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Interface in Mechanically Fastened Steel Joint, Studied by Contact Electrical Resistance Measurement

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A steel-to-steel joint obtained by mechanical fastening at a compressive stress of 7% (or less) of the yield strength was found to exhibit irreversible changes in the contact electrical resistance upon repeated fastening (loading) and unfastening (unloading). These changes occurred even after many cycles of fastening and unfastening, although the changes were more severe during the initial few cycles. They were primarily due to plastic deformation at asperities.

Keywords electrical resistance, fastening, interface, joint steel

1. Introduction

Mechanical fastening is one of the most widely used methods of joining material.[1,2] In fastening, a force is applied to the components to be joined, thereby preventing the components from separating in service. Fasteners include rivets, bolts, screws, nuts, and nails. Neither components nor fasteners should undergo plastic deformation in service. As a consequence, the stresses encountered by them in service are, by design, below their yield stresses and deformations are elastic. Nevertheless, the occurrence of plastic deformation locally at points of stress concentration at the joint interfaces cannot be ruled out and can affect the performance of the joint, particularly upon separation and subsequent rejoining. It is important to be able to unfasten and fasten repeatedly and still attain a joint of controlled quality. Moreover, the structure of the joint interface is affected by the plastic deformation and the interface structure affects the corrosion resistance. In addition, knowledge of the deformation is valuable for the design of joints, including the design of fasteners, and for understanding the fatigue behavior of fastened joints.[3,4] Moreover, the interfacial structure affects the corrosion resistance of the joint.[5] In spite of these considerations, there has been little work on the interfaces in fastened joints. This paper is focused on studying the interface between fastened steel, which is the most common material for both components and fasteners.

Interfaces in fastened joints are best studied in service, *i.e.*, upon fastening at different stresses and upon unfastening and repeated fastening. In this way, both elastic and plastic deformations can be studied. In contrast, studying the interfaces after unfastening would allow study of the plastic deformation only. For the purpose of an *in situ* study, this work used measurement of the contact electrical resistance of the joint interface. The greater is the extent of actual contact at the asperities across the interface, the lower is the contact resistance, if all else (such as surface defect concentration and surface oxidation extent) is not changed. On the other hand, corrosion at the interface causes the contact resistance to increase.[6] A reversible decrease in the resistance upon fastening (loading) indicates the occurrence of elastic deformation. An irreversible decrease indicates plastic deformation. In addition to providing fundamental information, the resistance technique is a nondestructive method for real-time manufacturing process monitoring and joint quality control. Information on the contact resistance is also relevant to resistance welding.

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2. Experimental Methods

The steel used was low carbon steel that had been mechanically polished by 600-grit sandpaper, in which the average SiC abrasive particle size was 25 μm. Two rectangular strips of steel (20.0 × 11.7 × 6.0 mm) were allowed to overlap at 90° to form a square junction (11.7 × 11.7 mm), as illustrated in Fig. 1. The junction was the joint under study. Uniaxial compression (corresponding to the fastening load) 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), while the contact electrical resistivity of the junction was measured. To measure the contact resistivity, a DC current was applied from A to D, so that the current traveled down the junction from the top steel strip to the bottom strip. At the same time, the voltage was measured between B and C using a Keithley (Cleveland, OH) 2002 multimeter; this voltage was the voltage across the junction between the top and bottom strips. 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, which is a quantity that is independent of the area of the junction.

The compressive stress-strain curve of the steel was determined by using a hydraulic mechanical testing system (MTS Systems Corp., Eden Prairie, MN) and stressing rate of 0.965 MPa/s. The strain was measured by using an attached strain gage. The sample was 12.40 (in the stress axis) × 9.42 × 5.90 mm.

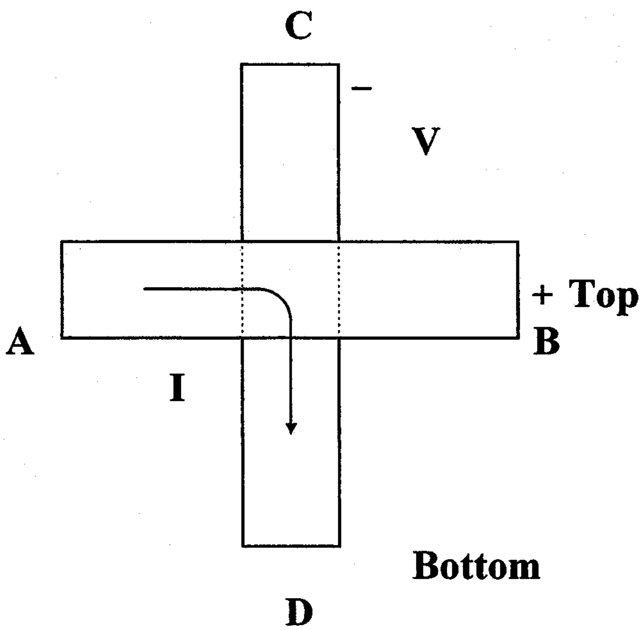

Fig. 1 Steel joint testing configuration

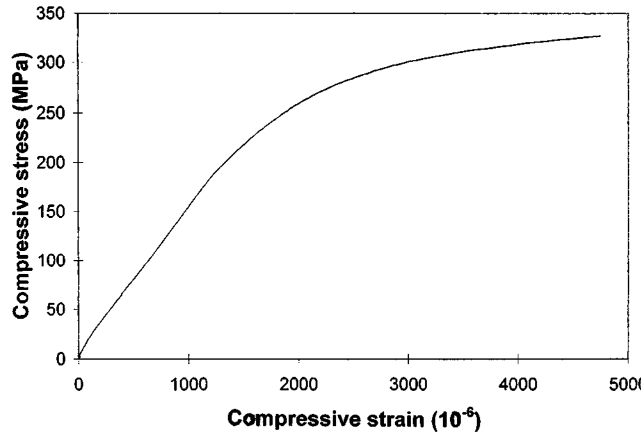

Fig. 2 Compressive stress-strain curve of steel

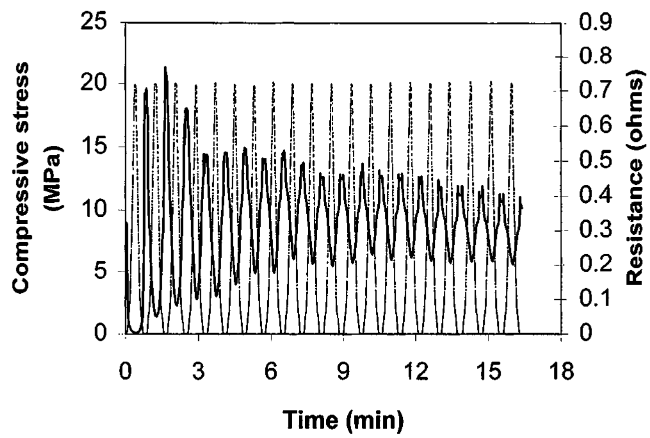

Fig. 3 Variation of contact resistance (solid curve) and stress (dashed curve) during cyclic compression at a stress amplitude of 20.0 MPa

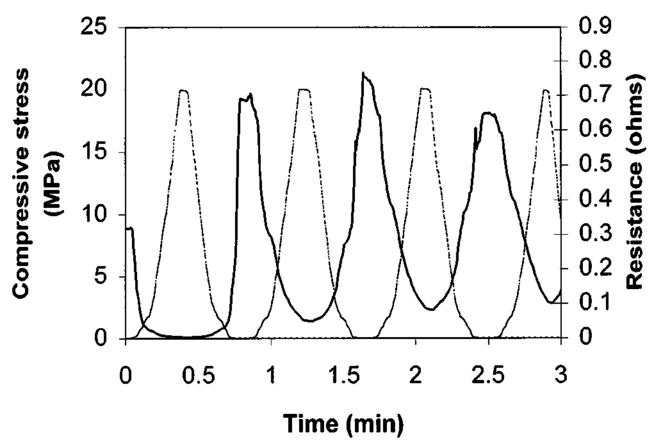

Fig. 4 Variation of contact resistance (solid curve) and stress (dashed curve) during cyclic compression at a stress amplitude of 20 MPa for the first few cycles

3. Results and Discussion

Figure 2 shows the compressive stress-strain curve of the steel. The 0.2% offset yield strength was thus found to be 300 MPa and the modulus was 150 GPa.

Figure 3 shows the variation in resistance and displacement during cyclic compressive loading at a stress amplitude of 20.0 MPa. 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 corresponded to the maximum resistance. The minimum resistance (at the maximum stress) of every cycle increased upon cycling. The maximum resistance (in the unloaded condition) of every cycle increased in the first two cycles and then decreased upon further cycling. Figure 4 shows the initial few cycles more clearly. In the first cycle, the resistance decreased abruptly even at a low stress level and the resistance subsequently attained the minimum value at the maximum stress. The stress amplitude (20.0 MPa) was much lower than the yield strength of the steel (300 MPa). However, due to the small area of the asperities at the interface, the local stress on the asperities was much higher than the applied stress. The local stress probably exceeded the yield strength of the steel, thus resulting in local plastic deformation. As a result, upon loading, the actual contact area at the asperities increased. In other words, the surface was flattened to a certain extent. Moreover, the contact resistivity of the flesh contact surface created by the plastic deformation is expected to be lower than the old surface, due to oxidation having occurred at the old surface. These two phenomena are believed to primarily affect the minimum resistance value at the maximum stress. Upon unloading, despite the increased contact area due to plastic deformation, the contact resistance increased, probably due to the oxidation occurring at the flesh surface. As a result, the contact resistance in the subsequent unloaded condition was even higher than the initial value. After the first loading cycle,

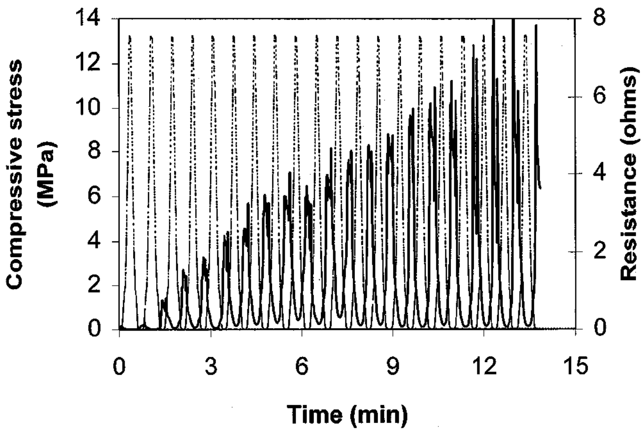

Fig. 5 Variation of contact resistance (solid curve) and stress (dashed curve) during cyclic compression at a stress amplitude of 13.2 MPa

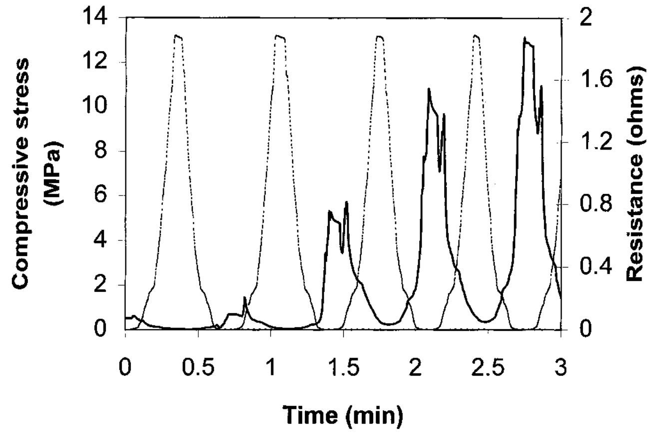

Fig. 6 Variation of contact resistance (solid curve) and stress (dashed curve) during cyclic compression at a stress amplitude of 13.2 MPa for the first few cycles

due to the strain hardening caused by the plastic deformation, further plastic deformation was more difficult. As a consequence, the resistance curve became sharper at its minimum in each cycle as cycling progressed, due to the higher and higher stress level required for the resistance to decrease during loading. Both strain hardening and surface oxidation are believed to contribute to causing the increase in the minimum resistance (at the maximum stress) cycle by cycle. This resistance increase became more gradual as cycling progressed due to the decreasing amount of further plastic deformation. On the other hand, upon unloading, due to the irreversible contact area increase, the resistance decreased cycle by cycle from the third cycle onward. However, this resistance decrease became more gradual as cycling progressed due to the decreasing amount of further plastic deformation.

Figures 5 and 6 show results obtained at a lower stress amplitude of 13.2 MPa. In contrast to Fig. 3, the resistance maximum (in the unloaded condition) increased monotonically and the resistance curve at its minimum remained blunt as cycling progressed. These characteristics are attributed to the smaller extents of strain hardening and oxidation at the lower stress amplitude and the consequent gradual buildup of strain hardening and oxidation as cycling progressed. Hence, the phenomena that dominated the first two cycles at the higher stress amplitude persisted for numerous cycles at the lower stress amplitude.

The observations reported here mean that a mechanically fastened joint exhibits a microstructure at the joint interface that changes upon fastening and unfastening, even at stress amplitudes below 7% of the yield strength and even after numerous cycles of fastening and unfastening (although the changes were more severe during the initial few cycles). The microstructure relates to the actual contact area at the asperities, the surface oxidation, and the strain hardening.

4. Conclusions

A steel-to-steel joint obtained by mechanical fastening at a compressive stress of 7% (or less) of the yield strength was found to exhibit irreversible changes in the contact electrical resistance upon repeated fastening (loading) and unfastening (unloading). The resistance at the maximum stress increased upon load cycling and the stress required for the resistance to decrease during loading increased upon cycling. Moreover, the resistance in the unloaded condition increased or decreased upon cycling, depending on the stress amplitude and the number of cycles. These effects on the resistance are attributed to plastic deformation occurring locally at the asperities of the joint interface. The plastic deformation affected the actual contact area at the asperities, as well as causing strain hardening and surface oxidation. The increase in actual contact area contributed to decreasing resistance. These effects occurred even after numerous cycles of fastening and unfastening, although the changes were more severe during the initial few cycles.

References

1. M. Diamond: *Sheet Met. Ind.,* 1989, vol. 66 (11), pp. 587 and 589.
2. P.J. Rodgers-Wilson and N.C. Williams: *Proc. Pacific Structural Steel Conf.,* New Zealand, Heavy Engineering Research Association, Manudau City, New Zealand, 1986, vol. 1, pp. 295-318a.
3. J.D. DiBattista, D.E.J. Adamson, and G.L. Kulak: *J. Struct. Eng.—ASCE,* 1998, vol. 124 (7), pp. 792-97.
4. Y.L. Xu: *J. Struct. Eng.—ASCE,* 1995, vol. 121 (3), pp. 389-98.
5. H.E. Townsend, C.D. Gorman, and R.J. Fischer: *Mater. Performance,* 1999, vol. 38 (3), pp. 66-70.
6. E. P. Fowler: IEE Conf. Publ. No. 396, IEE, Stevenage, England, 1994, pp. 125-31.