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Fretting Fatigue of Galvanised Steel Roping Wire

Fatigue au frottement des câbles métalliques en fils d'acier galvanisés

Reibermüdung galvanisierter Stahldrahtseile

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SUMMARY

Both hot-dipped and drawn galvanised wire show a marked increase in fatigue strength under fretting conditions in air and artificial seawater. In air the zinc layer accomodates the fretting movement due to its capacity for plastic deformation. The drawn galvanised wire is superior to the hot-dipped beause the final drawing operation closes up porosity and other defects. In seawater the cathodic protection provided by the zinc is the operative factor.

RÉSUMÉ

Les fils d'acier galvanisés à chaud aussi bien que ceux zingués retréfilés font preuve d'une résistance à la fatigue nettement accrue, dans des conditions de frottement à l'air et dans l'eau de mer artificielle. Dans l'air, la couche de zinc absorbe le mouvement de friction grâce à sa capacité de déformation plastique. La supériorité des fils zingués retréfilés sur ceux galvanisés par trempage à chaud provient de la fermeture des pores et d'autres défauts de surface pendant le processus d'étirage. Dans l'eau de mer, la couche de zinc assure une protection cathodique déterminante.

ZUSAMMENFASSUNG

Sowohl heißgetauchte als auch gezogene galvanisierte Drähte zeigen eine deutlich gesteigerte Ermüdungsfestigkeit unter Reibbedingungen an der Luft und in künstlichem Meerwasser. An der Luft nimmt die Zinkschicht die Reibbewegung mittels plastischer Verformung auf. Die Überlegenheit gezogener galvanisierter Drähte gegenüber heißgetauchten ist auf den Verschluß von Poren und anderen Fehlstellen im Ziehprozeß zurückzuführen. In Meerwasser ist der kathodische Schutz durch das Zink entscheidend.

1. INTRODUCTION

All steel ropes, whatever their construction, contain multitudinous inter-wire contacts. In stranded ropes and in particular in single strand ropes where the wires are arranged in close-packed layers with succeeding layers wound in opposing sense, the inter-wire contacts are of two distinct types. Between wires in the same layer the contact is a line contact, but between wires in adjacent layers the contact is angled and is usually referred to as a "trellis" contact. When such a rope is under tension and subjected to fluctuating stresses, there is the possibility of oscillatory relative motion of small amplitude at such contacts resulting in fretting damage. Fig. 1 shows a fatigue failure resulting from such damage. In the particular application considered in this paper, the rope was a single strand rope containing several hundred wires of diameter 5mm, and its function was as a mooring rope for an offshore oil rig. Although the rope was sheathed in polythene the possibility had to be considered that damage might be caused to the sheathing and seawater gain access to the steel rope. It is thought that the experience gained with this type of rope could well be of relevance to ropes used in suspension bridges, although it is unlikely that bridge ropes would ever be immersed in seawater, they could nevertheless be operating in severe corrosive conditions in coastal areas or regions of industrial pollution. There is evidence, however, that fretting in bridge ropes has a dominating influence on the extent of fatigue damage [1].

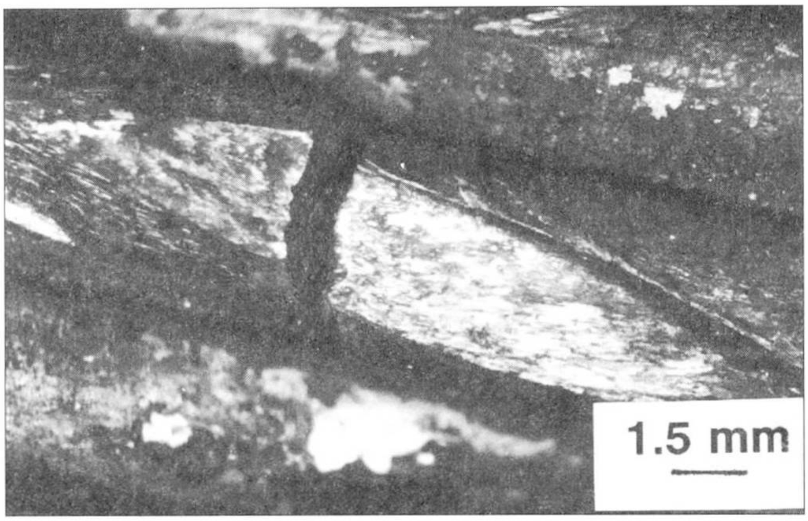

Fig. 1 Failure in a wire due to fretting at a trellis contact.

The mooring rope is under tension but experiences fluctuating stresses resulting from the movement of the surrounding seawater.

In the present work the behaviour of inter-wire contacts was investigated when a single wire was subjected to fluctuating tension. An important factor in such contacts was found to be the location of the contact in relation to the residual stress field in the surface of the wire [2]. In the work described in this paper, the contacts were made at the ends of a diameter of the wire perpendicular to the plane of the coil of the wire, where the residual stresses are the same and have a maximum tensile value. The magnitude of the residual stresses depends on the degree of reduction in the final die in the drawing process. The greater that reduction the higher the residual stresses. However, the heat-treatment experienced by the wire in hot-dipped galvanising, where the wire is passed through a bath of molten zinc, considerably modify these stresses.

2. EXPERIMENTAL

The fretting fatigue tests were carried out using a 20 kN servo-hydraulic fatigue machine. The ends of the wire were gripped in a capstan device to minimise fretting and failure at these points. Fretting was produced by clamping a pair of bridges comprising four short lengths of the same wire as the specimen on to the specimen with a proving ring which allowed the clamping load to be adjusted. The fretting device was surrounded by a transparent plastic cell which allowed the environment to be controlled. In the present case this was limited to laboratory air and seawater, the latter being continuously pumped through the cell. The experimental arrangement is shown in Fig. 2.

Tests were carried out at a frequency of 5 Hz with a constant maximum stress of 950 MPa and a variable minimum stress to give stress amplitudes of the range 120 to 400 MPa. Over this range of stress the slip amplitude varied between 3 and 10μm. The clamping load of 250 N at each contact was maintained constant in all tests.

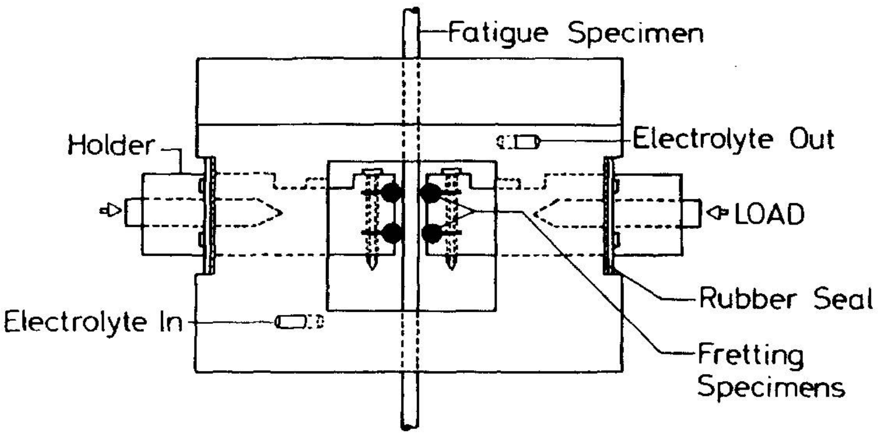

Fig. 2 Experimental rig for testing steel wires under fretting conditions.

For operation in severe corrosive conditions such as seawater it is usual to use galvanised wires. In this work two types of galvanised wire were used. The first was hot-dipped galvanised where the passage through the molten zinc bath is the final stage of production. The second type was where the wire was passed through the molten zinc prior to drawing through the final die. The thickness of the outer layer of equiaxed crystals of zinc in the two cases is 30μm for the former and 5μm for the latter. The underlying Fe-Zn alloy layer and the intermediate layer of columnar crystals is approximately the same in both cases.

The manufacturing conditions were such as to maintain the mechanical properties of the wire at a constant level whether galvanised or not galvanised, as shown in Table 1.

Breaking load N	UTS MPa	0.2% PS MPa	Hardness VHN
34000	1700	1300	520

Table 1 Mechanical Properties of Wire Samples

3. RESULTS

One effect of the galvanising process is to reduce the residual tensile stress in the wire. A specimen of the wire given the equivalent heat treatment of the galvanising process reduced the maximum residual stress from 340 Mpa to 80 MPa. The effect on the fatigue strength of the wire can be seen in Fig. 3 where the increasing residual stresses were produced by reductions in the final die of 5, 12 and 26.5%. Measurement of residual stress on the hot-dipped galvanised wire after removal of the zinc coating was found to be 125 MPa.

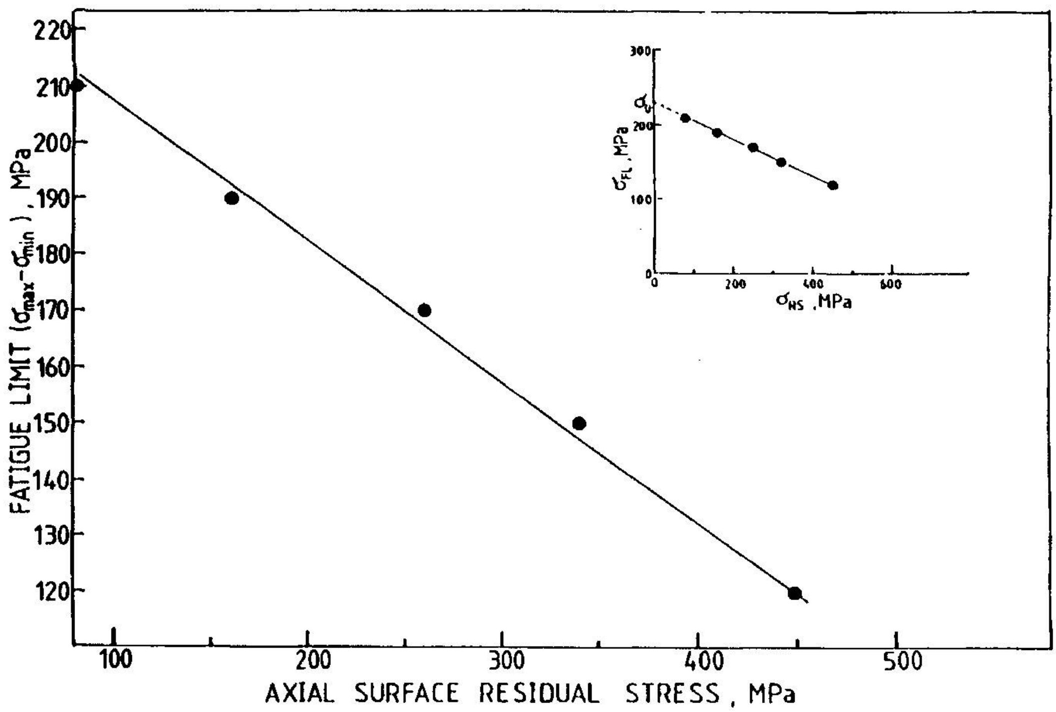

Fig. 3 Effect of axial surface residual stress on the fatigue limit of 5mm dia. steel roping wire under fretting conditions.

The effect of the two types of galvanising on the fatigue curves in air and seawater are shown in Figs. 4 and 5. It is apparent that both treatments produce approximately the same result both in air and seawater. Included in the figures are the curves for the untreated wire in the two environments. It should be noted that the untreated wire in seawater has no fatigue limit.

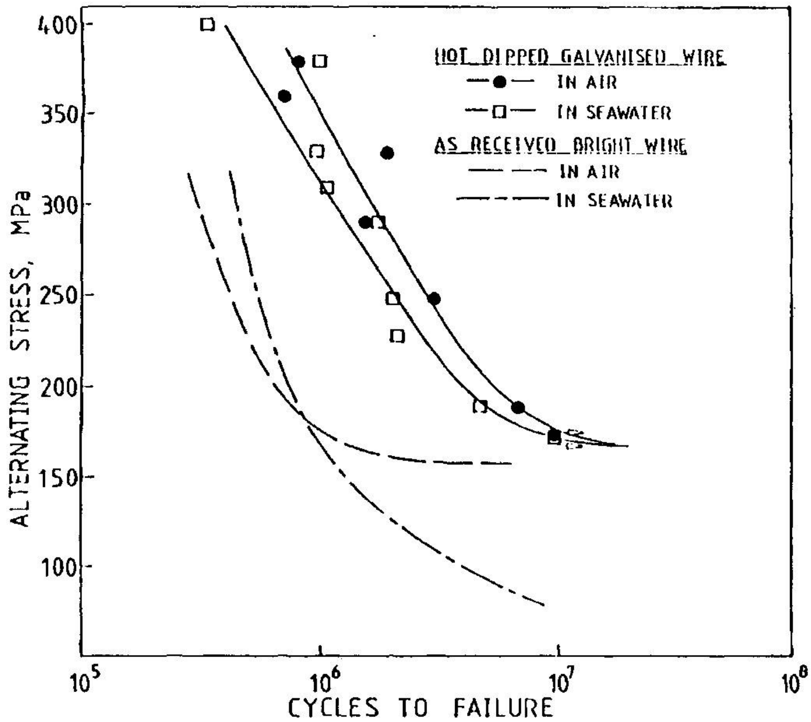

Fig. 4 Fatigue curves for hot-dip galvanised wire in air and seawater under fretting conditions.

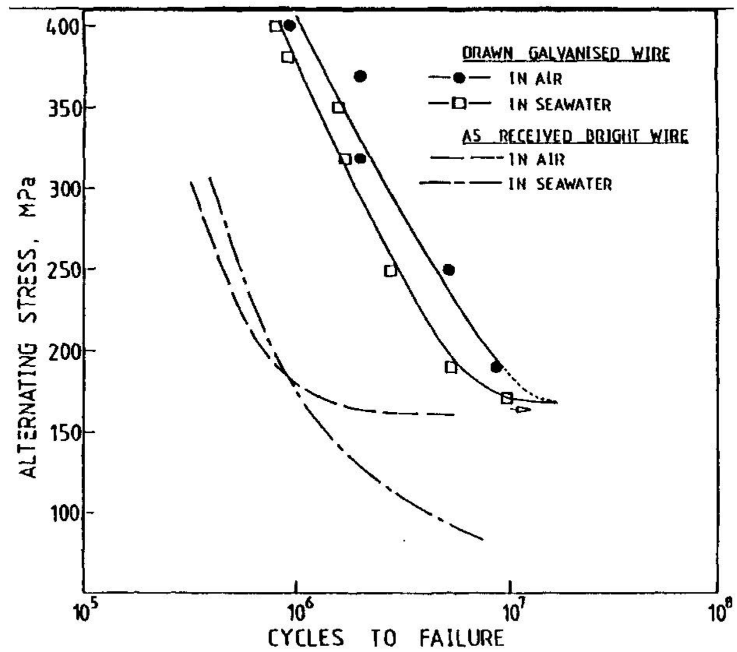

Fig. 5 Fatigue curves for drawn galvanised wire in air and seawater under fretting conditions.

Fig. 6 shows cracks developed in a pair of fretting scars. In all cases they were at the outer edge of the scar.

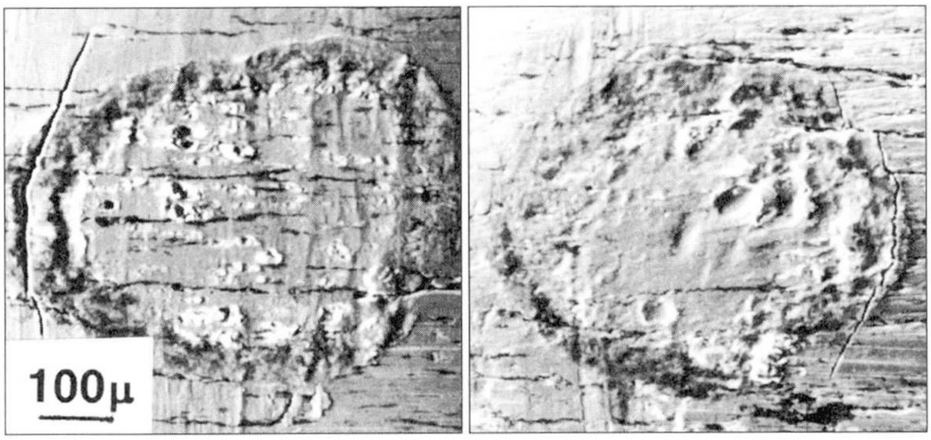

Fig. 6 Pair of fretting scars on ungalvanised wire showing fatigue cracks.

4. DISCUSSION

By making the fretting contacts at the points of maximum residual tensile stress in the surface means that the fretting results in the most severe fatigue damage. In earlier work on 1.5mm dia. wires of UTS 1900 MPa, it was found that hot-dip galvanising produced a reduction in the fatigue limit in air of the as-drawn wire of 7% [3]. This was attributed to the presence of the hard, brittle Fe-Zn alloy layer resulting from the galvanising. Fatigue curves of electrodeposited zinc coated wires showed an increase in fatigue strength depending on the thickness of the zinc layer. This increase was a linear function of the square of the coating thickness [4]. This relationship had been found with other electrodeposited metal coatings on steel [5]. In the absence of the Fe-Zn alloy layer the soft zinc coating has a protective effect against fretting.

In the present case the wires with the two types of galvanised coating both have almost the same fatigue strength as the uncoated wire in air. There is evidence that fretting causes the initiation of fatigue cracks in the Fe-Zn alloy layer which then propagate into the underlying steel. In the 1.5mm dia. wire such cracks would result in rapid failure, whereas in the larger 5mm dia. wires the crack has a much greater distance to propagate to failure. The observation in Figs. 4 and 5 that the fatigue life at alternating stresses above the fatigue limit is considerably longer in the galvanised wires than in the uncoated wire shows that the zinc coating has an appreciable effect on the overall propagation of the fatigue crack. In the case of the 1.5mm dia. wires the fatigue lives above the fatigue limit were the same for the galvanised and uncoated wires [4].

In seawater the two galvanised coatings produce a marked increase in the fatigue strength due to the cathodic protection afforded by the zinc coating. This improvement has been shown to be comparable to that produced by imposing cathodic protection of -950 mV vs. SCE [6]. Above the fatigue limit the fatigue lives in seawater are slightly shorter than in air. It has been shown earlier that cathodic protection is only effective in retarding crack growth up to a crack length of about 30μm [7]. At greater depths the crack will be propagating under the corrosive influence of the seawater and therefore at a greater rate than in air.

At alternating stresses above the fatigue limit the drawn galvanised wires have a somewhat longer fatigue life in both media. This is attributed to the drawing process, while not influencing the alloy and columnar layers, consolidates and closes up defects in the outer equiaxed layer and reducing its thickness.

5. CONCLUSION

The hot-dip and drawn galvanised wires both produce an increase in fretting fatigue life in air above the fatigue limit, but have little effect on the fatigue strength of 5mm steel wires. In seawater the fatigue strength is restored to that in air.

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