Irreversible Structural Change at the Interface Between Components During Fastening

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At compressive stresses much below the yield stress, damage of the passive film on stainless steel fasteners occurs upon repeated fastening and unfastening of the mechanical joint.

Degradation of the interface in mechanically-fastened stainless steel joints can result from repeated fastening at various compressive stresses much below the yield stress.

This degradation is often indicated by an increase in the contact electrical resistance of the interface, and can be attributed to damage of the passive film found on stainless steel and the consequent surface oxidation. The higher the compression stress amplitude, the fewer the stress cycles for the damage to start.

The effects of plastic deformation at the asperities can be observed, particularly at low stress amplitudes. At high stress amplitudes, the effects of passive film damage dominates.

Study of the Interface Between Fastened Steels

Mechanical fastening is one of the most widely used methods of joining materials.[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 interface 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 surface is affected by the plastic deformation and the interface structure affects the corrosion resistance. And knowledge of the deformation is valuable for the design of joints, including design of fasteners as well as for understanding the fatigue behavior of the fastened joint.[3, 4] Moreover, the interfacial structure affects the corrosion resistance of the joint.[5] Despite these considerations, there has been little work on the interfaces in fastened joints.

This article focuses on a study of the interface between fastened steel (the most common material for both components and fasteners). Stainless steel is different from carbon steel in that it has a passive film,[6-13] which is important to the corrosion resistance of stainless steel. The effect of repeated fastening and unfastening on the passive film is of concern.

Interfaces in fastened joints are best studied in service (repeated fastening/unfastening) so that 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 more the actual contact at the asperities across the interface, the lower the contact of resistance, if all else (such as surface defect concentration and surface oxidation) is not changed. And corrosion at the interface causes contact resistance to increase.[6] A reversible decrease in resistance upon fastening (loading) indicates 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.

Study Methods

The steel used in the study was 304 stainless steel (annealed, modulus of 193 GPa (28 million psi) and tensile yield strength of 330 MPa (47,862 psi).[14] It was mechanically polished by 600-grit sandpaper where average SiC abrasive particle size was 25μm (0.98 mil). Two rectangular strips of stainless steel measuring 47 x 11.7 x 1.40 mm (1.85" x 0.46" x 0.06") and 42 x 11.2 x 1.40 mm (1.7" x 0.44" x 0.06") were overlapped at 90° to form a square junction of 11.7 x 11.2 mm (0.46" x 0.44") as seen in **Figure 1**. The junction was the joint under study.

Uniaxial compression (corresponding to fastening load) was applied at the junction, perpendicular to the junction, using a screw-action mechanical testing system, 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 travelled down the junction from the top steel strip to the bottom strip. 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. This resistance, multiplied by junction area, gave contact resistivity (a quantity that is independent of the area of the junction).

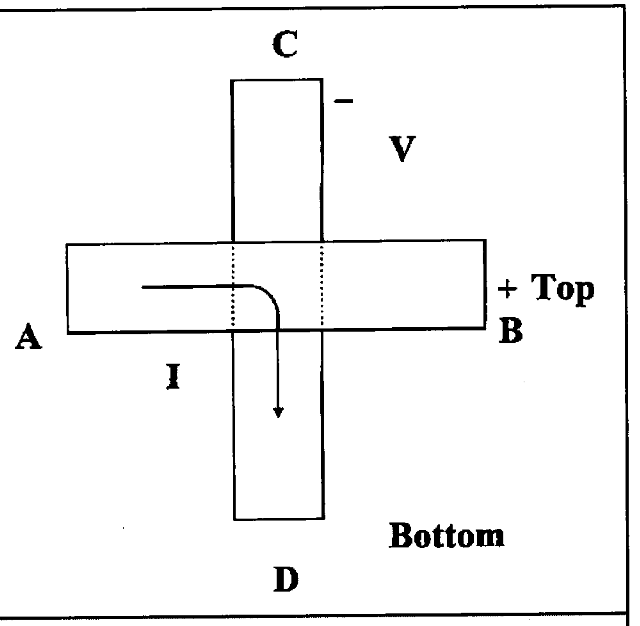

Fig. 1 — Steel joint testing configuration.

Results & Discussion

Figure 2 shows variation in resistance and displacement during cycle compressive loading at stress amplitude of 3.5 MPa (508 psi). In every cycle, the resistance decreased as compressive stress increased, such that max stress corresponded to minimum resistance and minimum stress corresponded to maximum resistance (**Figure 2a**). Max resistance (in unload condition) of every cycle decreased upon stress cycling for the first seven cycles and then leveled off (**Figure 2a**) due to plastic deformation that was especially significant during the first few cycles. This minimum resistance (at maximum stress) of every cycle increased slightly upon cycling (**Figure 2b**), likely due to strain hardening at asperities.

Figure 3 shows results obtained during cycling compressive loading at stress amplitude of 14 MPa (2031 psi). The maximum resistance (in unloaded condition) of every cycle increased upon stress cycling, such that the increase was not significant until after 13 cycles (**Figure 3a**). The increase is due to the damage of the passive film and consequent surface oxidation. The minimum resistance (at the maximum stress) of every cycle increased slightly upon cycling (**Figure 3b**), probably due to strain hardening.

Figure 4 shows results obtained at a stress amplitude of 28 MPa (4061 psi). The max resistance (in unloaded condition) of every cycle increased upon stress cycling, such that the increase was drastic after about seven cycles (**Figure 4a**). The increase is attributed to passive film damage. It was more drastic and occurred earlier in **Figure 4** than in **Figure 3**, because of the higher stress amplitude. The minimum resistance (at the maximum stress) of every cycle increased slightly upon cycling, such that the variation was irregular after eight cycles (**Figure 4b**). The irregularity is due to the severe damage of the passive film and the consequent severe oxidation.

The higher the stress amplitude, the lower is the number of stress cycles for passive film damage to start. At the lowest stress amplitude of 3.5 MPa (508 psi), passive film damage was not observed up to 30 cycles.

Comparison of the results above on stainless steel to those of carbon steel shows that the carbon steel joint is dominated by effects associated with plastic deformation and the stainless steel joint is affected by passive film damage. The passive film's effect is absent in the carbon steel joint, due to the absence of the passive film. Effects of plastic deformation and strain hardening are much more for carbon steel than stainless steel, as expected from carbon steel's lower yield.

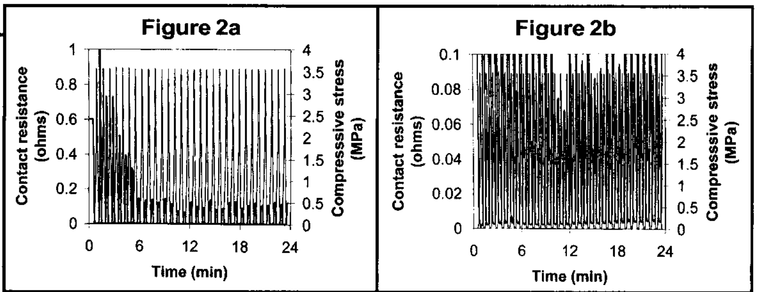

Fig. 2 — Variation of contact resistance (thick curve) and stress (thin curve) during cyclic compression at a stress amplitude of 3.5 MPa (508 psi).

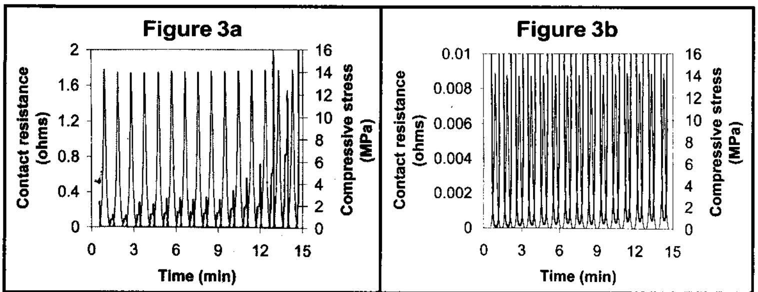

Fig. 3 — Variation of contact resistance (thick curve) and stress (thin curve) during cyclic compression at a stress amplitude of 14 MPa (2031 psi).

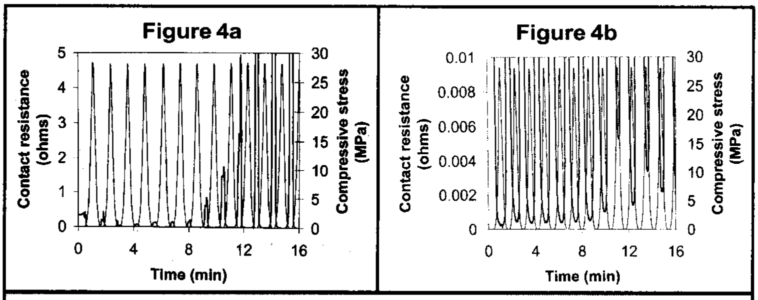

Fig. 4 — Variation of contact resistance (thick curve) and stress (thin curve) during cyclic compression at a stress amplitude of 28 MPa (4061 psi).

Conclusion

At compressive stresses much below the yield stress, damage of the passive film on stainless steel occurs upon repeated fastening and unfastening of a stainless steel joint. The higher the compressive stress, the more is the severe damage and the lower the number of stress cycles necessary for damage to start. The damage leads to surface oxidation, and hence, an increase in the contact electrical resistance of the joint interface. Plastic deformation at the asperities occurs, but it is less significant than that in a carbon steel joint.

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