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The effect of wire rope "safety" clamps on rope terminations

Summary

Some technical regulations require an additional safety clamp to act as a 'back-up' for the filled conical socket end connection of aerial tramway ropes. This kind of clamp is sometimes also used on suspended bridges for the same purpose. The authors wondered whether this additional clamp would really increase the safety of the termination and therefore conducted a series of tests.

This paper reports on tensile fatigue tests conducted on Ø16 mm full locked coil (FLC) and six-strand ropes with and without a rope safety clamp installed. It has been found that the tensile fatigue performance of the six strand rope is *reduced* by about 60% and that of the FLC by about 80%. The authors describe the tests undertaken and discuss the failure mechanism of the ropes with the clamps installed.

1 Background

In the field of transportation of people such as an aerial tramway, safety is of the upmost importance. In cases where a filled conical socket is used as an end connection, some technical regulations concerning the carrying ropes of such systems stipulate the use of an additional clamp to provide extra safety [**1**].

Figure 1, below, shows an example of such a clamp in service on an aerial ropeway, and Figure 2 one in service on a bridge. The basic idea behind the use of the clamp is that should the filled socket fail, the clamp will provide sufficient holding force to maintain the integrity of the end connection. This is a completely different arrangement to other uses of rope clamps, for example on a winch drum where the clamp is an integral part of the assembly rather than an additional element.

Figures 1 and 2 show, that in order for the safety clamp to be effective, it has to be mounted on the rope in front of the socket, and is therefore on a section of rope which will experience the same service loading as the socket. Figure 3, (which is for another aerial ropeway) shows how the clamp is positioned within a supporting framework such that it will only support axial load should the main socket fail. The question arises as to whether the additional safety clamp really does improve safety, or whether its clamping pressure combined with the service loads will lead to accelerated wear and fatigue damage.

This paper reports the results from a study which was undertaken to investigate the effect of a rope clamp on the fatigue performance of wire rope. Two rope constructions were investigated: a six strand IWRC, and a full locked coil (FLC) rope. Whilst also reporting the results for the six strand rope, this paper will focus on the tests undertaken on the FLC rope.

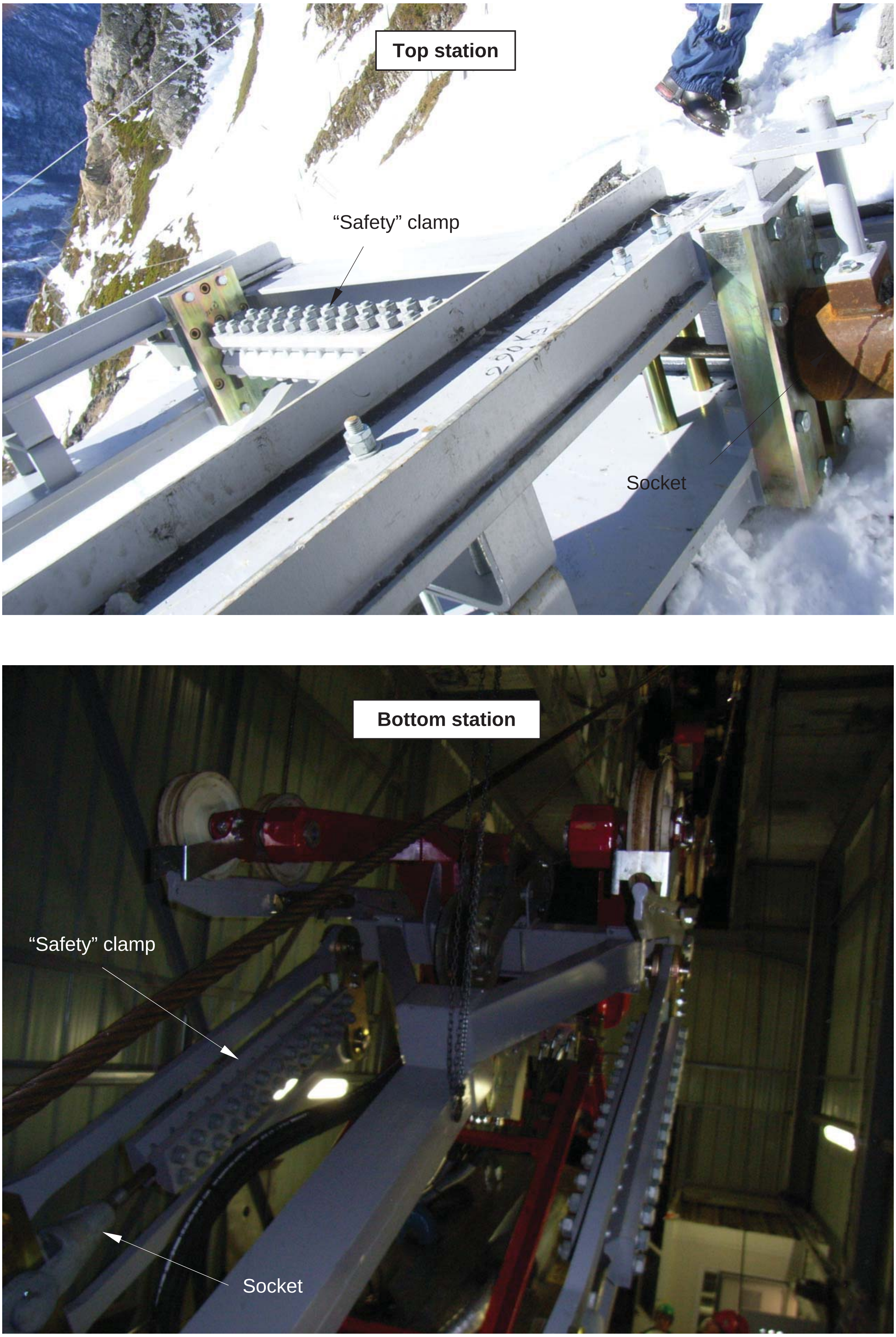


Figure 1: Showing safety clamps in service on an aerial ropeway.

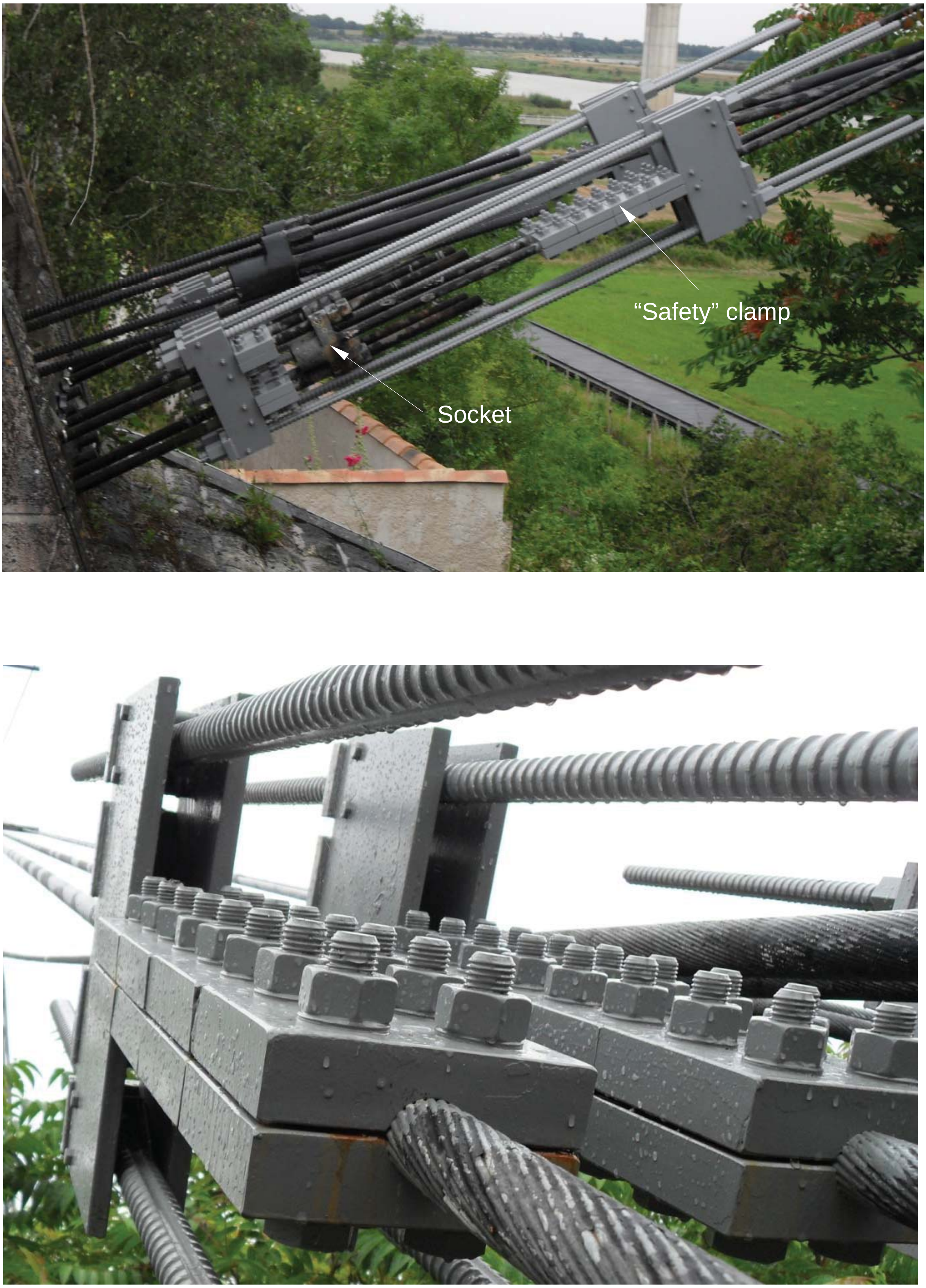


Figure 2: An example of a safety clamp employed on a cable stayed bridge.

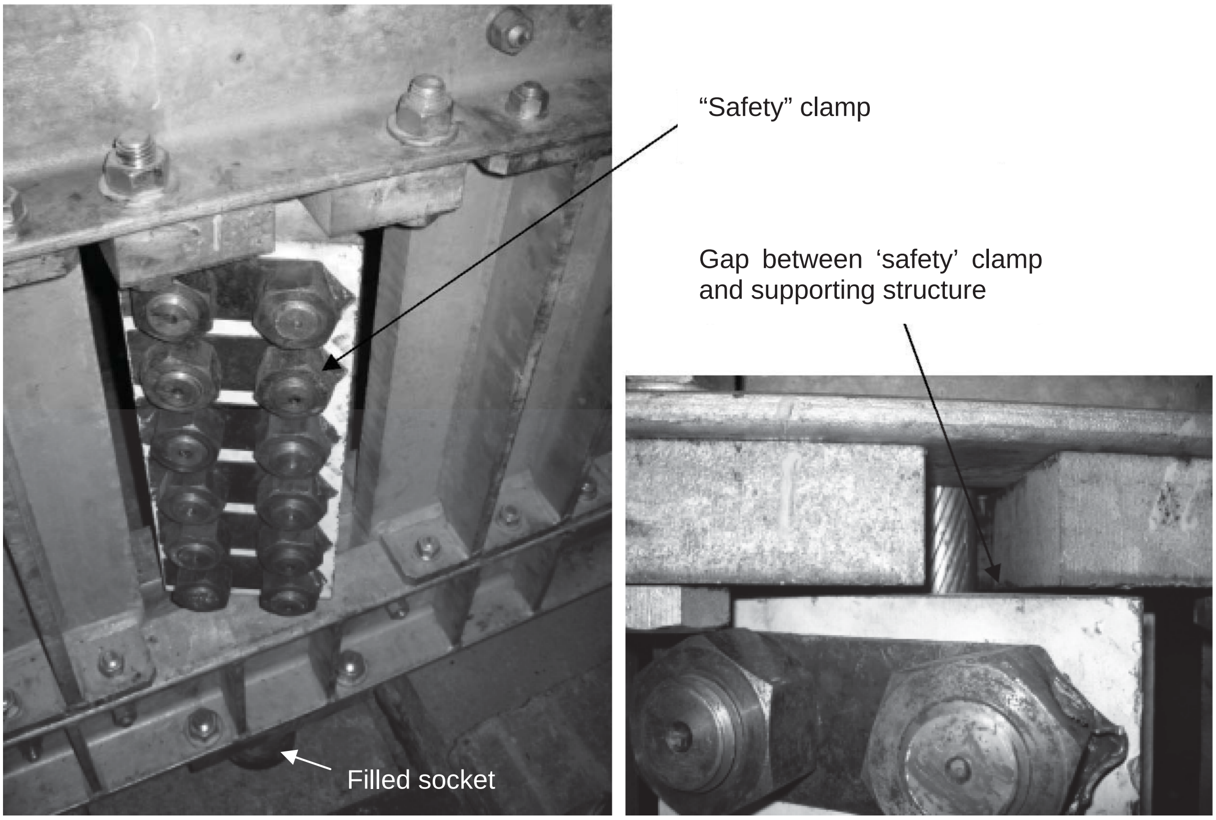


Figure 3: Showing an example of positioning of the safety clamp on an aerial ropeway installation – the clamp will only become axially loaded if the filled socket fails.

2 Design of the rope safety clamp

The standard EN12927-4 (§10 Bolted clamp) [**2**] sets out the design requirements for the rope safety clamp. The standard notes that the clamp should have cylindrical grooves with diameter in the range 1.05 – 1.1 times the nominal diameter of the rope, d, and that a total angular contact, α, in excess of 250° (see Figure 4).

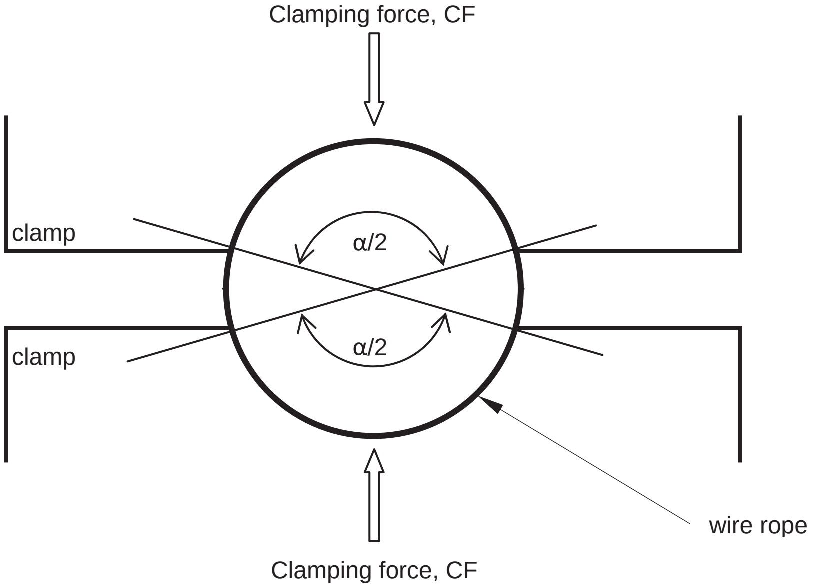


Figure 4: Section of a safety clamp showing the notation for calculating the slipping force (after [**2**]).

The mean clamping pressure, p, is given by the ratio of the clamping force, CF and the contact surface area, S (Equation 1):

$$p = \frac{2CF}{S} = \frac{2CF}{\frac{\alpha}{360}\pi dL} \qquad (1)$$

where *L* is the length of the clamp.

The slipping force *SF*, is calculated based on the clamping force, *CF*, and the coefficient of friction, *f*, (Equation 2).

$$SF = 2 \cdot CF \cdot f \qquad (2)$$

The EN standard [**2**] specifies a coefficient of friction of 0.13 for a FLC rope and 0.16 for a stranded rope. Further, the nominal clamping pressure is limited to 150 MPa for a FLC rope and 50 MPa for stranded rope. This means that the main design variable in the clamp design will be the length.

Figure 5 shows the clamp which was designed for, and used in, the tests reported here. In this design stacks of Belleville washers were used to provide an accurate clamping force. This meant that the size of the clamp (260 mm long × 150 mm wide) compared to the diameter of the rope was unusually large, to accommodate the diameter of the spring washers. By varying the configuration of the washers, the same clamp was used for both the 150 MPa and the 50 MPa clamping pressures.

The standard [**2**] also specifies that special care shall be taken to provide a radius at the exits of the clamps to avoid any sharp edges in these areas. For the test clamp a chamfer 1 mm × 45° was machined at each end of the clamp grooves (this can be seen in Figure 12).

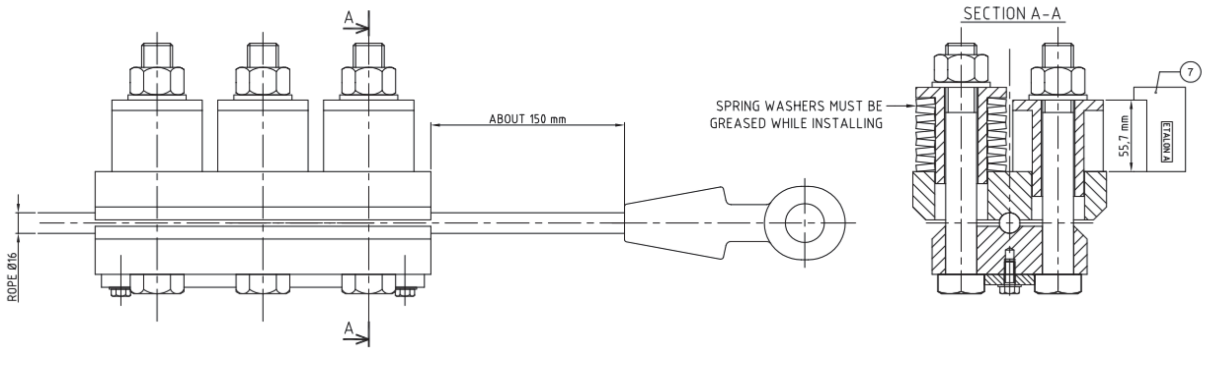


Figure 5: Rope clamp used in the test programme.

3 Test programme

The purpose of the test programme was to assess any effect of the rope clamp on the fatigue endurance of the FLC rope. Accordingly tests were undertaken on the rope in tensile fatigue with and without the clamp. (As previously mentioned, while tests were run for both six strand and FLC rope, and this paper will concentrate on the FLC rope.)

Details of the FLC rope construction are presented in Table 1 below.

Parameter		**Value**
Diameter		16 mm
Construction		1 × 37(1 + 6 + 12 + 18Z)
Lay		outer layer RH
Wire grade (N/mm^2)	round wires (1 + 6 + 12) Z wires (18): rope nominal (average):	1960 1770 1833
Wire finish		Galvanised
Manufacturer		Teufelberger Seil GmbH.
Manufacturer's Minimum Breaking load, MBL (kN)		283
Calculated Breaking load, (kN)		323

Table 1: Details of the FLC wire rope.

The 250 kN test machine at TTI Testing, Wallingford, was used for the fatigue tests. This universal tensile testing machine, with main parameters listed in Table 2, was ideally suited to the testing required.

Parameter	
Load capacity (kN)	± 250
Actuator stroke (mm)	150
Adjustable cross head for slack removal	Yes
Maximum 'day light' below crosshead (mm)	1250
Controller	M9500 SERIES
Fatigue rated	Yes

Table 2: Main parameters of the 250 kN universal testing machine at TTI Testing, Wallingford.

For the FLC rope reported here no fatigue data was available for guidance in the selection of test loads. It was decided to conduct an initial test on the FLC at 10% - 30% of calculated breaking load (323 kN), giving test loads of 32.3 kN – 113.0 kN. The tests were run at a frequency of 0.75 Hz. This allowed the test duration to be a reasonable length (10^6 cycles would take about 9 days) without being so fast as to cause adverse heating in the rope.

Where required, the clamp was installed on the rope about 150 mm above the lower termination (Figure 6). The rope was put under a nominal tension before the clamp was fitted. The Belleville washers were well greased and placed in the specified stacking configuration.

The nuts were tightened on the clamp as opposite pairs and the compression checked with digital callipers. The level of compression combined with the spring configuration was designed to produce a clamping pressure of 150 MPa (for the FLC rope). The compression was checked once again for each stack with the rope at the minimum test load of 32.3 kN.

Once the clamp was installed on the rope, the rope was marked with white paint at the top and bottom of the clamp to assess any slippage during the subsequent fatigue cycling.

It is noted that, by employing stacks of Belleville washers, less pressure is lost when the rope is subject to service loads than if the simpler bolting (such as shown in Figure 2) is used.

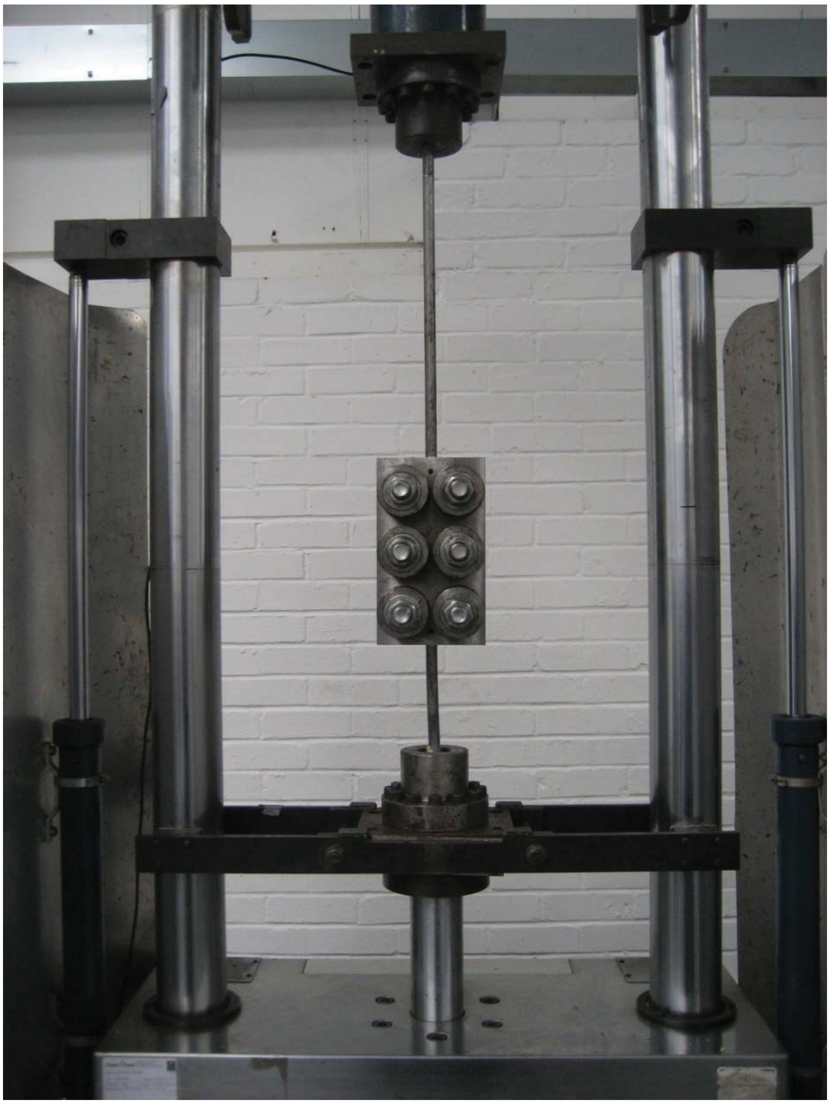


Figure 6: General view of rope safety clamp installed on a FLC rope tensile fatigue sample.

4 Results

4.1 Tensile fatigue reference test

All the FLC rope samples were made up with cast resin (Wirelock®) conical sockets. Table 3 summarises the results of the tensile fatigue tests which were undertaken. An initial tensile fatigue test (FLC01) was stopped as a termination failure after 312,420 cycles, with 10 broken Z wires at the top termination. Although not ideal as a reference test, it was decided that owing to the limited length of FLC rope available (ca. 5 m), it would be best to conduct the ‘with clamp’ test next (FLC02), and then repeat the reference test on the remaining rope.

Two further tensile fatigue tests were conducted. FLC03 was halted at 137,304 cycles, also as a termination failure. FLC04 was prepared using longer cylindrical sockets (into which the resin cone was cast directly) with a parallel section at the front to ensure that the rope stayed concentric and axial to the termination. FLC04 sustained a total of 501,227 cycles before the test machine stopped the test on a stroke trip (total sample elongation of one rope diameter).

Test number	No. of cycles	Comments
FLC01	312,420	Termination failure (10 Z wires broken at top termination)
FLC03	137,304	Termination failure
FLC04	501,227	Good result – wire breaks along sample length (650 mm)

Table 3: Summary of the results from the tensile fatigue reference tests (no clamp) fatigue loads 10-35% ABS.

The FLC04 result was considered very satisfactory. A single Z wire break was noted 230 mm above the lower termination at 321,842 cycles, and there were wire breaks along the length of the FLC sample and all clear of the terminations on completion of the test. Table 4 lists the wire breaks which were noted in the outer Z wires upon cleaning and inspection of the failed sample. It is noted that the distortion of the sample suggests that the inner layers were broken in many places, but these have not been individually recorded. Figures 7 and 8 shows appearance of the sample and close up views of the groups of wire breaks.

Position along sample (measured from lower termination) [mm]	Details of wire breaks	Comments
25	two adjacent wire breaks	near termination, but clear of socket.
99	single wire break	
230	single wire break	noted at 321,842 cycles
360	two adjacent wire breaks	
435	single wire break	
515	two wire breaks circumferentially 4 wires apart	

Table 4: Damage to the Z layer noted on tensile fatigue sample (Test FLC04) - fatigue loads 10-35% ABS - after failure at 501,227 cycles and following cleaning in degreaser.

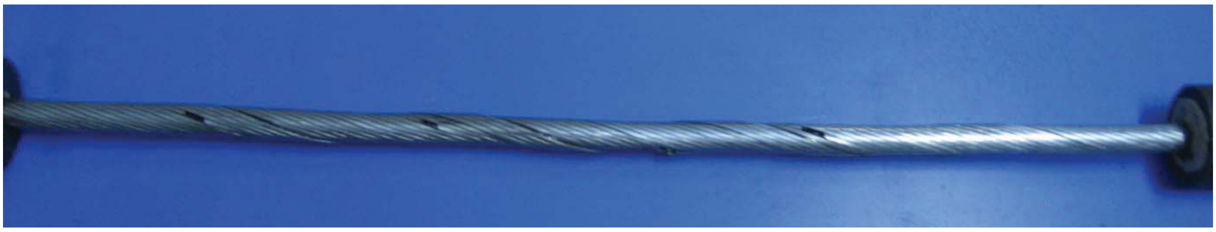
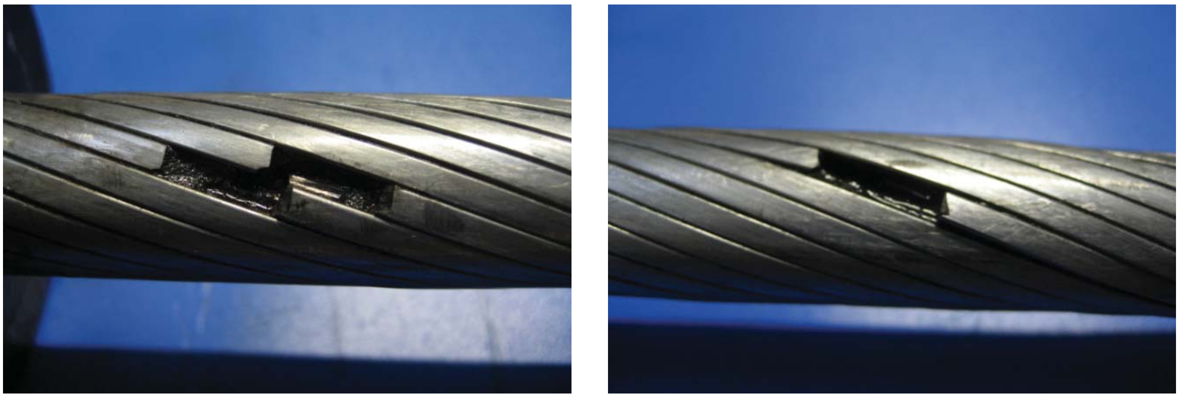
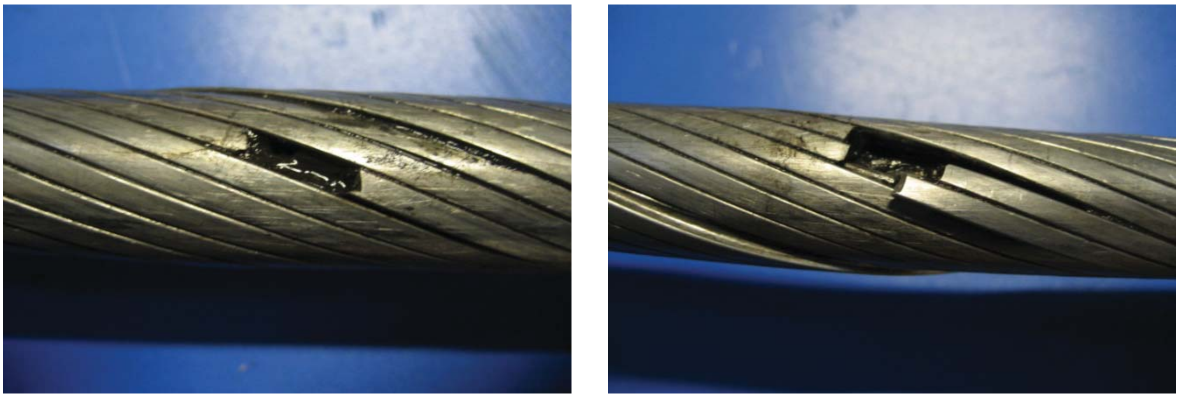


Figure 7: Appearance of the tensile fatigue sample (Test FLC04) after failure at 501,227 cycles and following cleaning in degreaser.



(a) Two wire breaks at 25 mm

(b) Single wire break at 99 mm



(c) Single wire break at 230 mm

(d) Two wire breaks at 360 mm

(e) Single wire break at 435 mm

(f) Two wire breaks at 515 mm

Figure 8: Close up view of Z wire breaks on the tensile fatigue sample (Test FLC04) after failure at 501,227 cycles and following cleaning in degreaser. Air gaps were approx. 10 mm.

4.2 Tensile fatigue with clamp

Figure 9 shows the test FLC02 with the rope clamp which failed after 102,305 cycles. Figure 10 shows the rope failure location at the bottom of the clamp with the front half removed. It can be seen that several of the Z wires (ten were counted on later inspection) and all of the inner round wires have failed. Figure 11 shows the corresponding condition of the rope at the top of the clamp. Two views are shown ‘front’ (as viewed in Figure 9) and ‘back’. A total of seven failures in the Z layer wires can be seen. It is noted that none of these wire breaks could be seen with the clamp in position as the breaks were just ‘inside’ the clamp.

Figure 9: Overview of rope failure at the bottom of the rope clamp after 102,305 cycles.

Figure 10: Clamp lower exit point at which the main failure occurred. Note the Z wires which were at the ‘sides’ of the clamp groove have not failed. Note also the fretting rouge at the position of the rope just inside the clamp.

Figure 11: Clamp upper exit point (‘front’ (left) and ‘back’ (right)). Note the wire breaks and fretting rouge at the position of the rope just inside the clamp (the edge of the clamp is marked on the front view with the white paint). It is thought that the marks on the Z wires (back view) are from the damage to the clamp from the previous tests on the six-strand rope.

Finally, Figure 12 shows the typical condition of the rope clamp groove in the area close to the ends. Note the damage to the chamfer caused by the broken Z wires which would have sprung slightly out of the rope construction. There is also some damage which was pre-existing from the earlier test on the six-strand rope.

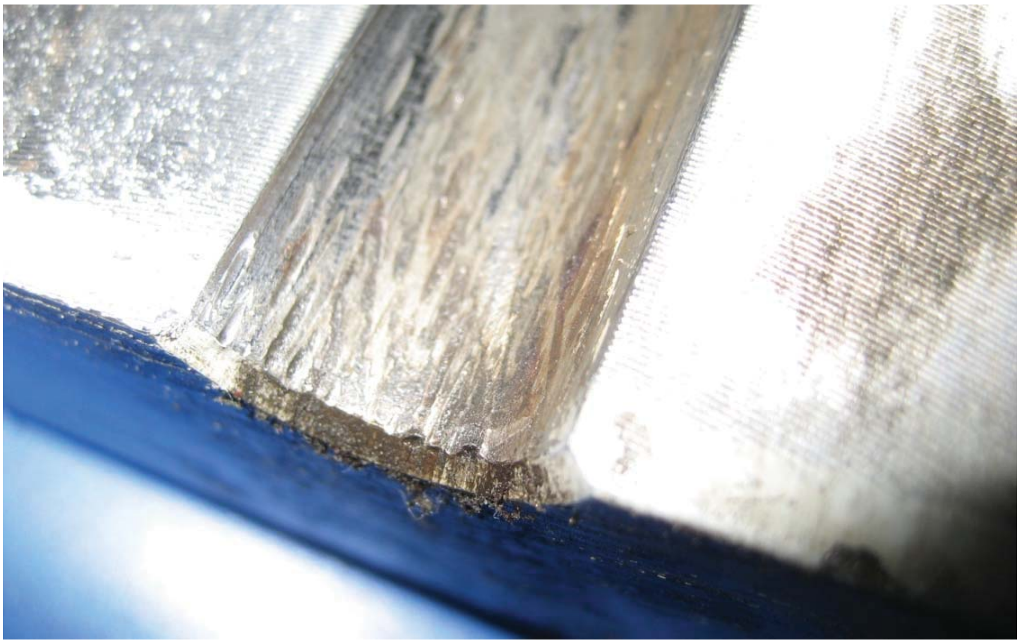


Figure 12: Typical condition of the clamp groove at the exit points after the fatigue test (FLC02).

4.3 Summary of the FLC rope tensile fatigue tests

Table 5 summarises the results of the accepted tensile fatigue tests with and without rope clamp.

Test	**Result**
Reference test (FLC04)	501,227 cycles
Clamp test (FLC02)	Rope failed after 102,305 cycles. (10 Z wires and all round wires at the bottom of the clamp.)

Table 5: Summary of the results of the FLC tensile fatigue tests.

4.4 Summary of the six strand rope tensile fatigue tests

The fatigue tests in the previous work on the six-strand rope employed the same %ABS test loads as for the FLC rope.

Unlike the FLC rope, good tensile fatigue data was available for the six strand rope. The fatigue data indicated that for the given fatigue loads, the reference endurance was 2×10^6 cycles.

The fatigue test on the rope with the clamp installed finished after 793,571 cycles (see Table 6). Thus tensile fatigue performance of the six-strand rope was reduced by an estimated 60% by operating with the clamp installed.

Test	**Result**
Reference	Available S-N data indicated a fatigue life of 2×10^6 cycles.
Clamp test (TT02)	Three strands of the rope failed at the top of the clamp after 793,571 cycles.

Table 6: Summary of the results of the six strand + IWRC tensile fatigue tests.

5 Microscopic inspection of fatigue samples

Inspection of the wire fractures in the locked coil rope samples was made using optical microscope and SEM equipment at Wire Rope Technology Aachen.

Figure 13 shows the fracture surface of one of the outer layer of shaped lock wires. It can be seen that the fatigue failure has initiated on the edge of the wire in the left hand side of the figure.

Figures 14 – 15 show views of fatigue breaks in the round internal wires. The wire in Figure 14 has two crack initiation points, one from each of neighbouring wires. Final failure has been in shear.

Figure 15 shows another internal round wire, this time with a single crack which has grown to cover about two-thirds of the wire area before final failure. Figure 16 shows surface of the failure at the transition of the crack from fatigue to a shear failure. It is interesting to note the very different appearance of the fracture surfaces.

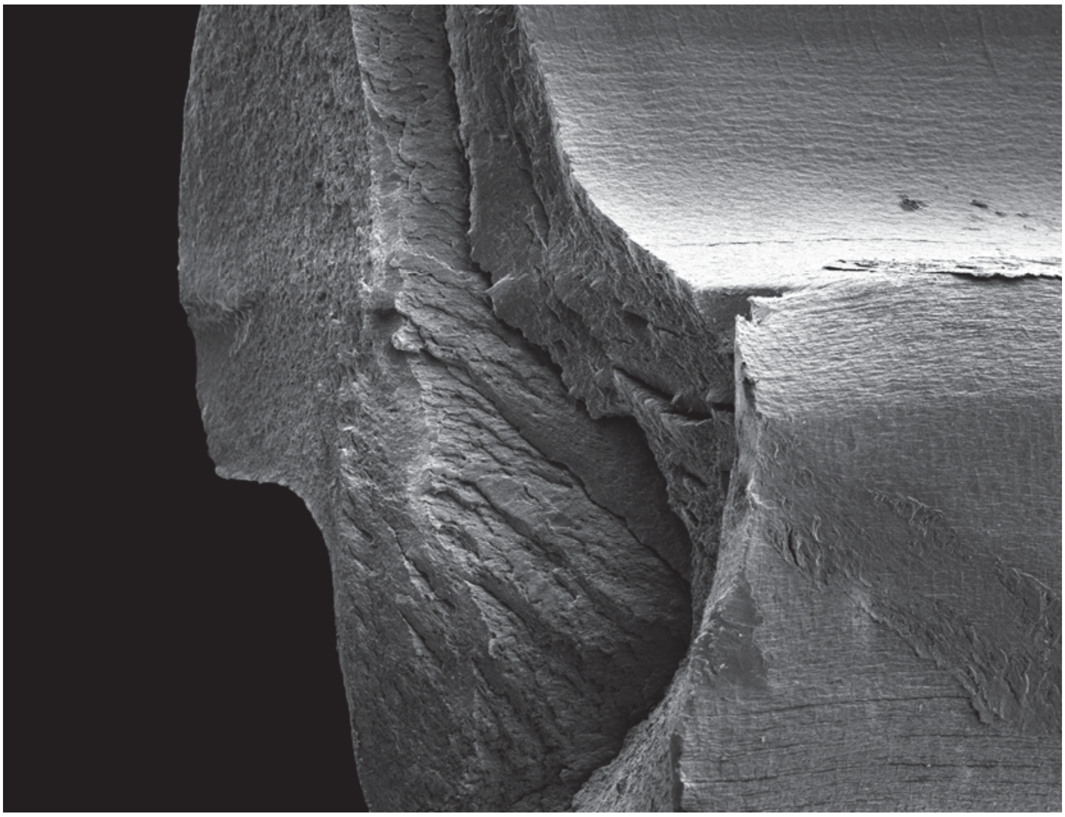


Figure 13: Shaped outer wire, cracks have initiated at the points of contact with neighbouring wires. The start of the fatigue crack can be seen on the left of the picture.

Figure 14: An internal round wire. Two adjacent fatigue cracks have started at points of contact with neighbouring wires. The wire finally failed in shear. (approximate magnification × 15).

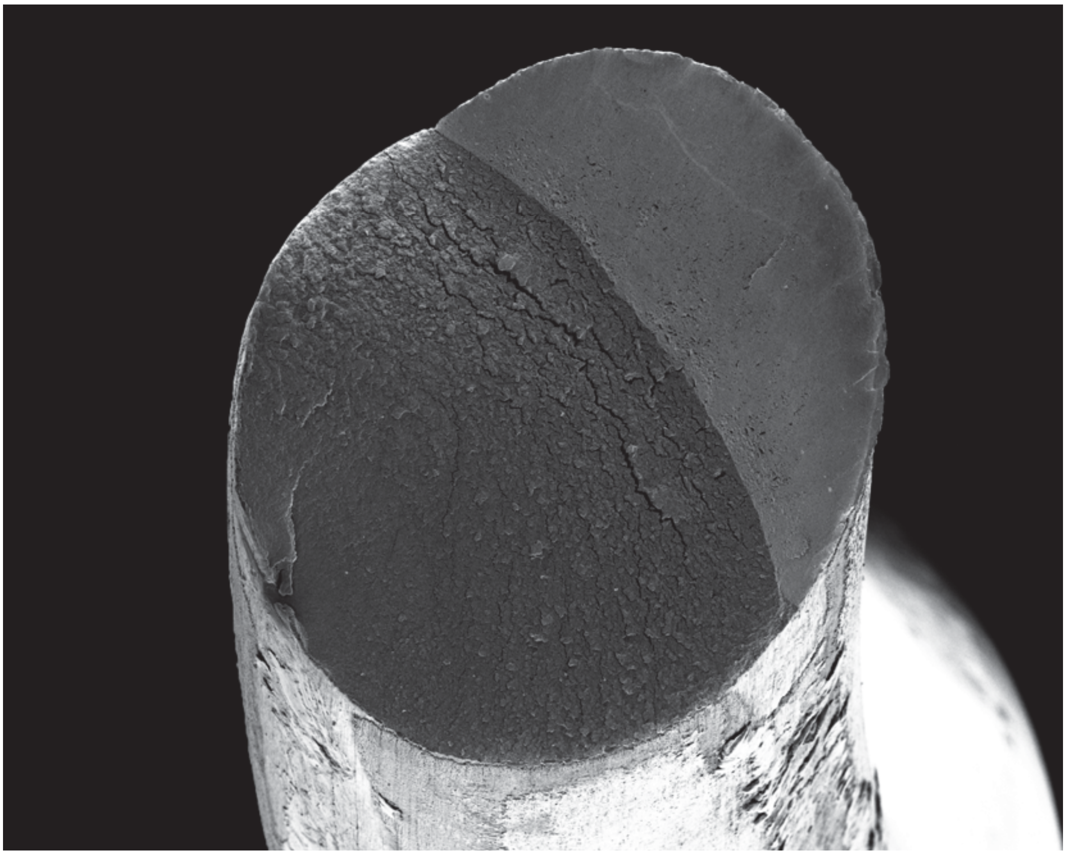


Figure 15: Fatigue crack in another internal wire. The fatigue crack started at the lower left hand side. After weakening the wire by about two-thirds the wire finally failed in shear (approximate magnification × 29).

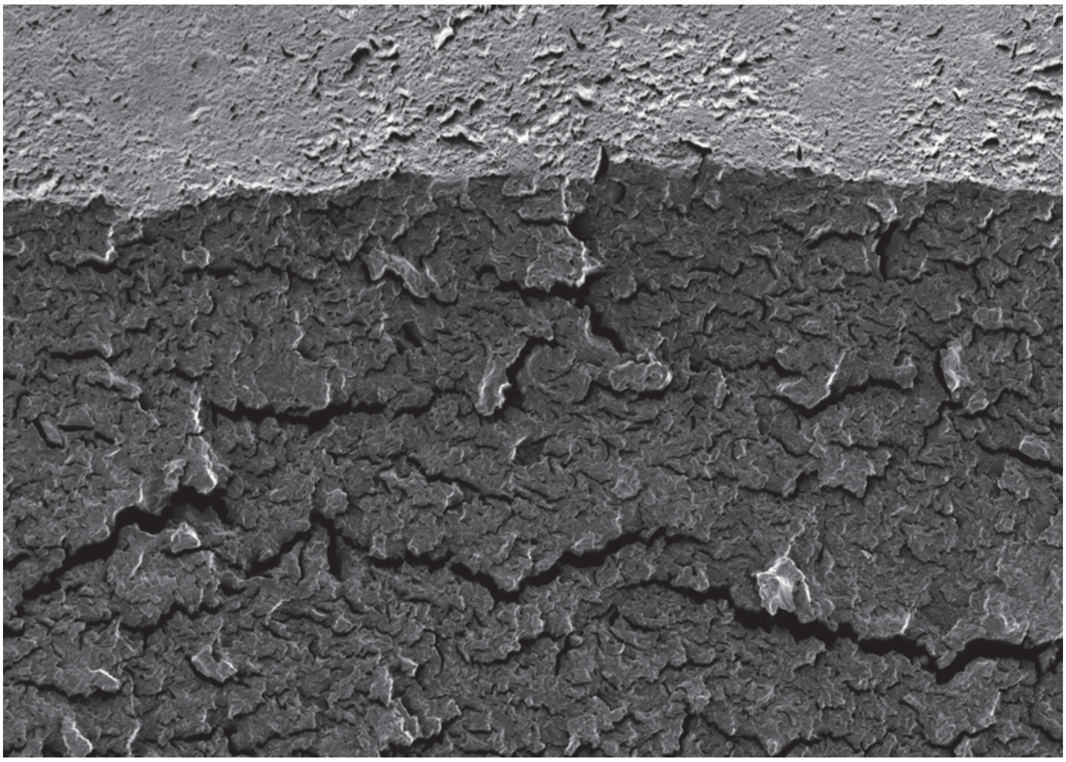


Figure 16: Detail on Figure 15 showing the transition from the fatigue crack (lower part of the picture) to the shear crack (upper part) (approximate magnification × 158).

6 Discussion and Conclusions

This report has described tensile fatigue tests on a FLC rope sample to assess the effect on endurance of a rope clamp. The results show that for the same fatigue loading conditions, the rope without the clamp sustained 501,227 cycles, whilst with the clamp sustained only 102,305 cycles. This represents a loss in rope endurance of about 80%. In equivalent tests conducted on a six strand + IWRC rope the estimated loss of endurance was 60%.

It is reiterated that the clamping pressure employed for the six-strand rope was 50 MPa, whilst for the FLC test reported here, 150 MPa. However, these clamping pressures are as specified in the EN Standard 12927-4:2004 [**2**].

On the basis of these limited tests it may be concluded that the effect of the use of the clamp on the endurance of the locked coil rope is to reduce it by about 80%. This is more than the estimated reduction of 60% found for the six-strand rope.

The clamp which was designed and used in the tests reported here was a 'single' piece in that the clamping length was made of one continuous section. Reference to Figure 2 shows that for ease of installation, clamps may be made up of several shorter sections. The work undertaken here has not addressed how the fretting amplitude may be affected by this difference in design, but it might be expected that shorter clamps would lead to reduced fretting motion, but in more places (at the entrance and exit to each clamp section).

Figure 2 also shows evidence of some local corrosion associated with the rope clamp. It is not clear what the source of the rust is – but it is likely that the clamp acts in some way to allow water to sit on the rope/clamp assembly, which is clearly undesirable.

An indirect result from these tests was to confirm again the importance of the "quality" of the fabrication of the rope termination. In the tests reported here the samples were made up with conical resin terminations, with the focus on measuring the fatigue performance of the rope – and from that the effect of the clamp on rope fatigue performance. It is noted, and confirmed by the results of our tests, that the fatigue performance of a correctly designed and fitted resin filled socket or a white metal spelter (ZL6) filled socket will be of the order of 100% efficient [**3**].

The performance of a "bad" socket can lead to a reduction of more than 70% in service life compared to that of a "good" socket. It is noted that this is in any case better than the reduction of 80% caused by the "safety" clamp. Thus the actual service life of a secured "good" socket is shorter than the service life of a "bad" socket…

7 Acknowledgements

The authors would like to thank Teufelberger Seil GmbH who kindly supplied the FLC rope sample used in the study reported here.

8 References

[**1**] STRMTG, *Remontées mécaniques RM2, Conception générale et modification des téléphériques,* section A5 5.1.11 Sécurisation des culots des câbles porteurs, des cables de tension et d’ancrage, published by STRMTG, version 20th April 2010.

[**2**] EN 12927-4:2004 *Safety requirements for cableway installations designed to carry persons – Ropes – Part 4: End fixings*, CEN: European Committee for Standardisation, 2004.

[**3**] Ridge, I.M.L. & Verreet, R. *Wire rope end connections: an overview,* OIPEEC Round Table Conference on Rope Terminations and Fittings (ed. I.M.L. Ridge), Bethlehem USA August 20th-22nd 2001 1-29 ISBN: 0 7049 2284 1.