allowed this to be conducted in real time nondestructively.

2. Experimental methods

The cement used was portland cement (Type I) from Lafarge (Southfield, MI). The sand used was natural sand (100% passing 2.36-mm sieve, 99.9% SiO_2). The sand/cement ratio was 1.0. The water/cement ratio was 0.35. A water-reducing agent (WR) was used in the amount of 1.0% by weight of cement. The WR was TAMOL SN (Rohm and Haas, Philadelphia, PA), which contained 93–96% sodium salt of a condensed naphthalene sulfonic acid. No coarse aggregate was used. A Hobart mixer with a flat beater was used for mixing, which was conducted for 5 min. After that, the mix was poured into oiled molds. A vibrator was used to facilitate compaction and decrease the amount of air bubbles.

A cylindrical piece of mortar labeled A (poured first) was concentrically surrounded by a cylindrical piece of mortar labeled B (poured 28 days after pouring A), such that the top flat surface of A protruded out of that of B, and the bottom flat surface of A was flush with that of B (Fig. 1). The A–B joint was subjected to shear when B had been cured for 28 days. Shear stress was imposed by applying a downward load on the top flat surface of A, while the bottom flat surface of B was supported by a steel annular ring C with a
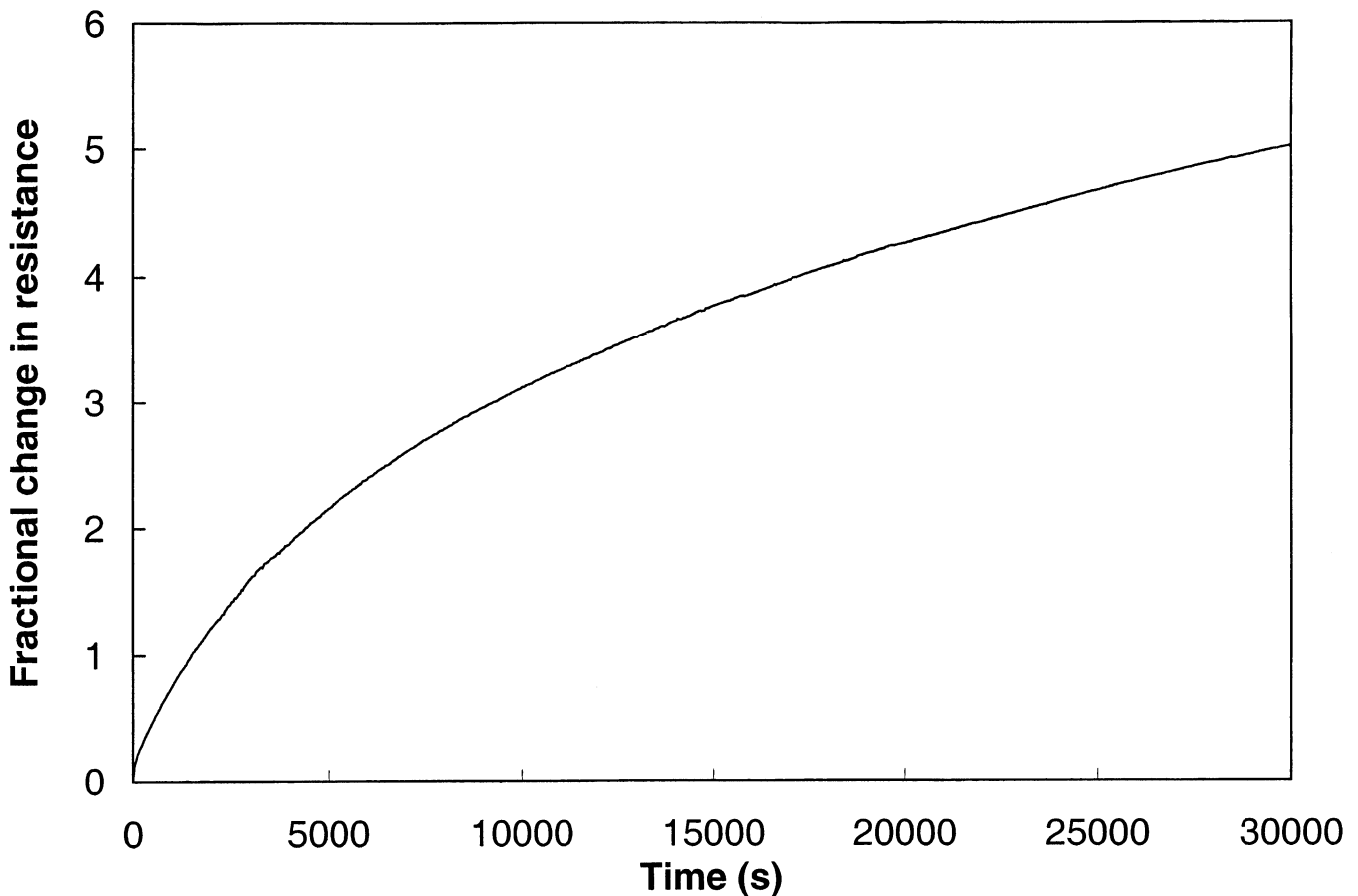

Fig. 3. Variation of the fractional contact resistance change with time during continuous resistance measurement.

central circular hole slightly larger than the cross section of A. In this way, A went through the hole of C upon complete debonding at the A−B joint. The C was electrically insulated from A and B by using a paper lining.

Electrical contacts in the form of silver paint in, conjunction with copper wire strands, were applied circumferentially around the protruded part of A and around B, as shown in Fig. 1, in order to measure the contact electrical resistance of the A−B joint during shear. The two-probe method (involving two electrical contacts, each for both current and voltage) rather than the four-probe method (involving four electrical contacts, the outer two of which are for passing current and the inner two of which are for voltage measurement) was used because of the very high values of the A−B joint contact resistance (of the order of 10 MΩ), which overshadowed the volume resistances of A and B, as well as the contact resistance of the silver paint contacts. The contact resistance was included in the measured resistance obtained by the two-probe method, but was excluded from the measured resistance obtained by the four-probe method. A Keithley 2002 multimeter was used.

Shear stress and contact electrical resistance were simultaneously measured during static loading up to failure and during cyclic loading at different shear stress amplitudes

(0.81, 0.97 and 1.21 MPa), which were chosen to give degradation (as shown by resistance measurement), but not failure, of the bond between old and new mortar in widely different numbers of loading cycles. The time for each cycle was 20 s. The curve of stress vs. time within a cycle was an isosceles triangle (Fig. 2). Six samples were tested for each loading condition. The loading rate during static loading was 0.027 MPa/s.

Due to the voltage present during electrical resistance measurement, electric polarization occurs as the resistance measurement is made continuously. The polarization results in an increase in the measured resistance [10]. This effect contributed negligibly to the observed resistance changes unless the time of continuous resistance measurement was long, as in the case of cyclic loading for more than 100 cycles. Nevertheless, the polarization-induced resistance increase, as separately measured as a function of the time of resistance measurement in the absence of stress (Fig. 3), was subtracted from the measured resistance change in order to correct for the effect of polarization.

In order to confirm that an abrupt increase in the contact electrical resistance during cyclic shear is due to degradation of the bond between old and new mortar, the shear bond strength was destructively measured before and after the
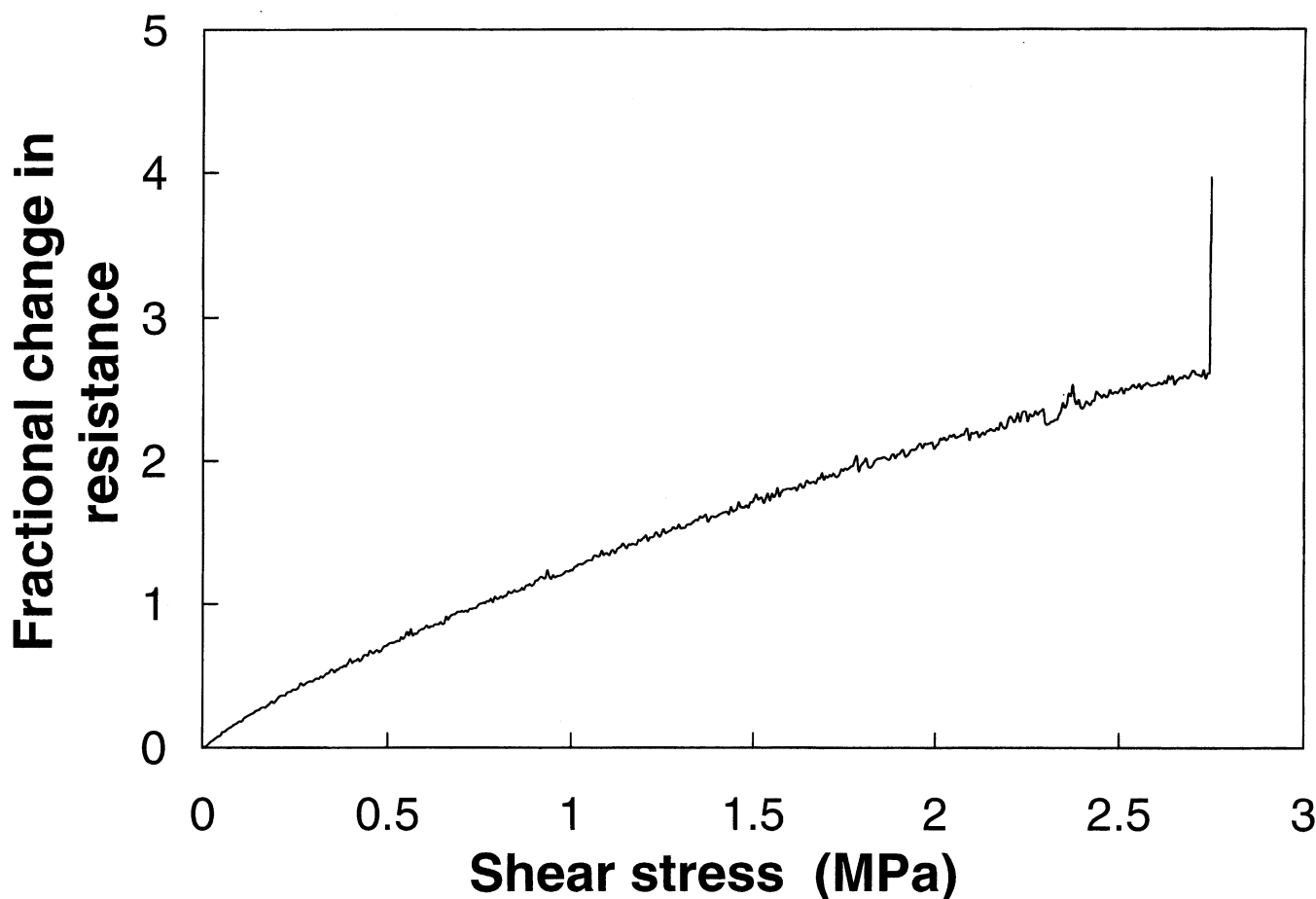

Fig. 4. Variation of the fractional contact resistance change with shear stress during static shear loading up to failure.

first abrupt resistance increase during cyclic shear at a stress amplitude of 1.21 MPa. Six samples were tested before the abrupt increase in resistance and six samples were tested after the abrupt increase. The shear bond strength was measured during static loading up to failure, using the testing configuration in Fig. 1.

3. Results and discussion

Fig. 2 shows the fractional change in contact electrical resistance of the joint between old and new mortar during cyclic shear loading at a shear stress amplitude of 1.21 MPa. The resistance did not change upon stress cycling except for an abrupt increase after one to six cycles (the particular cycle depending on the sample), when there was no visual sign of damage, and another abrupt increase at bond failure, which occurred at Cycles 18–27 (the particular cycle depending on the sample).

The bond strength before the first abrupt increase was 2.87 ± 0.18 MPa; that after the first abrupt increase was 2.38 ± 0.22 MPa. Thus, even though the first abrupt increase did not cause visually observable damage, bond degradation occurred.

During static loading, the contact resistance increased monotonically with increasing shear stress and abruptly increased at bond failure, as shown in Fig. 4 for the case of a specimen that had not been loaded prior to the measurement. No abrupt increase in resistance was observed during static loading prior to failure, in contrast to the observation of an abrupt increase prior to fatigue failure (Fig. 2).

Fig. 5 shows the fractional change in contact electrical resistance during cyclic shear loading at a shear stress amplitude of 0.97 MPa (lower than that of Fig. 2). The resistance showed the first abrupt increase after 22–48 cycles (the particular cycle depending on the sample), and another abrupt increase at bond failure, which occurred after 69–92 cycles (the particular cycle depending on the sample).

Fig. 6 shows the fractional change in contact electrical resistance during cyclic shear loading at a shear stress amplitude of 0.81 MPa (lower than that of Fig. 4). The resistance abruptly increased after 557–690 cycles (depending on the sample) due to bond degradation, which was not visually observable. Bond failure did not occur up to 1300 cycles, at which testing was stopped.

Comparison of Figs. 2, 5 and 6) shows that a higher stress amplitude caused bond degradation and bond failure to occur at lower numbers of cycles, as expected.
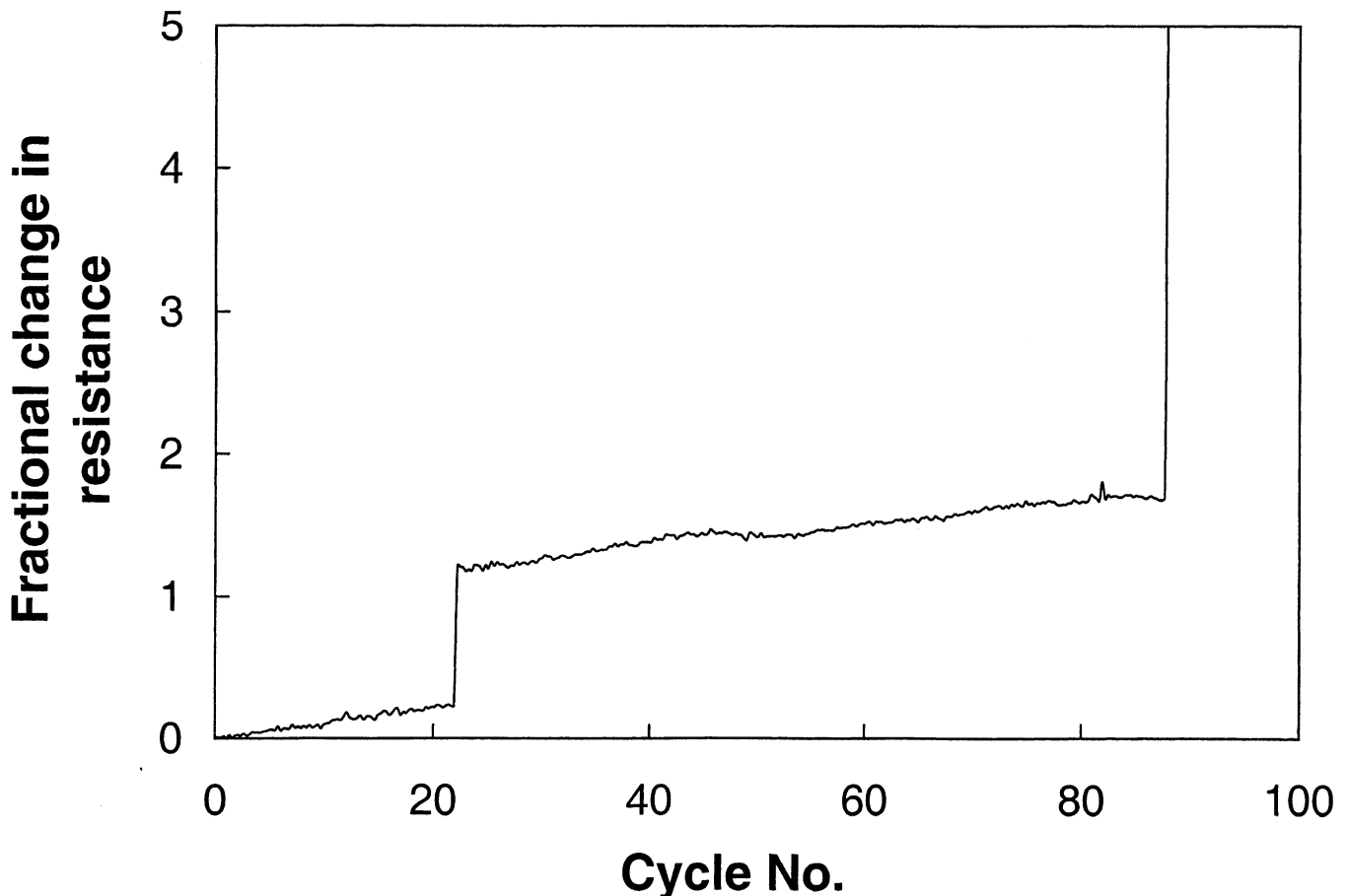

Fig. 5. Variation of the fractional contact resistance change with cycle number during cyclic shear loading at a shear stress amplitude of 0.97 MPa up to bond failure.
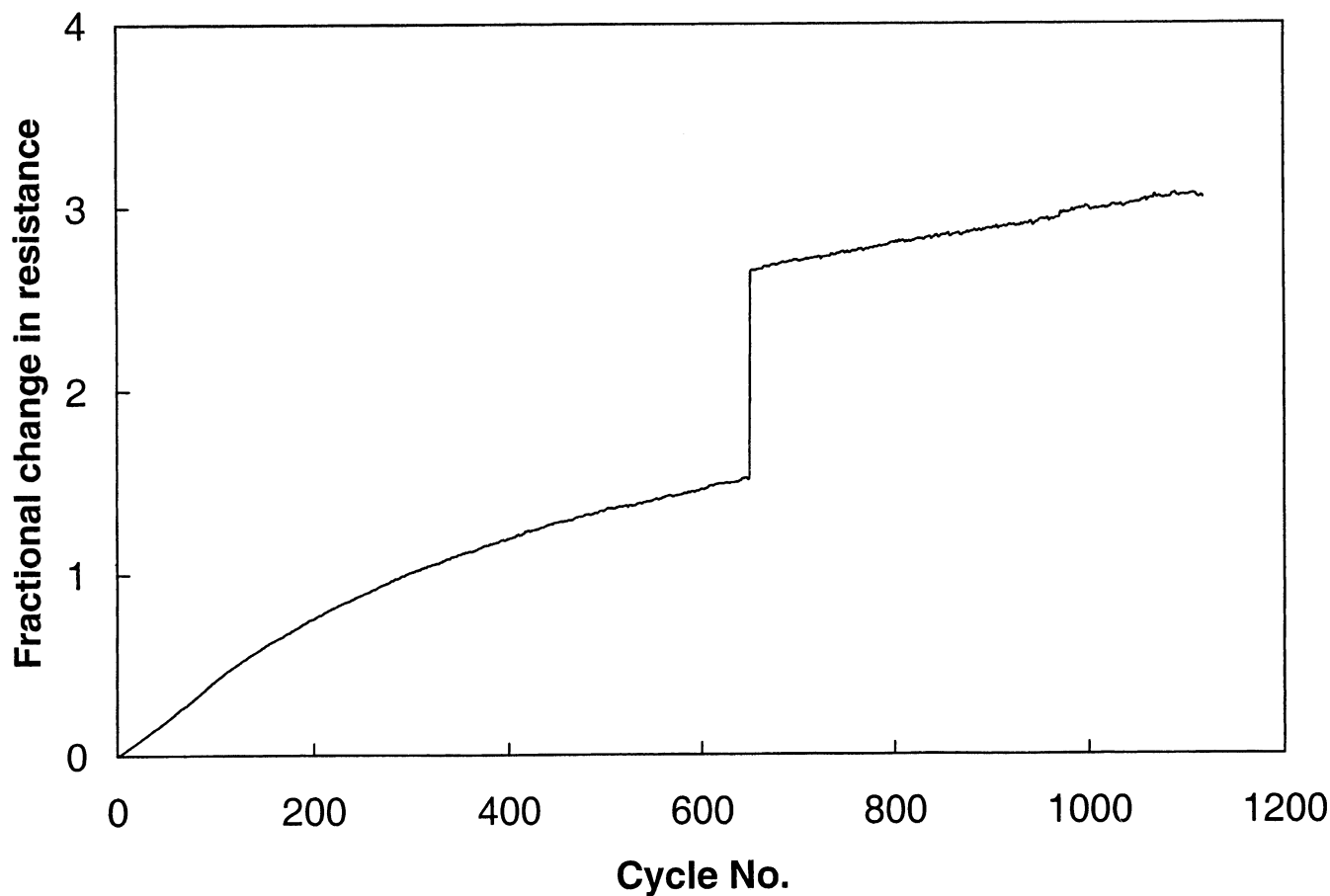
Fig. 6. Variation of the fractional contact resistance change with cycle number during cyclic shear loading at a shear stress amplitude of 0.81 MPa. The test was stopped prior to bond failure.

The abrupt increase in resistance due to bond degradation (not bond failure) (Figs. 2, 5 and 6) provides a method of monitoring bond quality nondestructively in real time during dynamic loading. In contrast, bond strength measurement by mechanical testing is destructive. The bond degradation is attributed to fatigue. This interpretation is consistent with the absence of an abrupt resistance increase during static loading prior to failure.

4. Conclusions

Degradation of the bond between old and new mortar under cyclic shear loading was observed nondestructively by measuring the contact electrical resistance of the joint. Degradation due to fatigue and causing decrease in bond strength, though causing no visually observable damage, was indicated by an abrupt increase in the resistance. It occurred at a small fraction of the fatigue life. Bond failure was also accompanied by an abrupt increase in resistance. Under static loading, no abrupt increase in resistance was observed prior to failure.

References

[1] G.K. Ray, Repairing concrete pavements, Concr. Int.: Des. Constr. 9 (6) (1987) 24–28.

[2] E.K. Schrader, Mistakes, misconceptions, and controversial issues concerning concrete and concrete repairs, Concr. Int.: Des. Constr. 14 (11) (1992) 54–59.

[3] C. Ozyildirim, Fly ash, silica fume, slag, and natural pozzolans in concrete, in: V.M. Malhotra (Ed.), ACI SP-132, American Concrete Institute, Detroit, 1992, p. 1287.

[4] M.D. Luther, Silica-fume (microsilica) concrete in bridges in the United States, Transp. Res. Rec. (1204) (1988) 11–20.

[5] D.G. Manning, J. Ryell, Decision criteria for the rehabilitation of concrete bridge decks, Transp. Res. Rec. (762) (1980) 1–9.

[6] L. Calvo, M. Meyers, Overlay materials for bridge decks, Concr. Int.: Des. Constr. 13 (7) (1991) 46–47.

[7] J.K. Bhargava, Applications of polymer concrete, in: D.W. Fowler, L.E. Kukacka (Eds.), ACI SP-69, American Concrete Institute, Detroit, 1981, p. 205.

[8] P.-W. Chen, X. Fu, D.D.L. Chung, Improving the bonding between old and new concrete by the addition of carbon fibers to the new concrete, Cem. Concr. Res. 25 (3) (1995) 491–496.

[9] P.-W. Chen, D.D.L. Chung, Carbon fiber reinforced concrete as an electrical contact material for smart structures, Smart Mater. Struct. 2 (1993) 181–188.

[10] S. Wen, D.D.L. Chung, Electric polarization in carbon fiber reinforced cement, Cem. Concr. Res. 31 (2) (2001) 141–147.