



Communication

Concrete-concrete pressure contacts under dynamic loading, studied by contact electrical resistance measurement

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Abstract

A mortar–mortar contact was studied under dynamic loading at different compressive stress amplitudes by measuring the contact electrical resistance. Irreversible decrease in the contact resistance upon unloading was observed at a low stress amplitude (5 MPa) due to local plastic deformation at the asperities at the interface. Irreversible increase in the contact resistance at the maximum stress was observed, probably due to debris generation; it was more significant at a higher stress amplitude (15 MPa). At a stress amplitude of 15 MPa, irreversible increase in the contact resistance upon unloading was observed in the first four loading cycles, probably due to severe debris generation. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Many concrete structures involve the direct contact of one cured concrete element with another, such that one element exerts static pressure on the other due to gravity. In addition, dynamic pressure may be exerted by live loads on the structure. An example of such a structure is a bridge involving slabs supported by columns, with dynamic live loads exerted by vehicles traveling on the bridge. Another example is a concrete floor in the form of slabs supported by columns, with live loads exerted by people walking on the floor. The interface between concrete elements that are in pressure contact is of interest, since it affects the integrity and reliability of the assembly. For example, deformation at the interface affects the interfacial structure, which can affect the effectiveness of load transfer between the contacting elements and can affect the durability of the interface to the environment. Moreover, deformation at the interface can affect the dimensional stability of the assembly. Of particular concern is how the interface is affected by dynamic loads. However, little attention, if any, has been previously given to the study of this interface.

Effective study of the interface between concrete elements that are in pressure contact and under dynamic loading requires the monitoring of the interface during dynamic loading. Hence, a nondestructive monitoring technique that provides information in real time during dynamic loading is desirable. Microscopic examination of the interface viewed at the edge cannot effectively provide interfacial information, though it can be nondestructive and be in real time. Microscopic examination of the interface surfaces after separation of the contacting elements can provide microstructural information, but it cannot be performed in real time. Mechanical testing of the interface, say under shear, can provide interfacial information, but it is destructive (unless the shear strain amplitude is within the elastic regime) and it cannot be conveniently performed in real time (due to the difficulty of having simultaneous dynamic compression and dynamic shear). The difficulties and ineffectiveness associated with these conventional techniques contribute to the scarcity of previous work on concrete-concrete pressure contacts.

In this paper, we have used contact electrical resistance measurement to monitor concrete–concrete pressure contacts in real time during dynamic pressure application. Since the surface of concrete is never perfectly smooth, asperities occur on the surface, thus causing the true contact area at the interface to be much smaller than the geometric junction area. As a consequence, the local stress at the asperities is

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much higher than the overall stress applied to the junction. The greater the true contact area is, the lower is the contact resistance. Deformation (flattening) of the asperities, as caused by the high local stress at the asperities, increases the true contact area. Therefore, the interfacial structure is changed. The contact resistance provides information on the interfacial structure, particularly in relation to the deformation at the interface. By monitoring the contact resistance in real time during loading and unloading, the extent, reversibility, and loading history dependence of the deformation at various points of loading and unloading can be investigated, thus providing new information on the structure and dynamic behavior of the interface.

Since concrete is somewhat conducting electrically, the contact resistance of the interface between contacting concrete elements can be conveniently measured by using the concrete elements as electrical leads: two for passing current and two for voltage measurement (i.e., the four-probe method), as provided by two concrete beams that overlap at 90° (Fig. 1). The volume resistance of each lead was negligible compared to the contact resistance of the junction, so the measured resistance (i.e., voltage divided by current) was the contact resistance. The contact resistance multiplied by the junction area gives the contact resistivity, which is independent of the junction area and describes the structure of the interface.

This study used mortar (with fine aggregate but no coarse aggregate) instead of concrete (with both fine and coarse aggregates). However, the interfacial effects should be quite similar for mortar and concrete.

Contact electrical resistance measurement has been previously used to study the interface between steel elements in pressure contact [1] and that between polymer elements in pressure contact [2], as these pressure contacts are encountered in mechanical fastening, in which loading and unloading correspond to fastening and unfastening. Contact electrical resistance measurement has also been used previously

to study the interface between laminae in a carbon-fiber polymer-matrix composite laminate [3] and to study the joint obtained between thermoplastic elements by autohesion [4,5]. In the field of concrete, contact electrical resistance measurement has been used previously to study the joint between old and new concrete [6], since this joint is relevant to the repair of concrete structures. It has also been used to study the interface between concrete and steel [7,8] and that between cement paste and carbon fiber [9,10]. However, contact electrical resistance measurement has not been previously used to study the interface between cured concrete elements.

Pressure contacts between steel elements differ in their dynamic behavior from those between polymer elements due to the tendency of steel to undergo surface oxidation and strain hardening, and the absence of these phenomena in the polymer case [1,2]. Since concrete is more brittle than steel or polymer, pressure contacts between concrete elements are expected to differ in their dynamic behavior from those involving steel or polymer elements, as indeed is observed in this work, which is an extension of the prior work on steel [1] and polymer [2] to concrete.

2. Experimental methods

The cement used was Portland cement (Type I) from Lafarge Corp. (Southfield, MI, USA). The fine aggregate used was natural sand (all passing #4 U.S. sieve, 99.9% SiO₂); the particle size analysis of the sand is shown in Fig. 1 of Chen and Chung [11]; no coarse aggregate was used, and the sand/cement ratio was 1.0. The water/cement ratio was 0.35. A water-reducing agent (TAMOL SN, Rohm and Haas Co., Philadelphia, PA, USA; sodium salt of a condensed naphthalenesulphonic acid) was used in the amount of 1% of the cement weight.

All ingredients were mixed in a rotary mixer with a flat beater. After pouring into molds, an external vibrator was used to facilitate compaction and decrease the amount of air bubbles. The samples were demolded after 24 h and then cured in a moist room (relative humidity = 100%) for 28 days.

The surfaces of the mortar strips had been mechanically polished by 600-grit sandpaper, in which the average abrasive SiC particle size was 25 μm. Two rectangular strips of mortar of similar size and shape (90.0 × 14.0 × 13.3 mm and 95.0 × 14.2 × 13.9 mm) were allowed to overlap at 90° to form a nearly square junction (13.9 × 13.3 mm), as illustrated in Fig. 1. The junction was the joint under study. Uniaxial compression (corresponding to loading) was applied at the junction in the direction perpendicular to the junction, using a screw-action mechanical testing system (Sintech 2/D, Sintech Research Triangle Park, NC, USA) while the contact electrical resistivity of the junction was measured. Copper wires were applied around the mortar strips together with silver paint to make the electrical contacts between mortar strips and the external electronic mea-

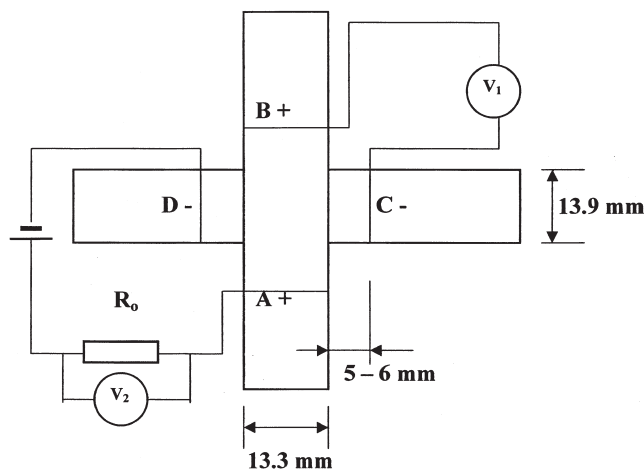


Fig. 1. Sample configuration for contact electrical resistance measurement.

surement device. To measure the contact resistivity, a DC power source and a standard resistor R_o with resistance of $30.4\text{ M}\Omega$ were used. A DC current was applied from A to D, so that the current traveled down the junction from the top mortar strip to the bottom strip. The voltage between B and C, V_1 , as well as the voltage across the standard resistor, V_2 , were measured using a Keithley 2002 multimeter (Keithley Instruments, Inc., Cleveland, Ohio). V_1 was the voltage across the junction between the top and bottom strips and V_2 was used to measure the current passing from A to D. The use of two current probes (A and D) and two voltage probes (B and C) corresponds to the four-probe method of resistance measurement. The voltage divided by the current yielded the contact resistance of the junction. This resistance, multiplied by the junction area, gave the contact resistivity.

3. Results and discussion

Fig. 2 shows the variation in resistance and stress during cyclic compressive loading at a stress amplitude of 5.0 MPa . The compressive strength of the mortar was $64 \pm 2\text{ MPa}$, as determined by compressive testing of $51 \times 51 \times 51\text{ mm}$ ($2 \times 2 \times 2\text{ in}$) cubes. The stress-strain curve was a straight line up to failure. In every cycle, the resistance decreased as the compressive stress increased, such that the maximum stress corresponded to the minimum resistance and the minimum stress (zero stress) corresponded to the maximum resistance. The minimum resistance (at the maximum stress) increased slightly as cycling progressed, but the maximum resistance (at the minimum or zero stress) decreased with cycling. Due to the asperities at the interface, the local compressive stress on the asperities was much higher than the overall compressive stress. As a result, plastic deformation occurred at the asperities, which means that more contact area was created during cycling. The occurrence of deformation is supported by the crosshead displacement observed within each cycle. The displacement was greatest (i.e., most deformation) at the maximum stress within each cycle and was not totally reversible. The plastic deformation is the reason the observed electrical resistance at the minimum stress (i.e., upon unloading) decreased as cycling progressed. On the other hand, due to the brittleness of the mortar, the compressive loading probably caused fracture at some of the asperities, thereby generating debris, which increased the contact resistance. Debris generation is probably the reason for the slight increase in the contact resistance at the maximum stress as cycling progressed. After about seven loading cycles, the maximum resistance (at the minimum stress) leveled off, due to the limit of the extent of flattening of the asperities. However, the slight increase of the minimum resistance (at the maximum stress) persisted beyond the first seven cycles, probably due to the continued generation of debris as cycling progressed.

The stress amplitude in Fig. 3 is 15.0 MPa , which is higher than that in Fig. 2. The minimum resistance (at the

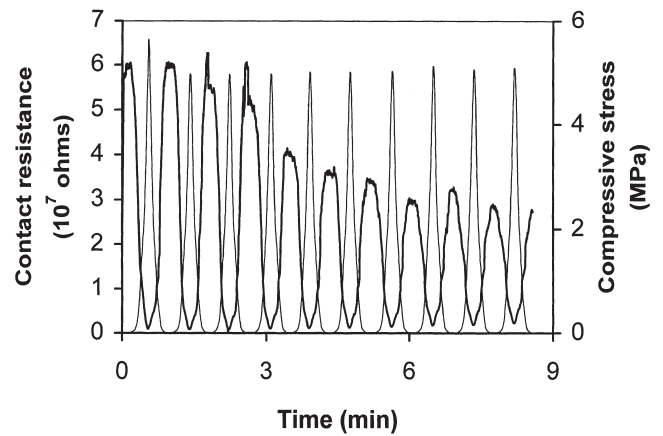


Fig. 2. Variation of contact resistance with time and of compressive stress with time during cycling compression at a stress amplitude of 5 MPa .

maximum stress) increased with cycling more significantly than in Fig. 2. This is probably due to the more significant debris generation at the higher stress amplitude. The maximum resistance (at the minimum stress) increased in the first four cycles. This is probably due to the effect of debris generation overshadowing the effect of the flattening of the asperities. After four cycles, the maximum resistance essentially leveled off, probably due to the limit of the extent of debris generation for this stress amplitude.

For mortar (this work), polymer [2], and steel contacts [1], the contact resistance all decreased as the compressive stress increased within a cycle and the contact resistance increased as the stress decreased within a cycle. In all three cases, plastic deformation occurred at the interface due to the asperities at the interface. Compared with the polymer and steel cases a significant difference for the mortar case is that the resistance curve within a cycle essentially did not change its sharpness at the maximum stress. For the polymer case, the sharpness increased with cycling due to matrix

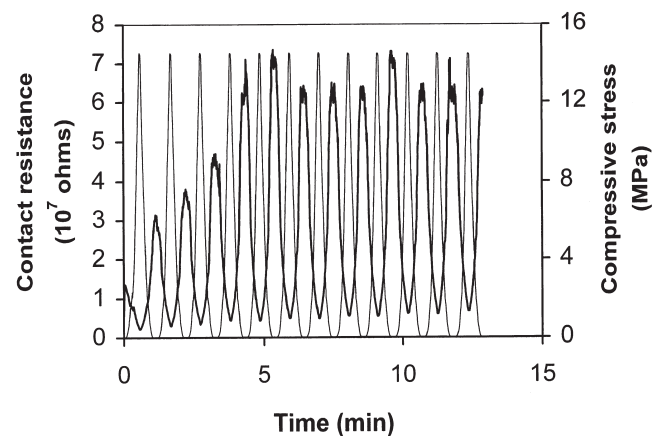


Fig. 3. Variation of contact resistance with time and of compressive stress with time during cycling compression at a stress amplitude of 15 MPa .

softening [2]. For the steel case, the sharpness decreased with cycling due to strain hardening [1]. Neither matrix softening nor strain hardening occurred in the mortar case, so the sharpness was not affected as cycling progressed for the mortar case. Another difference is that for the mortar case, the minimum resistance slightly increased with cycling, probably due to debris generation. This effect was absent in the polymer case [2], but was present in the steel case due to oxidation and/or strain hardening [1].

The results of this work mean that even at a low compressive stress amplitude of 5 MPa, the structure of a concrete–concrete contact changes during dynamic compression. Thus, the interfacial structure is dependent on the loading history. The debris generation at the interface may be of practical concern, as the load transfer between the contacting concrete elements may be affected by the debris.

4. Conclusions

A mortar–mortar contact under dynamic compressive loading was studied by measurement of the contact electrical resistance between two mortar bars during dynamic loading at different stress amplitudes. The contact resistance decreased upon compressive loading and increased upon unloading. At a low stress amplitude (5 MPa), the minimum resistance (at the maximum stress) slightly increased and the maximum resistance (at zero stress) decreased as load cycling occurred. The decrease of the maximum resistance is due to local plastic deformation at the asperities at the contact interface; the slight increase of the minimum resistance is probably due to debris generation at the interface. At a higher stress amplitude (15 MPa), the increase in the minimum resistance was more significant and even the maximum resistance increased with cycling in the first four cycles, both probably due to more severe debris generation.

Acknowledgments

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