CASAR®

SPECIAL WIRE ROPES

Wire Rope Forensics

WIRE ROPE FORENSICS

by Dipl.- Ing. Roland Verreet and Dr. Isabel Ridge

WIRE ROPE FORENSICS

If you have ever read a Sherlock Holmes story, you know the the pattern:

A dead body is lying on the floor. Was it murder or suicide? If it was murder, <u>who</u> killed the person? <u>Why</u> did he do it? And <u>how</u> did he do it?

Sherlock Holmes will inspect the room with his magnifying glass, collect a limited number of seemingly trivial and unrelated details and then present a surprising, but undisputable answer to all these questions.

The work of a wire rope detective resembles very much that of Sherlock Holmes: A steel wire rope has failed and the accident has caused a lot of damage. The rope user, and maybe also a judge in court, will want to know whether the rope was murdered (by external factors) or committed suicide (e. g. in multi layer spooling on the drum). They will want to know how it happened, for various reasons:

One reason, of course, is just human curiosity. Another reason is that they need to know what caused the accident in order to prevent similar occurences in the future. A third reason is money. Wire rope failures are often associated with expensive damage, and someone will have to pay the bill.

But you do not always need a wire rope <u>failure</u>: The analysis of a <u>discarded</u> rope can also give you valuable information about your crane, the way it operated and the rope you have been using. In the hands of an experienced inspector, this information might lead to a better crane or wire rope design or to an improvement in maintenance procedures and safety.

The tools of the detectives have changed: The fingerprint powder has been replaced by groove gauges, digital calipers, accelerometers, goniometers, digital cameras and laptops, and the magnifying glass has been replaced by the Scanning Electron Microscope (SEM).

Dipl.- Ing. Roland Verreet has spent more than thirty years in steel wire rope research and development and has investigated hundreds of rope accidents.

Dr. Isabel Ridge has almost 20 years of experience in wire rope research and the laboratory testing of steel wire rope behaviour and endurance.

WIRE ROPE FORENSICS

The evidence is there, you just have to look in the right places !

These two authors have pooled their experience in order to create this document. This is the first edition, compiled for the 10th International North Sea Offshore Crane Conference under enormous time restrictions. The authors intend to expand and improve the document in later editions.

The brochure might help you identify your own wire rope problem, or, even better, help you to prevent steel wire rope problems in the first place.

The authors would like give special thanks to Klaus Turotzi. Mr. Turotzi took most of the SEM photographs using the SEM now located in the laboratory of Roland Verreet's company, Wire Rope Technology, Aachen.

MECHANICAL WEAR

Mechanical wear in steel wire ropes is the removal of material due to mechanical abrasion.

Mechanical wear can be reduced by lubricating the rope. Mechanical wear on multi layer drums can be reduced by choosing a suitable rope design: the rope should be Langs lay, and it should have compacted outer strands. A swaged rope surface will give additional advantages.

Due to wear against sheaves, drums or neighbouring rope wraps, a rope diameter will initially reduce at a high rate. With increasing wear, however, the bearing surface of the wire rope will increase and the rope diameter reduction will slow correspondingly.

As long as the rate of diameter reduction due to wear is higher than the fatigue crack propagation rate, ropes will not develop fatigue wire breaks (Fig. 1, Langs lay, and Fig. 4, regular lay). Once the rate of diameter reduction slows down, fatigue breaks will appear (Fig. 9).

Mechanical wear must not be confused with plastic wear. Plastic wear is the deformation and displacement of material (without or with only little material loss). Figures 5, 6 and 7 show examples of plastic wear.

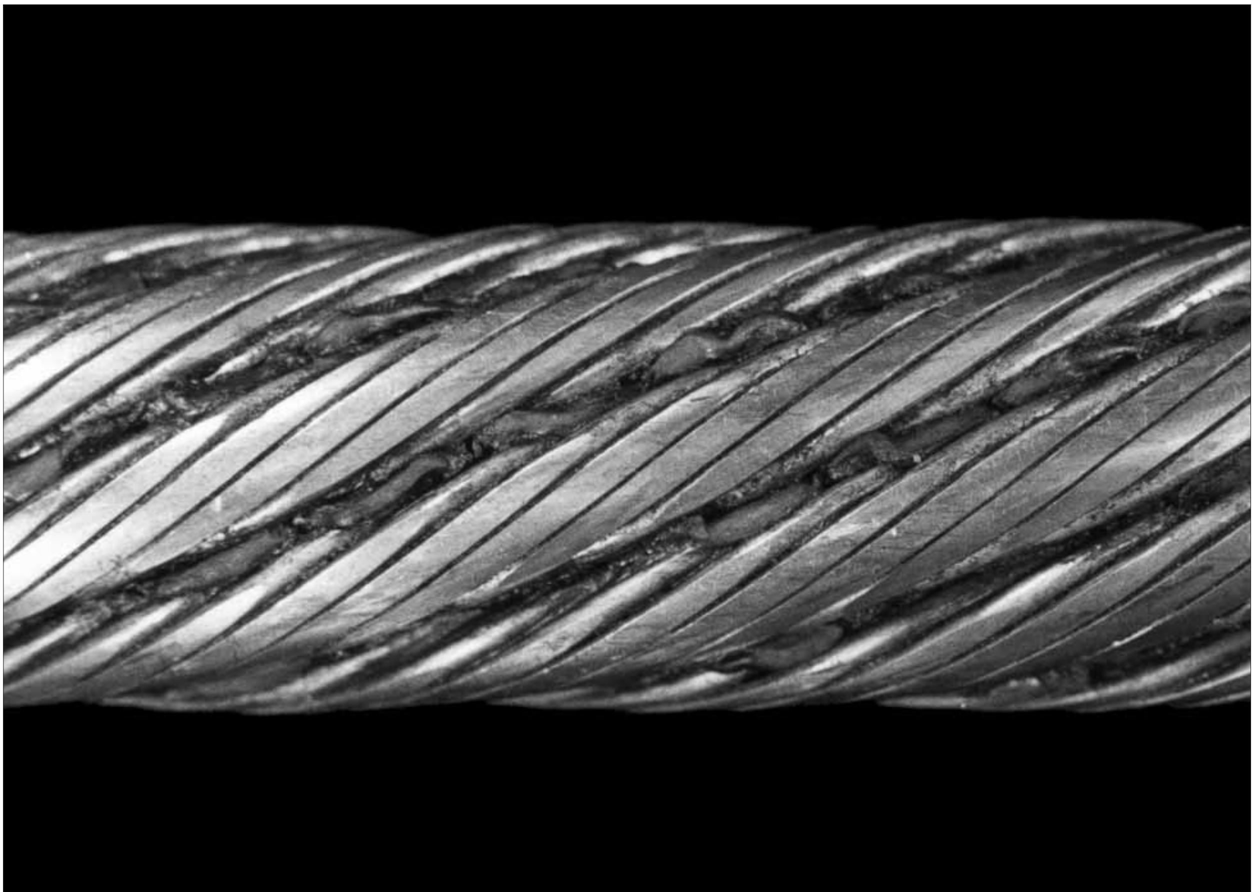


Fig. 1: A Langs lay rope with a great amount of uniform mechanical wear. Please note that the rope does not exhibit any fatigue breaks. The bearing surface on sheaves and drums has increased due to the mechanical wear.

MECHANICAL WEAR

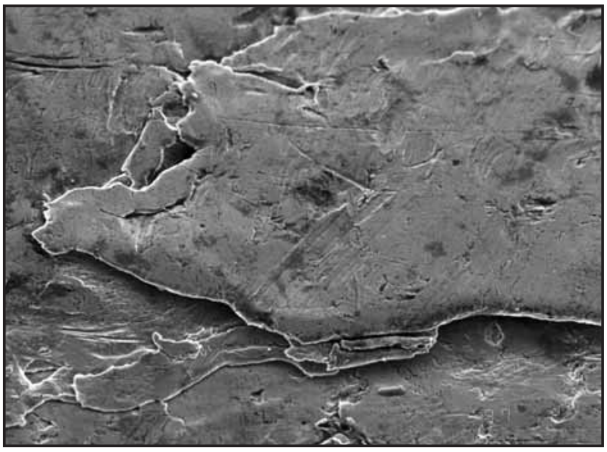


Fig. 2: Wear surface of an outer wire of a steel wire rope.

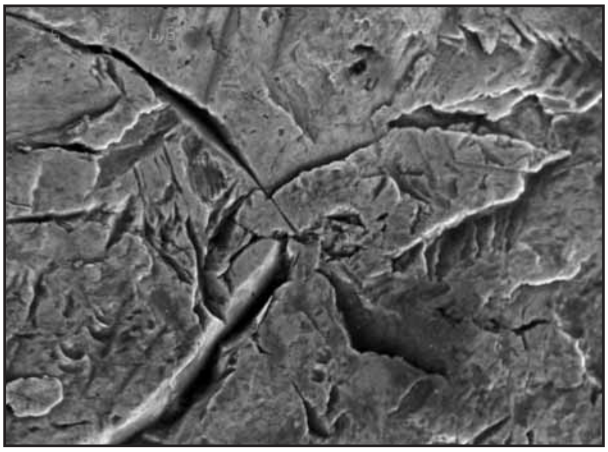


Fig. 3: Detail of Fig. 2 (high magnification).

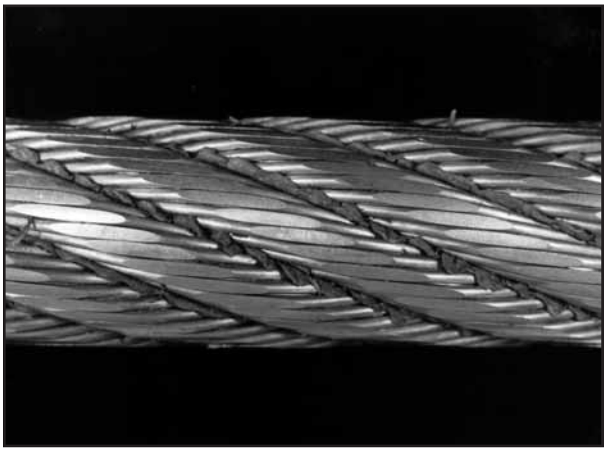


Fig. 4: Regular lay rope with a great amount of uniform mechanical wear. Please note that the rope does not show any fatigue breaks.

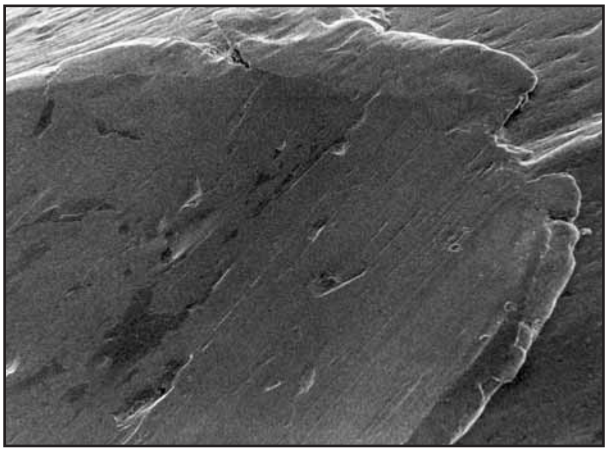


Fig. 5: Plastic wear of a rope wire at a cross-over point inside the rope. The cold-working will harden the material and form cracks.

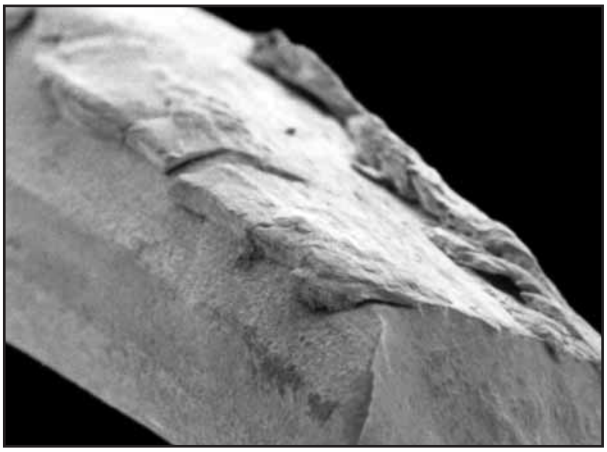


Fig. 6: Plastic wear on the surface of an outer wire. Cracks will initiate at the work hardened surface.

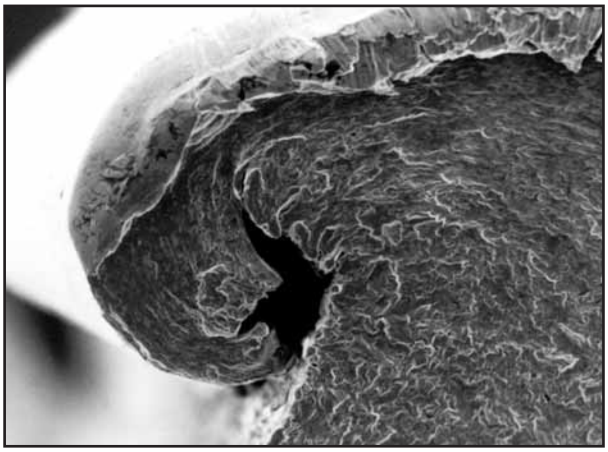


Fig. 7: Plastic wear on the surface of an outer wire. The material displacement is very visible.

BENDING FATIGUE BREAKS

Rope bending fatigue is caused by running over sheaves or on and off single layer drums. A fatigue crack normally starts at the points of contact between the outer wires and the sheave or drum surface or at cross-over points between individual rope wires. It then proceeds with increasing number of bends, finally creating a fracture which is perpendicular to the wire axis.

Fatigue breaks occur more often on the inside of the bend (at the point of contact with the sheave) than on the outside of the bend (at the points of highest bending stresses).

The fatigue resistance of steel wire ropes generally increases with increasing number and decreasing diameter of the outer wires of the rope. This improvement goes along, however, with a reduction in the rope’s resistance to wear.

Wire rope endurance can also be increased by increasing the sheave or drum diameter or by reducing the line pull.

Wear or corrosion might increase the rate of crack formation and crack propagation. Good wire rope lubrication and relubrication during service, however, will reduce the friction between the rope elements and therefore improve steel wire rope fatigue resistance.

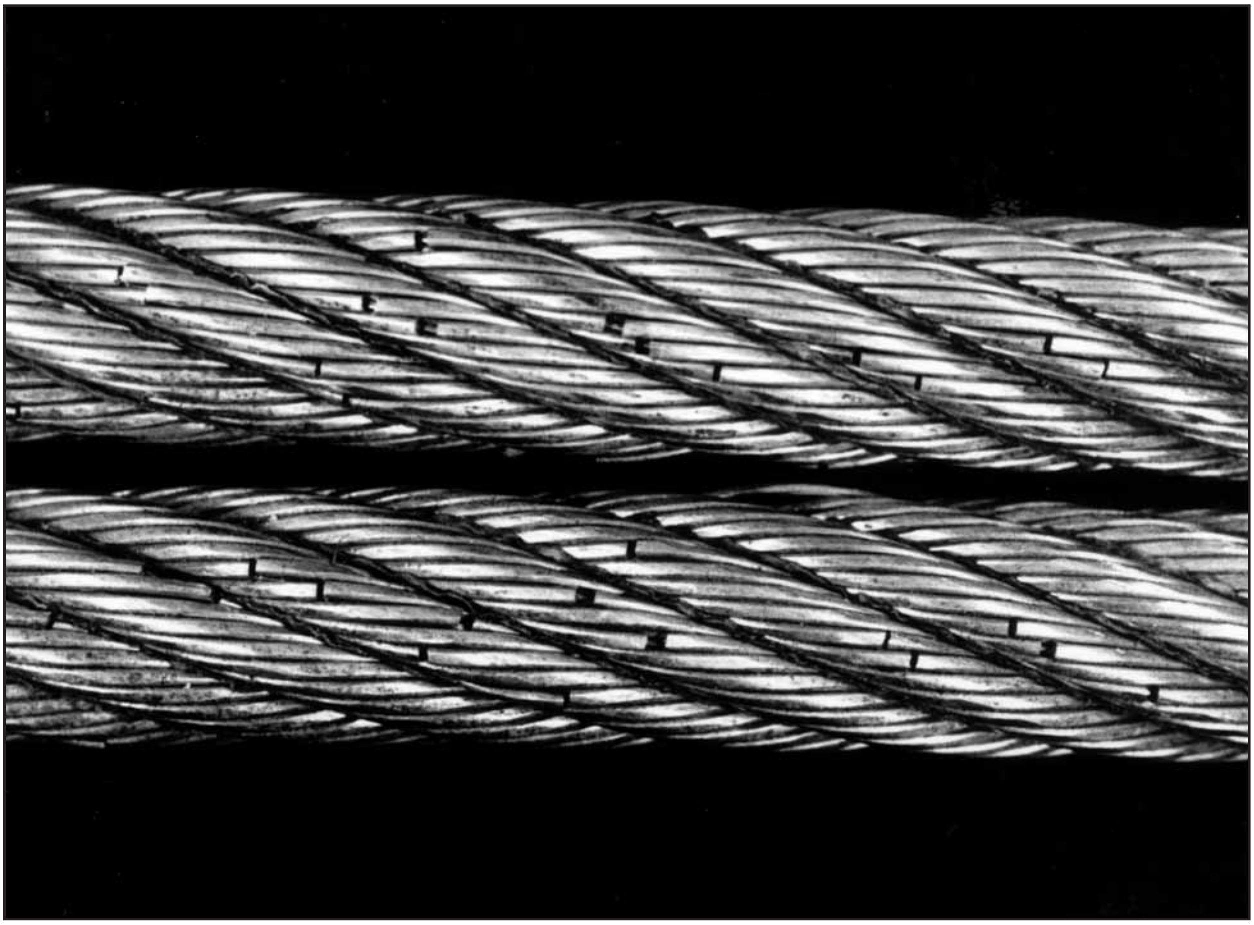


Fig. 8: Bending fatigue breaks on ropes made out of compacted outer strands. The distribution of bending fatigue wire breaks is typically random.

BENDING FATIGUE BREAKS

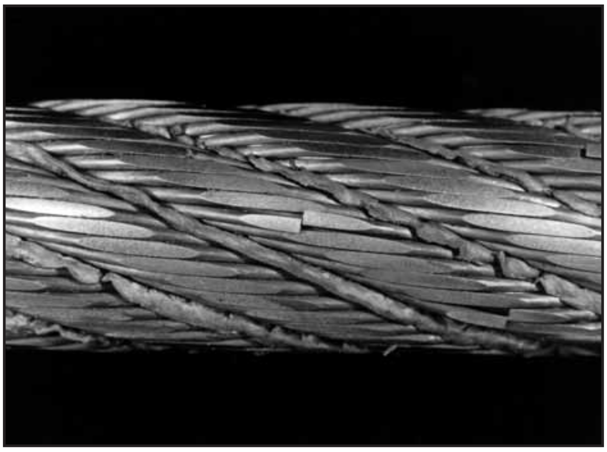


Fig. 9: Heavily worn wire rope with a few fatigue breaks. The wire ends are displaced in different directions because of rope twist.

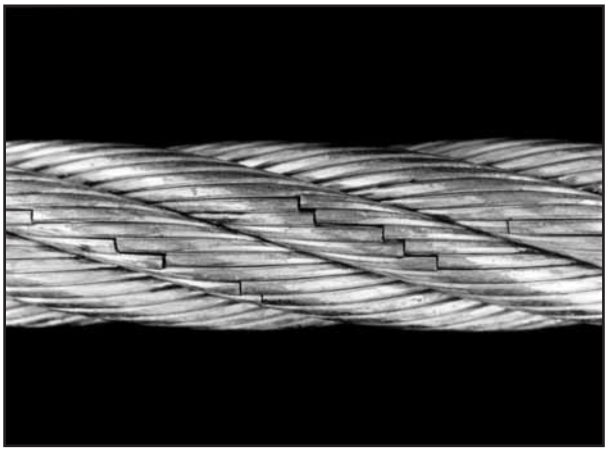


Fig. 10: This six strand rope displays almost no wear but a great number of fatigue breaks.

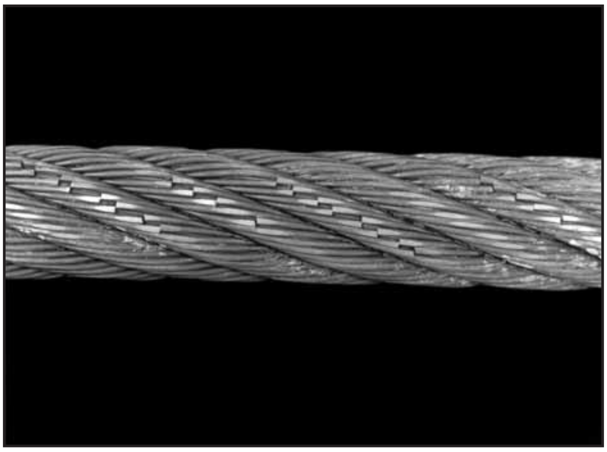


Fig. 11: Three adjacent strands <u>with</u> fatigue breaks followed by one <u>without</u> indicate uneven load sharing or a pulled-in strand.

Fig. 12: Fatigue cracks starting at the points of contact of individual wires. The cracks became visible after destroying the strand in a pull test.

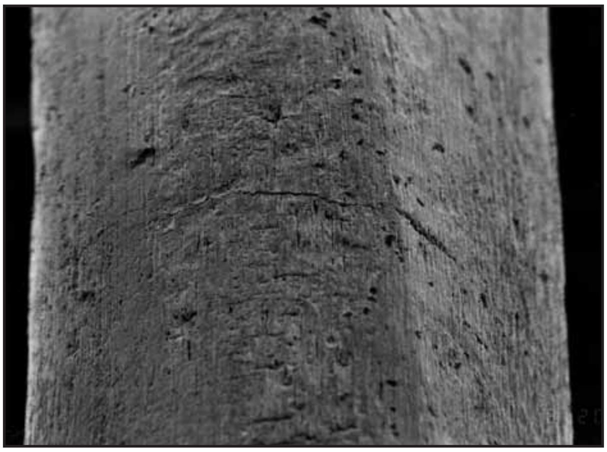


Fig. 13: Surface corrosion often initiates the formation of fatigue cracks.

Fig. 14: Pitting and corrosion associated with a fatigue crack (detail of Fig. 13).

BENDING FATIGUE BREAKS

Fig. 15: A fatigue crack starting at the point of contact with a sheave. Obviously the crack propagated concentric to its point of initiation. The crack only became visible after destroying the strand in a pull test.

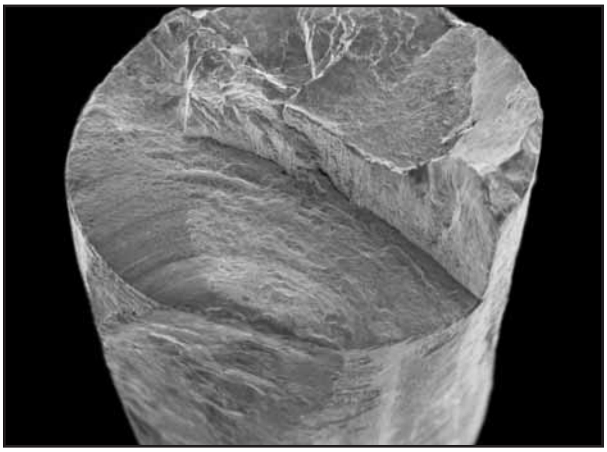


Fig. 16: A fatigue crack.

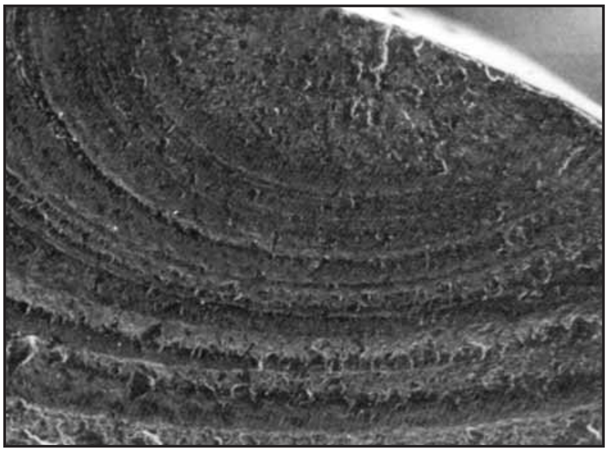


Fig. 17: The fatigue crack radiates out from the origin as a series of concentric rings (termed rest lines, beach lines or striations).

BENDING FATIGUE BREAKS

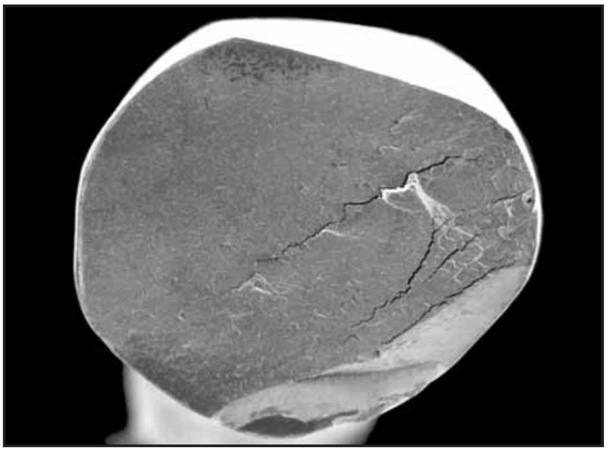


Fig. 18: If the line pull on a fatiguing wire is low (high design factor), the area affected by fatigue before final failure is large.

Fig. 19: Another fatigue crack.

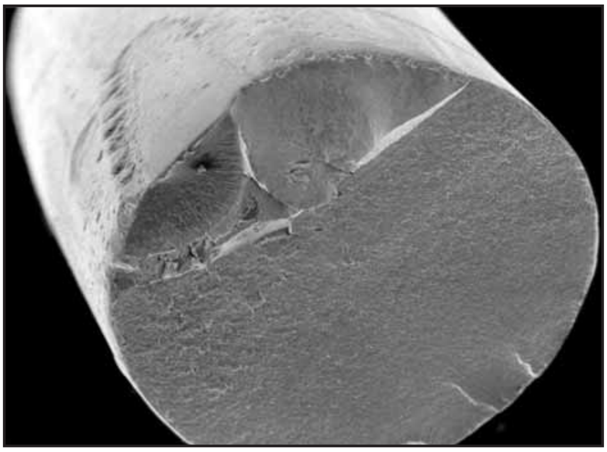


Fig. 20: A fatigue crack. The point of origin and the concentric propagation of the smaller fatigue crack is clearly visible.

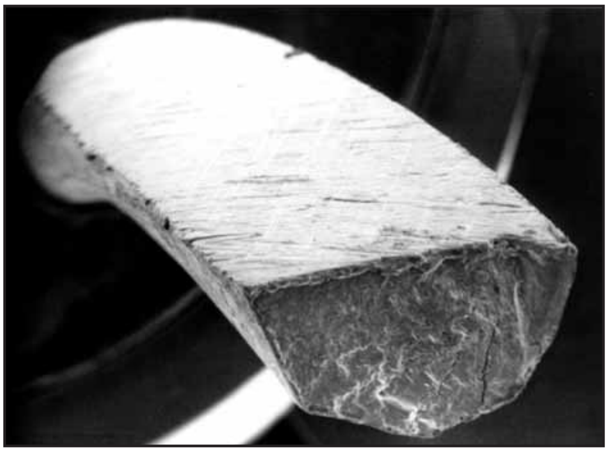


Fig. 21: Severely worn wire with a fatigue break.

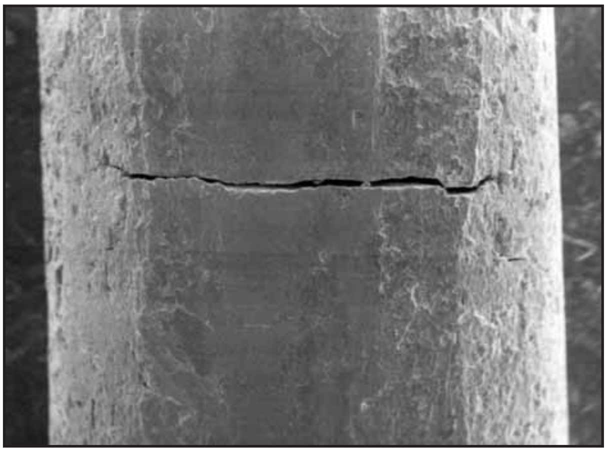


Fig. 22: A fatigue crack.

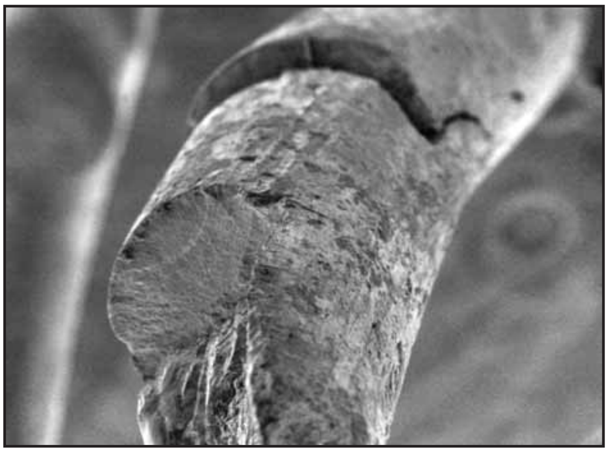


Fig. 23: Two adjacent fatigue cracks. This kind of failure can often be seen if wires are subjected to local bending and compression.

BENDING FATIGUE BREAKS

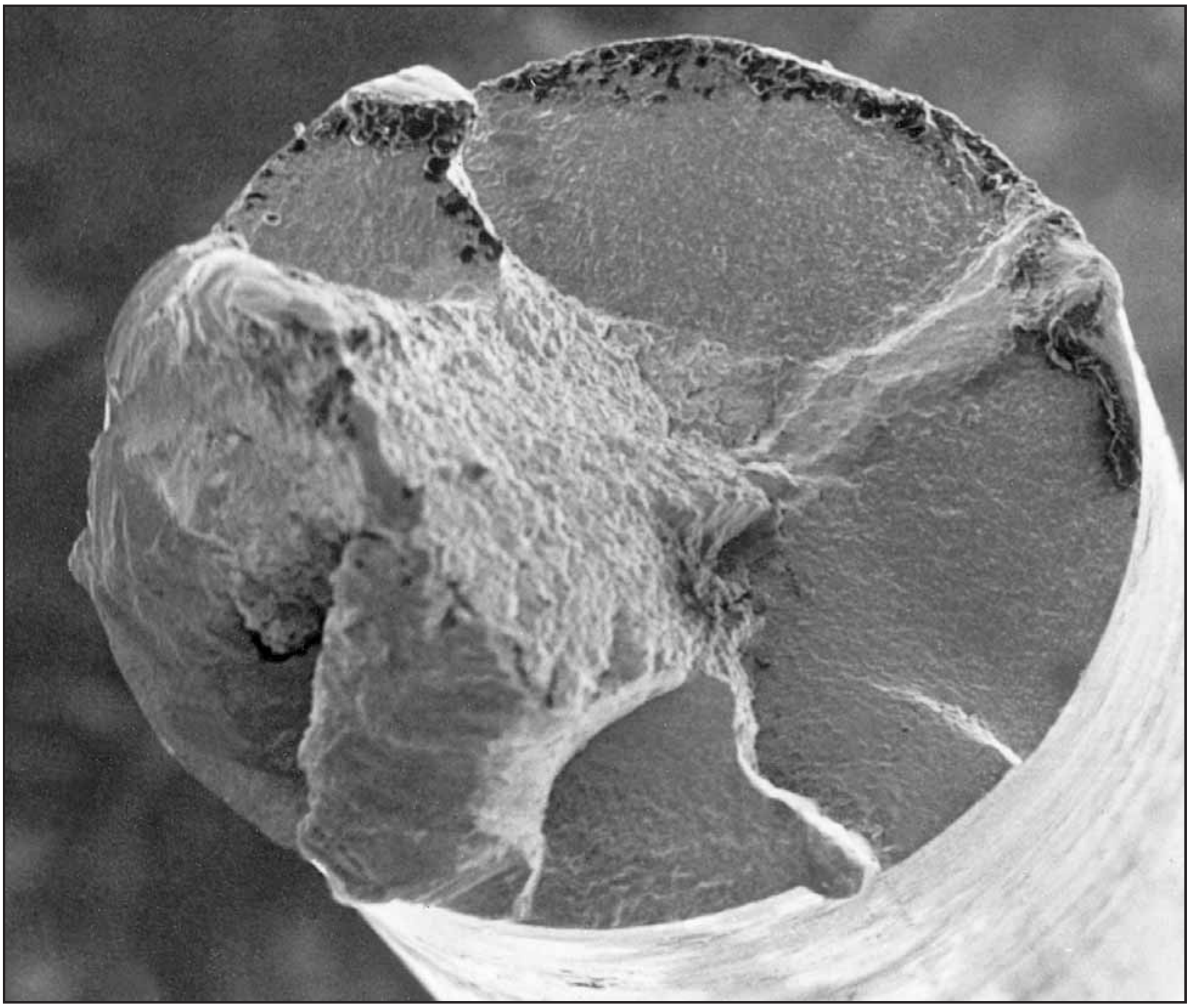


Fig. 24: Wire fatigued in rotary bending fatigue test. The cracks initiate from all around the circumference.

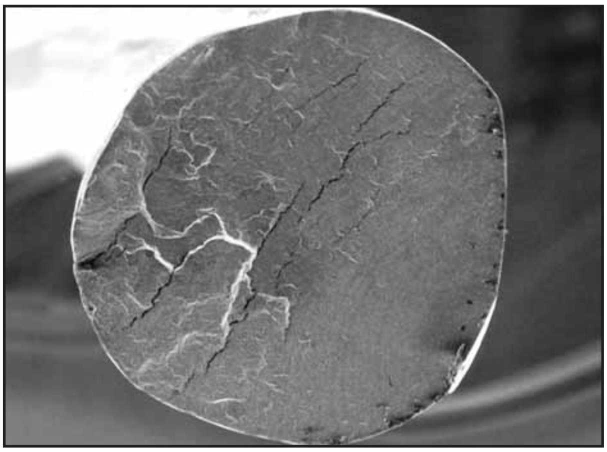


Fig. 25: Fatigue crack.The wire fatigued under the influence of both traction and compression.

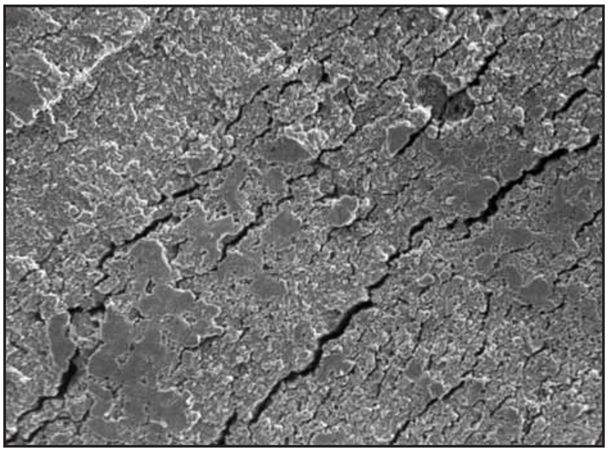


Fig. 26: Enlarged view of the crack shown in Fig. 25. The fatigue suface shows secondary deformations due to compression.

CORROSION DAMAGE

Corrosion is the reaction of metal with oxygen. In steel wire ropes, we distinguish between atmospheric corrosion (producing <u>uniform</u> “rust”), and more <u>local</u> forms of corrosion such as pitting corrosion (creating deep pits in areas where the protective coating is damaged or missing).

Corroded steel wire rope will lose its strength and flexibility. Corroded wire surfaces will form fatigue cracks much faster than protected surfaces. If high local stresses help propagate these cracks, we call this mechanism stress corrosion.

The amount of corroded metal is a function of the surface which oxygen can attack. Steel wire ropes have an exposed surface about 16 times larger than a steel bar of the same diameter and will therefore corrode correspondingly faster.

The amount of corrosion can be reduced by reducing the exposed surface. This can be done e. g. by galvanizing or heavy galvanizing the rope wires. A steel core can also be protected by a plastic coating. An internal and external lubrication will also reduce or prevent corrosion.

Steel expands when it corrodes. Therefore sometimes an increase in rope diameter over time might be an indication that the rope is corroding internally. Static ropes (suspension ropes or rope sections lying over a saddle or an equalizer sheave) are more likely to corrode than running ropes.

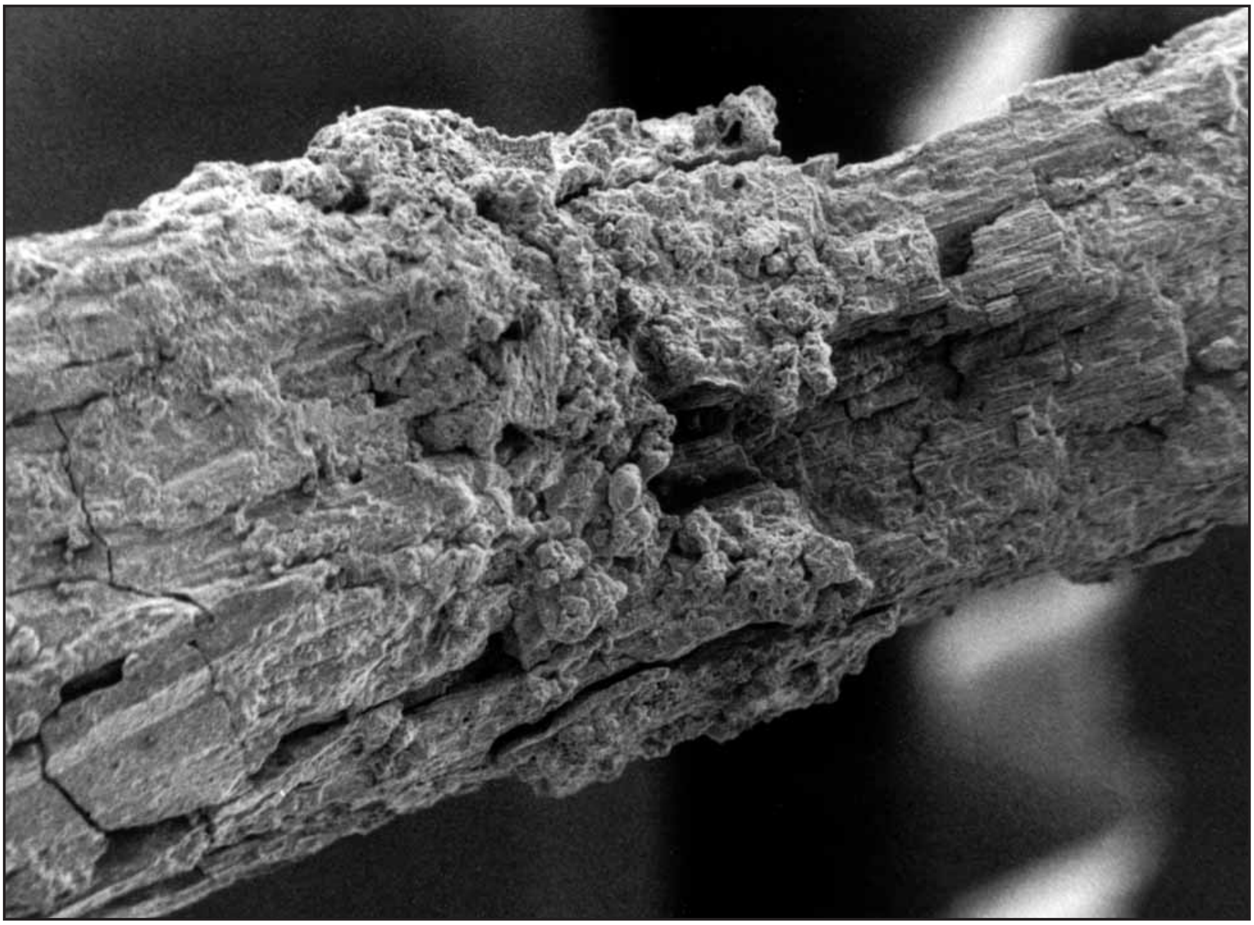


Fig. 27: Severe uniform corrosion (atmospheric corrosion). Static ropes and ropes operating in a marine environment should be galvanized and well lubricated. A plastic coating between the steel core and the outer strands will protect internal rope elements.

CORROSION DAMAGE

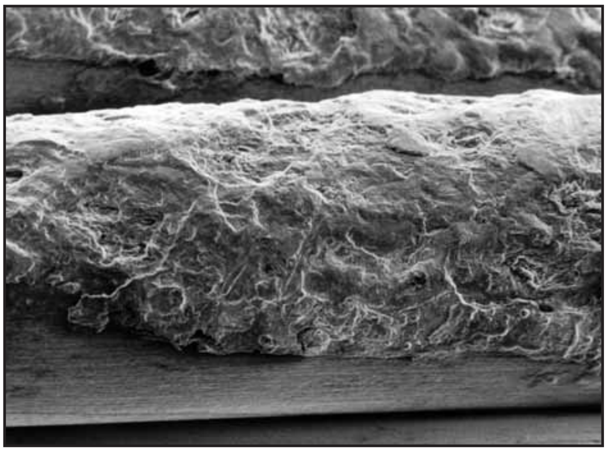


Fig. 28: Surface corrosion. Please note the increase in the effective diameter of the wire.

Fig. 29: Pitting corrosion (local corrosive attack creating deep pits).

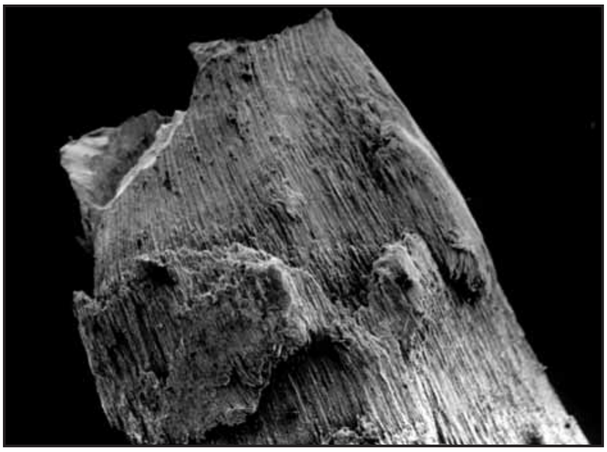


Fig. 30: Tensile failure of a wire weakened by corrosion.

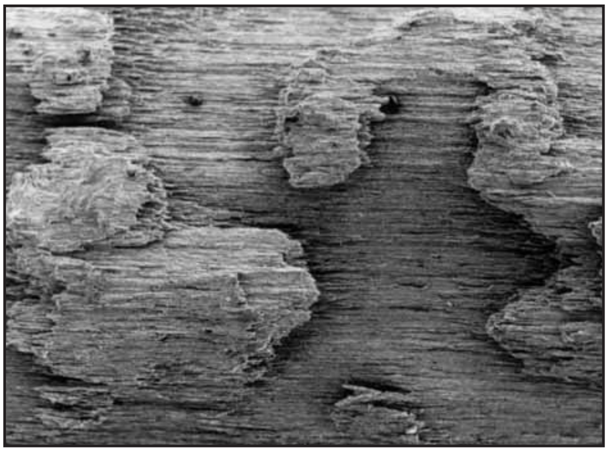


Fig. 31: The highly orientated microstructure of drawn high tensile wire becomes apparent in the corroded state.

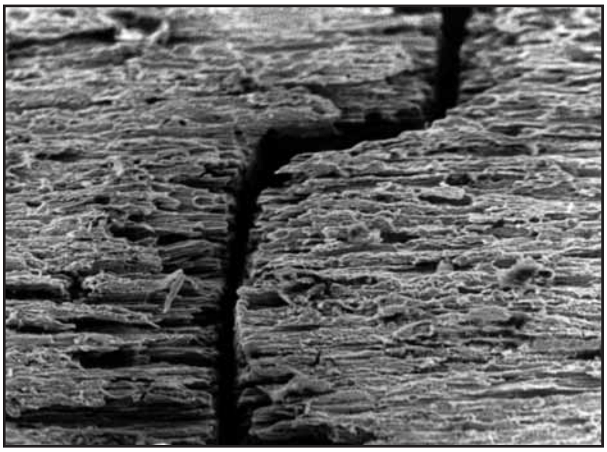


Fig. 32: Stress corrosion crack. Tensile stresses help propagate a crack initiated by corrosion.

Photograph by Jean- Marc Teissier

Fig. 33: Saddle of a bridge in an amusement park. Standing water (e.g. trapped on saddles) causes severe local rope corrosion.

TENSILE OVERLOAD BREAKS

Tensile overload breaks are created when the axial load in the individual wire exceeds the wire's breaking strength. Tensile overload breaks are generally associated with a ductile wire diameter reduction at the point of break and the formation of the typical "cup and cone" ends.

Every wire rope failure will be accompanied by a certain number of tensile overload breaks. The fact that tensile overload wire breaks can be found therefore does not necessarily mean that the rope failed because of an overload. The rope might have been weakened by a great number of fatigue breaks over time. The remaining wires were then no longer able to support the load, leading to tensile overload failures of these remaining wires.

Only if the metallic area of the tensile over–load breaks and shear breaks (see pages 15 and 16) combined is much higher than 50% of the wire rope's metallic cross section is it likely that the rope failed because of an overload.

Figs. 35 and 36 show typical examples of a tensile overload break. Fig. 39 shows an example of a wire which was first locally da maged by external influences. Once weakened, it failed in tensile overload.

Fig. 40 shows a wire which developed two areas of local necking before failing.

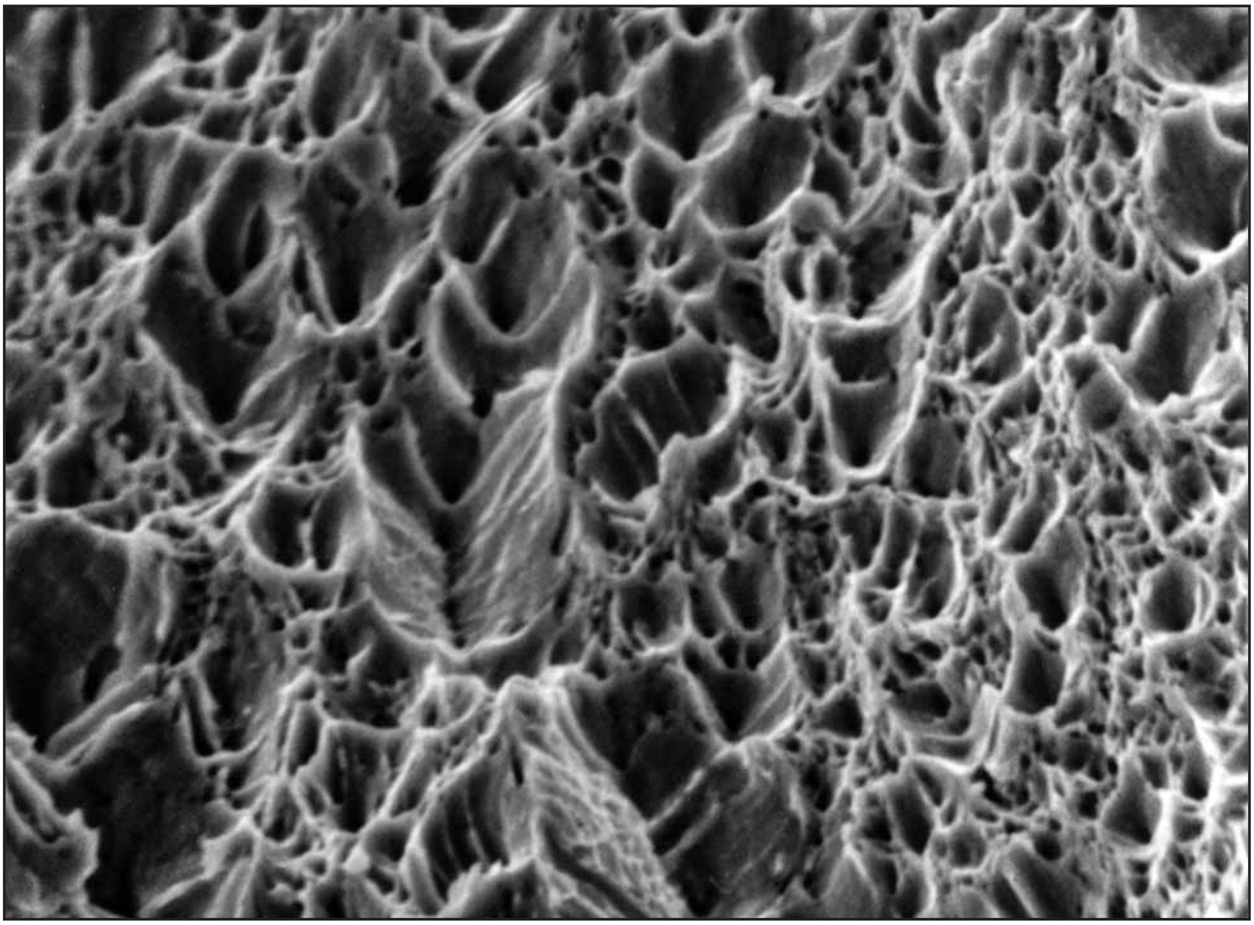


Fig. 34: Ductile dimple formations in the steel microstructure are a clear indication of a tensile overload (enlarged view of the break surface of a cone centre).

TENSILE OVERLOAD BREAKS

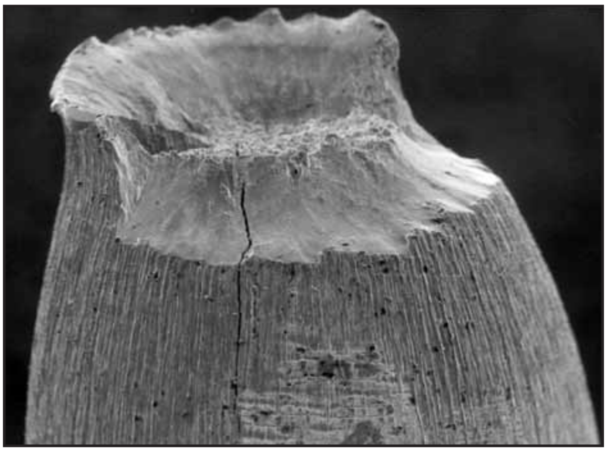


Fig. 35: Classic cup and cone tensile failure. Half of the end has a cup shape and half has a cone shape.

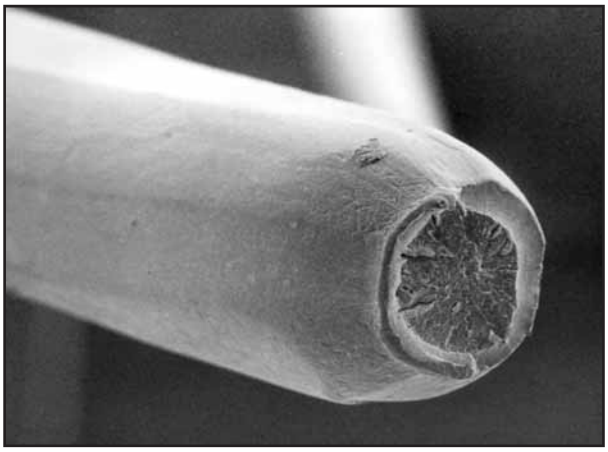


Fig. 36: Classic cup and cone tensile failure. The diameter reduction at the fracture is clearly visible.

Fig. 37: Cup and cone tensile failure at a crossover point.

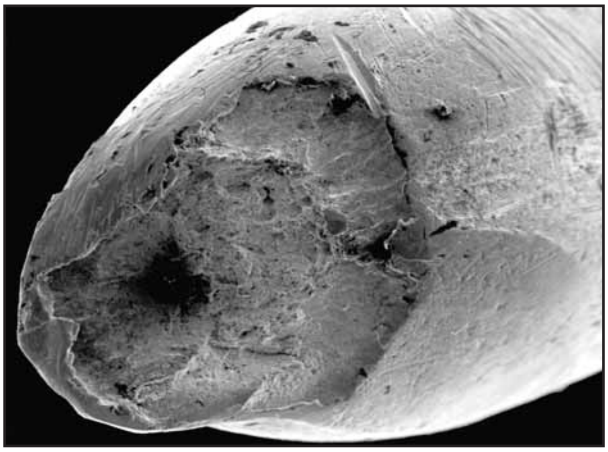


Fig. 38: Cup and cone tensile failure at a crossover point.

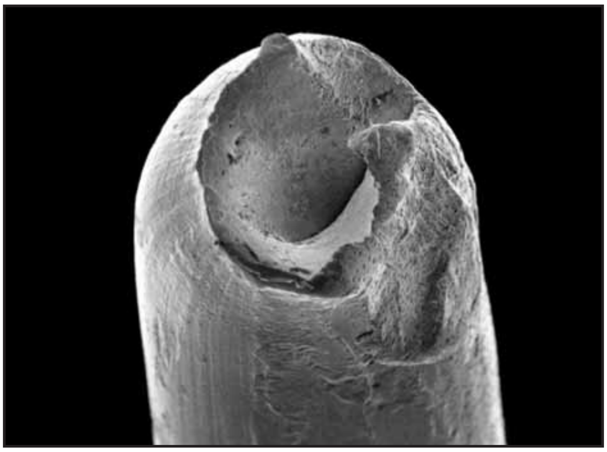


Fig. 39: This locally damaged wire finally failed in tensile overload.

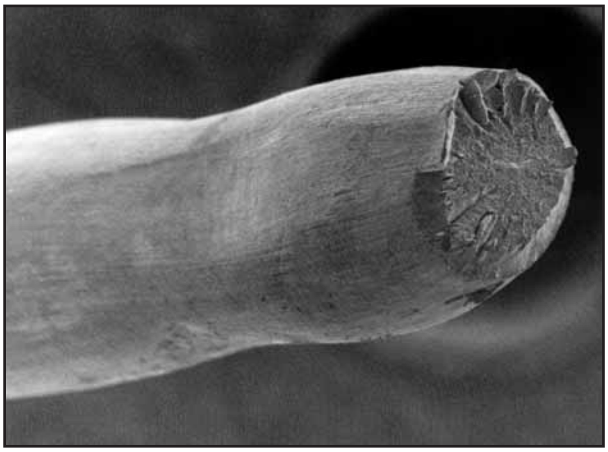


Fig. 40: Before failing by tensile overload, this wire developed two areas of local necking.

TENSILE OVERLOAD BREAKS

Fig. 41: End view of the cone half of a tensile overload break. The inner cone has failed due to tensile stresses before finally the outer ring fails in shear.

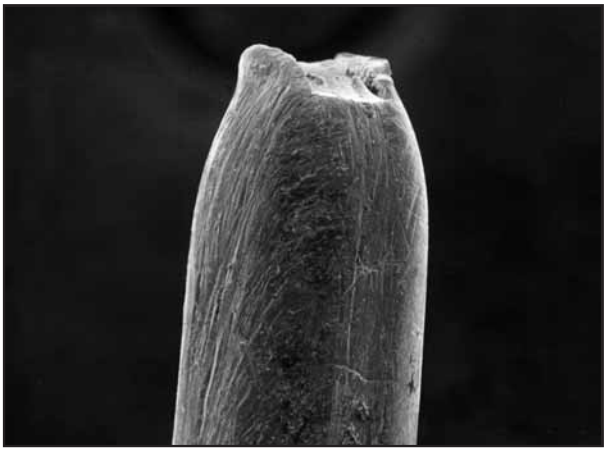


Fig. 42: Tensile overload break. If you've seen one you've seen them all.

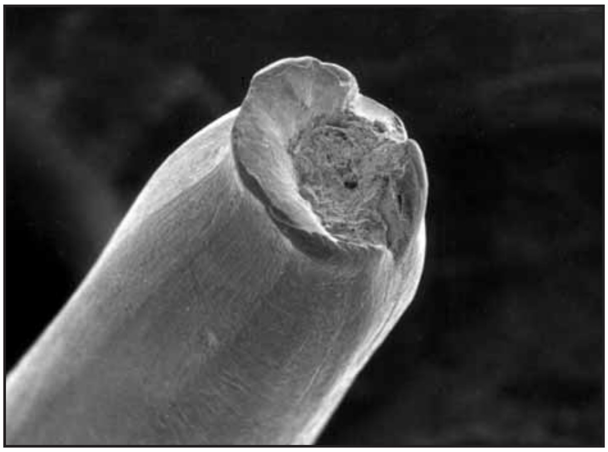


Fig. 43: Oh yes, another tensile overload break.

SHEAR BREAKS

Shear breaks are caused by high axial loads combined with perpendicuar compression of the wire. Their break surface is inclined at about 45° to the wire axis. The wire will fail in shear at a lower axial load than pure tensile overload.

If a steel wire rope breaks due to overload, a great percentage of the wire breaks will be shear breaks. This is because under high axial load, the wire rope will reduce in diameter and wires will be compressed, e. g. at crossover points.

If a steel wire rope breaks as a consequence of jumping a sheave or being wedged in, a majority of wires will exibit the typical 45° break surface.

Figure 44 shows a typical shear break.The fracture surface is fairly smooth in appearance. Please note that there is a small reduction in diameter at the edge of the fracture surface, but it is small compared with the necking associated with a ductile tensile cup and cone failure (see e.g. Fig. 36).

Quite often a wire shear failure will be associated with wear (Fig. 45), plastic wear (Fig. 47), or fatigue (Fig. 48).

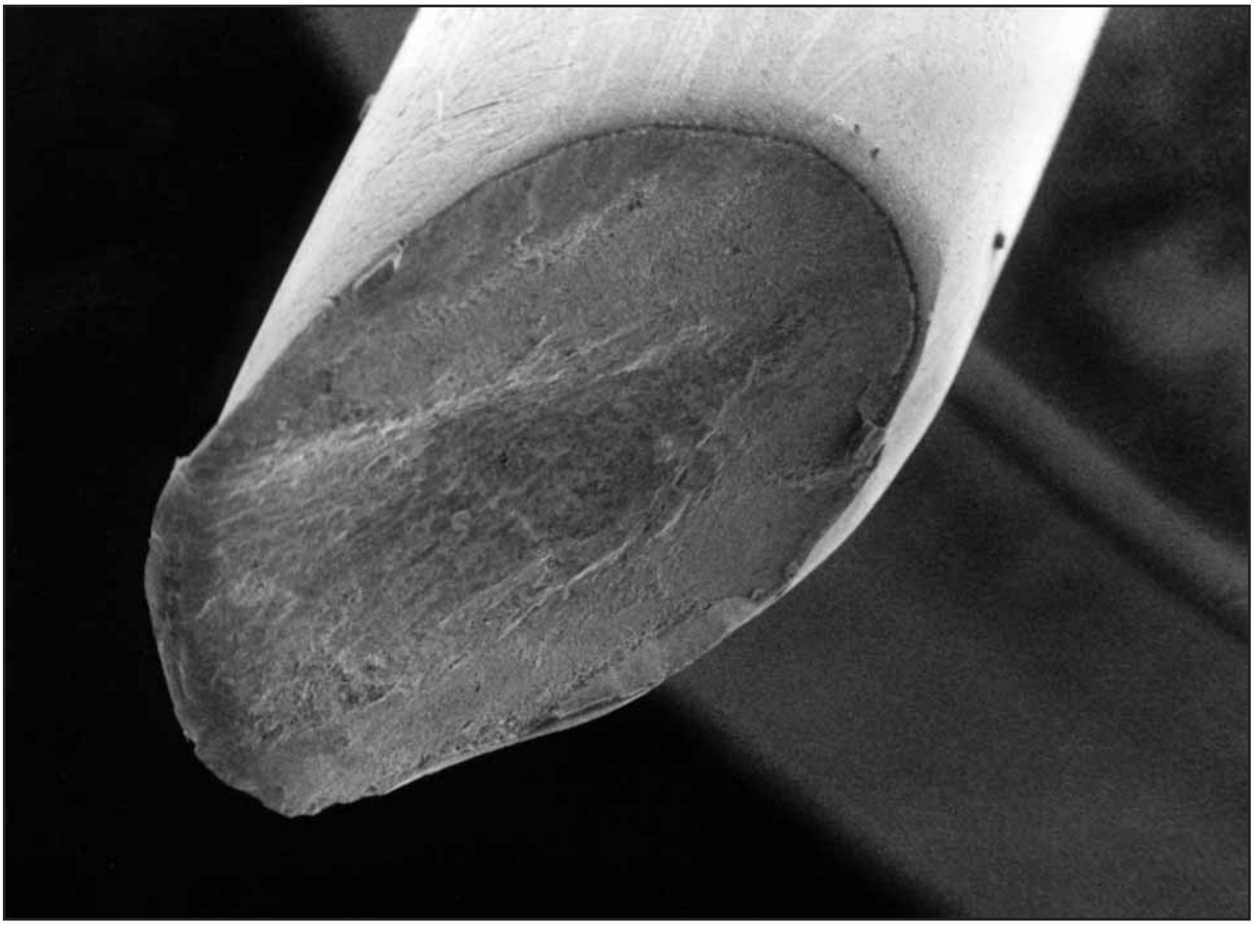


Fig. 44: A typical 45° shear break. Please note that there is a small reduction in diameter at the edge of the fracture surface, but it is small compared with the necking associated with a ductile tensile cup and cone failure (see e.g. Fig. 36).

SHEAR BREAKS

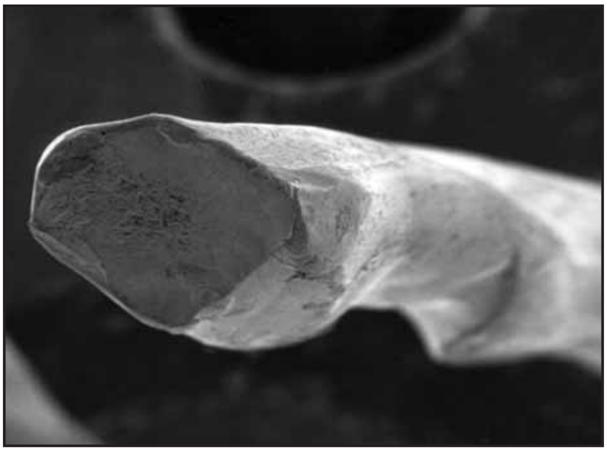


Fig. 45: Shear wire failure caused by high tensile load and interwire nicking.

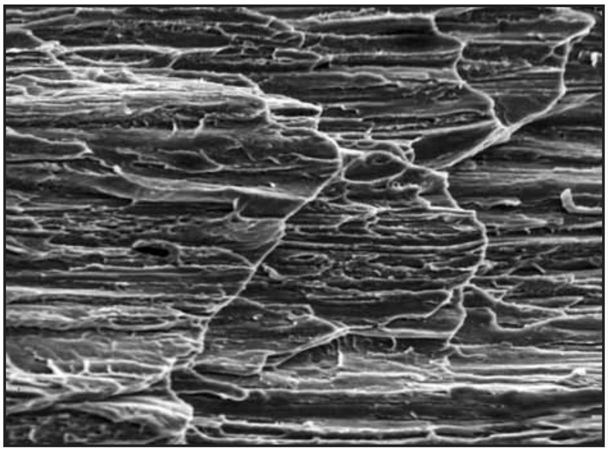


Fig. 46: An example of the microstructure of the sheared wire surface.

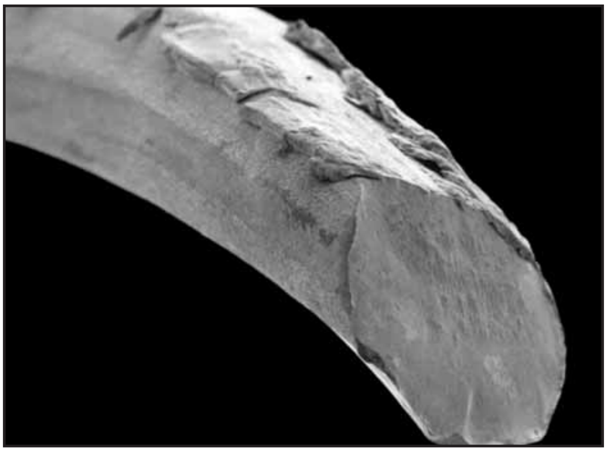


Fig. 47: High transverse loading initially caused severe plastic wear. Finally the wire failed in shear.

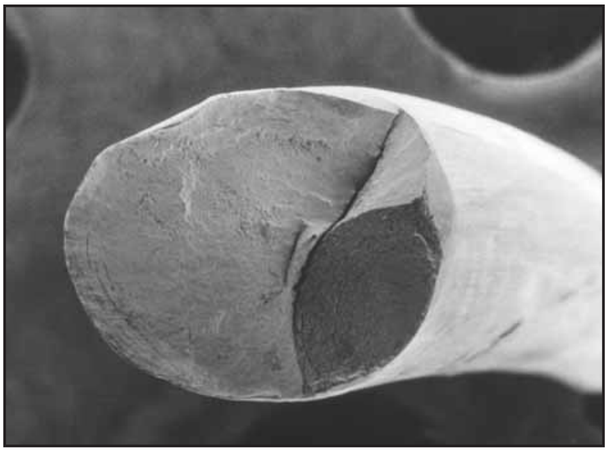


Fig. 48: A fatigue crack has propagated to a critical level before the remainder of the wire failed in shear.

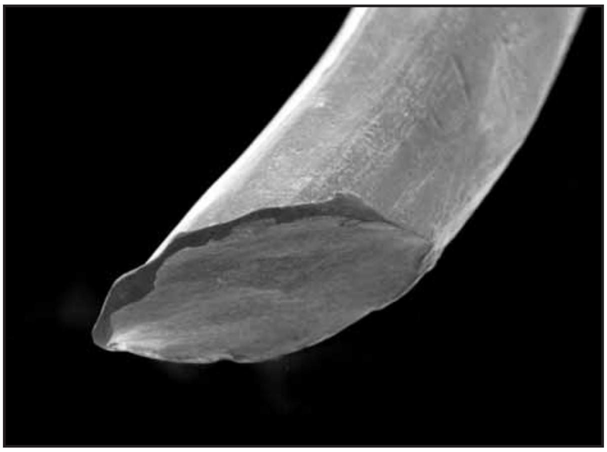


Fig. 49: Another shear break. If you've seen one...

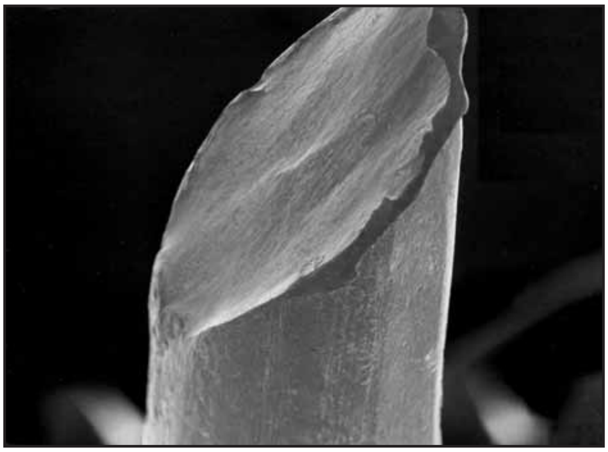
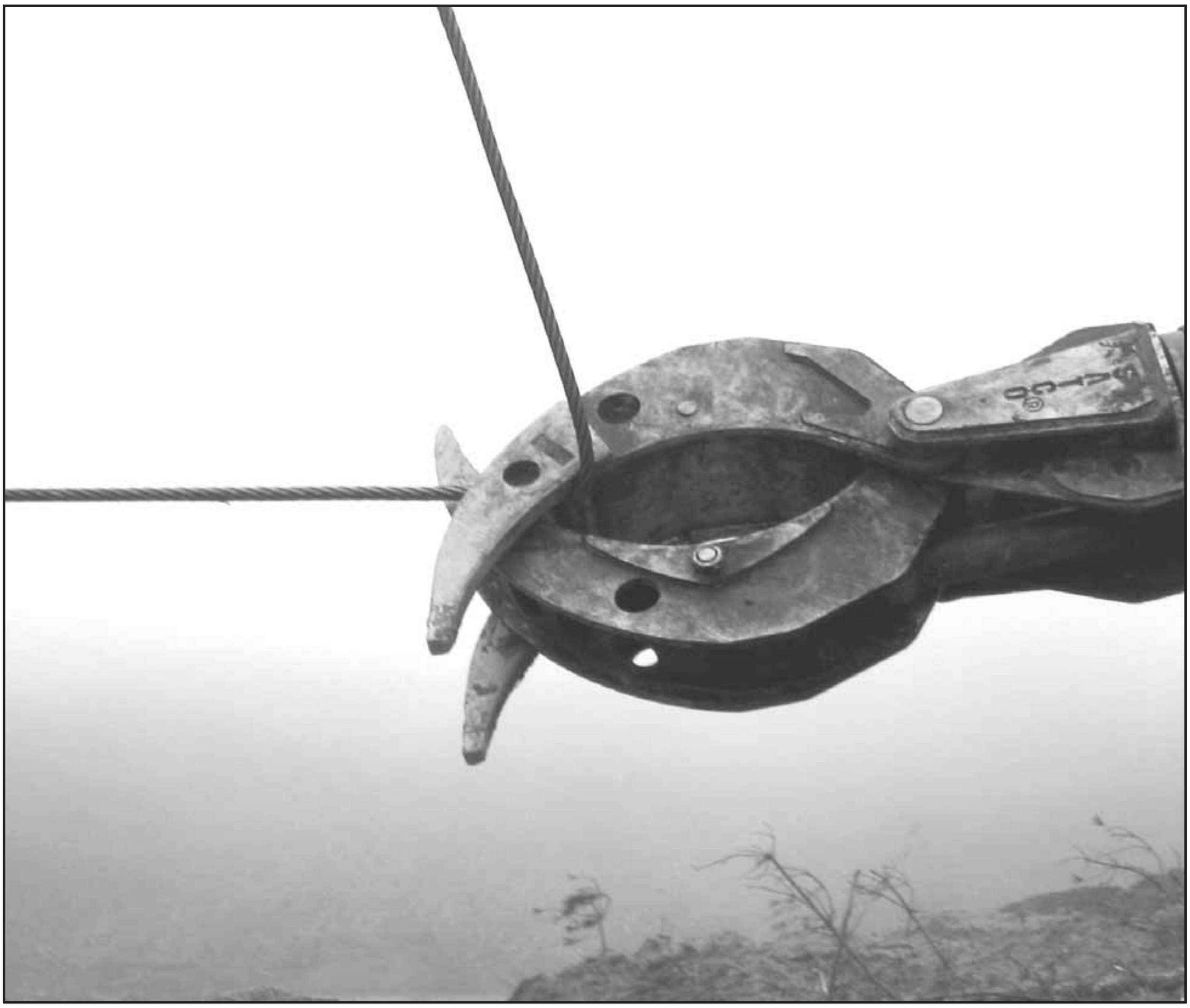


Fig. 50: ...you've seen them all.

EXTERNAL DAMAGE



Photograph by Dennis Verreet

Fig. 51: There is more than one way to destoy a steel wire rope. You should not be suprised if this user later calls his rope supplier to tell him that this rope was “no good”.

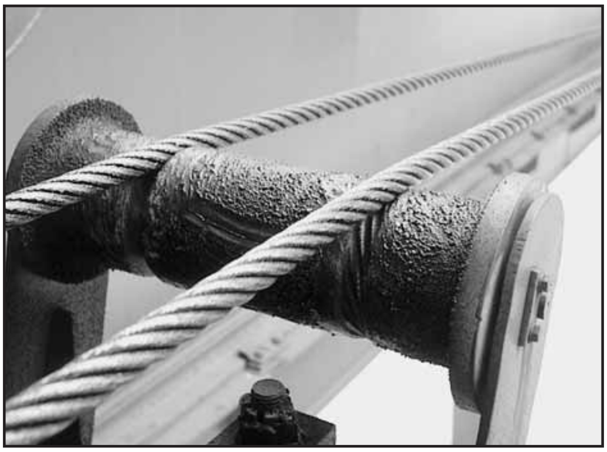


Fig. 52: Rollers are also very efficient at destroying ropes, ...

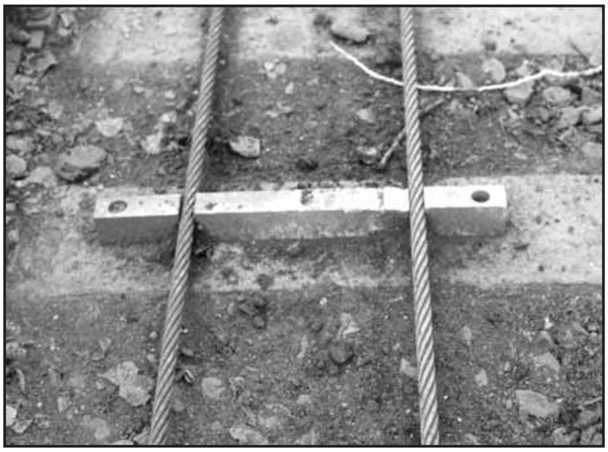


Fig. 53: ...not to forget worn support plates.

EXTERNAL DAMAGE

Steel wire ropes are often mechanically damaged during service.The rope might hit a steel structure, thereby locally damaging some outer wires (Fig. 54), or it might be dragged along a hard surface, creating a great amount of mechanical wear. As an example, Fig. 55 shows a rope which has been pulled over a stuck sheave.

A wear or damage pattern along the rope's axis or slightly helical to it always indicates that the rope has been dragged along an object.

Fig. 56 shows a rotation resistant rope, and Fig. 57 an 8 strand rope, both of which have been dragged over the rims of sheaves.

Ropes that have been pulled over a sharp edge have a tendency to coil when unloaded (Fig. 62).

Fig. 59 shows rope damage caused by shot-blasting the crane before repainting. The metal shot stuck to the lubricant and later got wedged into the strand.

Fig. 61 shows a closing rope of a grab crane. All outer wires had broken due to severe abrasion. The flared exit funnel of the grab has pushed all the loose wire ends along the rope length to one location, creating this impressive hedgehog.

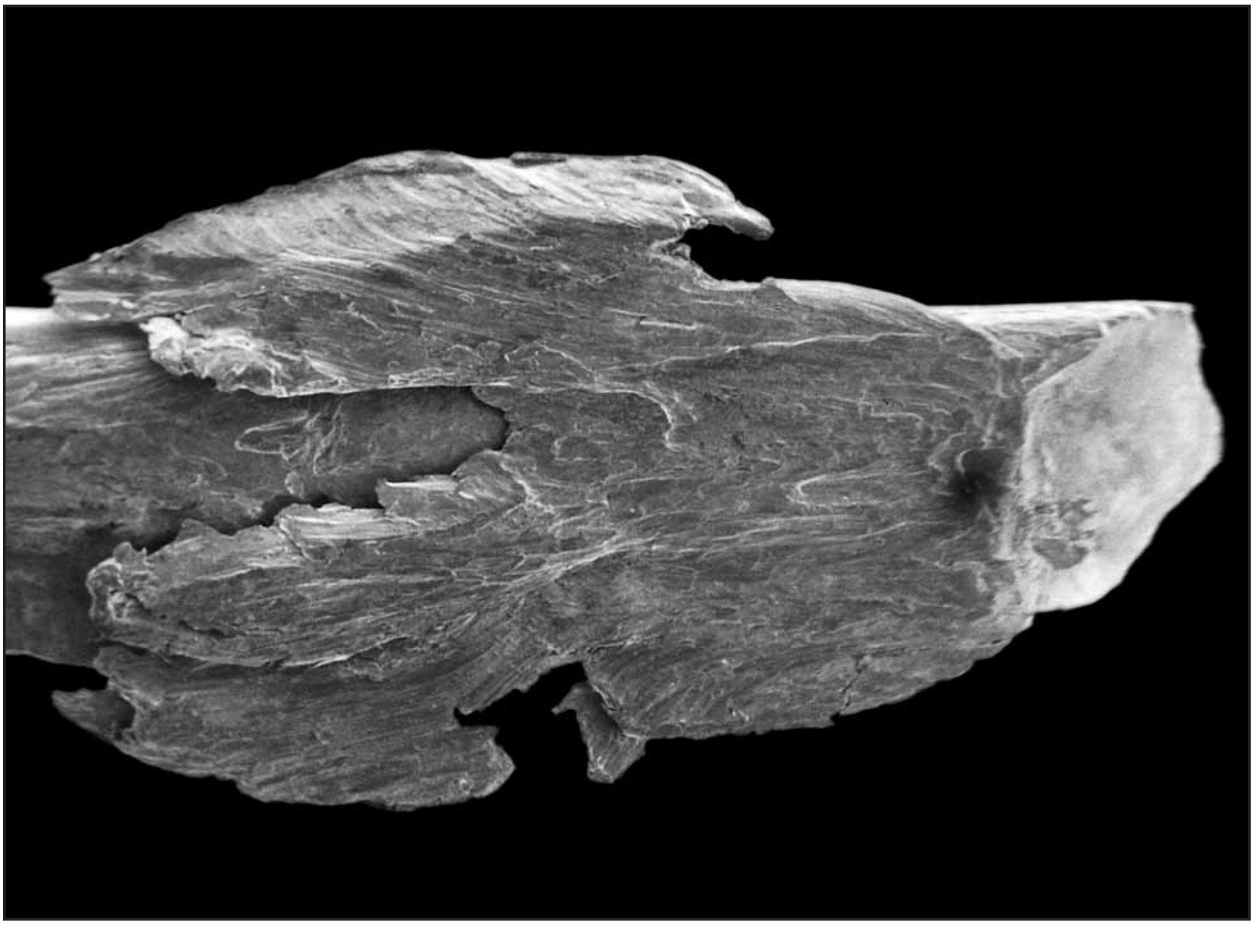


Fig. 54: Severe plastic deformation caused by the rope hitting a steel structure. The high axial line pull combined with high transverse loading, has finally lead to the shear failure of the wire.

EXTERNAL DAMAGE

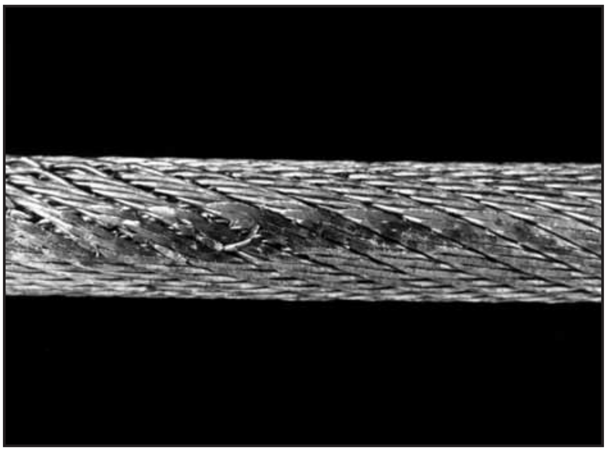


Fig. 55: This rope has been damaged by being pulled over a stuck sheave.

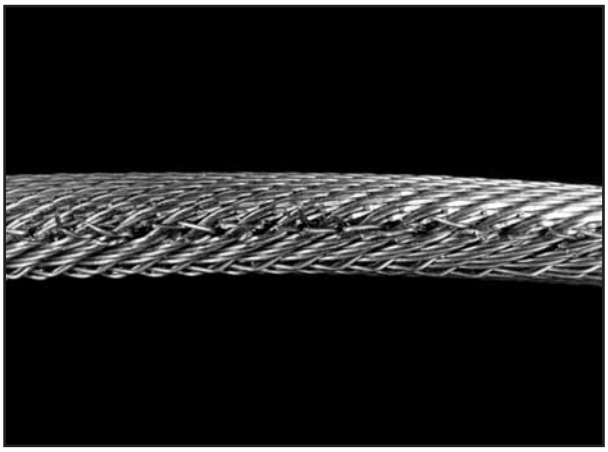


Fig. 56: Rotation resistant rope damaged by being dragged over the rim of a sheave.

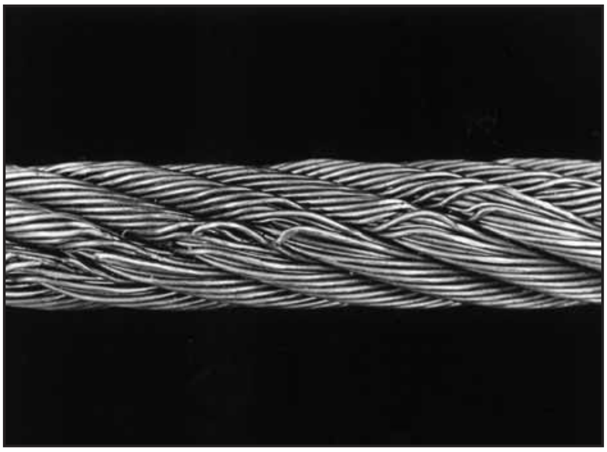


Fig. 57: An eight strand rope damaged by being dragged over the rim of a sheave. Please note the helical damage pattern.

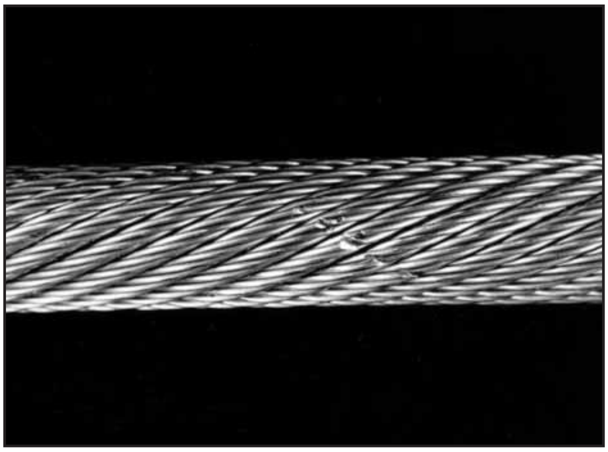


Fig. 58: Rotation resistant rope damaged by striking a sharp edge.

Fig. 59: Damage caused by shot-blasting a crane before repainting. Shot stuck to the lubricant and later wedged into the strand.

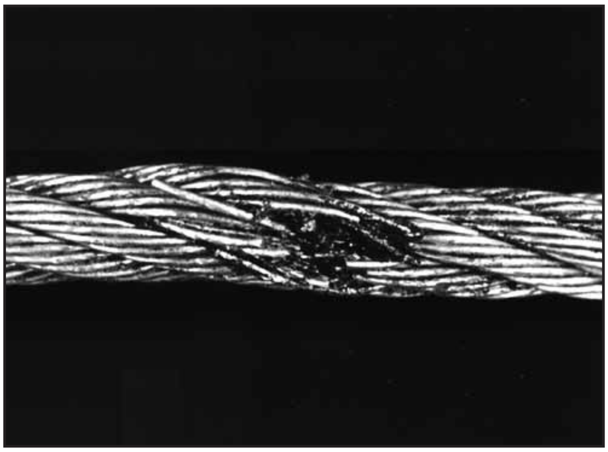


Fig. 60: Six strand rope damaged by striking a sharp edge. This rope is in a dangerous condition and must be discarded.

EXTERNAL DAMAGE

Fig. 61: Closing rope of a grab crane. All the outer wires had broken due to severe abrasion. The flared exit funnel of the grab has pushed all loose wire ends along the rope length to one location, creating this impressive hedgehog.

Fig. 62: Ropes that have been pulled over a sharp edge have a tendency to coil when unloaded.

MARTENSITE FORMATION

Martensite is a very hard and brittle metal structure. It is formed when steel is heated above the transformation temperature and then rapidly cooled.

In steel wire ropes, martensite is often found as a thin layer on the crowns of rope wires where these have been dragged over a hard surface (Figs. 63 and 64). This thin martensite layer will easily crack when the wire is being bent, initiating a fatigue crack which will rapidly propagate (Figs. 66 and 67).

Martensite formation on the wire surface is difficult to detect. Even in a mounted sample it has to be made visible by etching the microstructure.

Lightning strikes or arcing caused by welding on the crane structure might also produce martensite on wire surfaces (Fig. 65).

The wire shown in Figs. 63 and 64 has been dragged along the edge of a hatch several times when unloading a ship. Each time a new layer of martensite formed, partly tempering the underlying martensite layers. The white structure is martensite, the darker bands are tempered martensite.

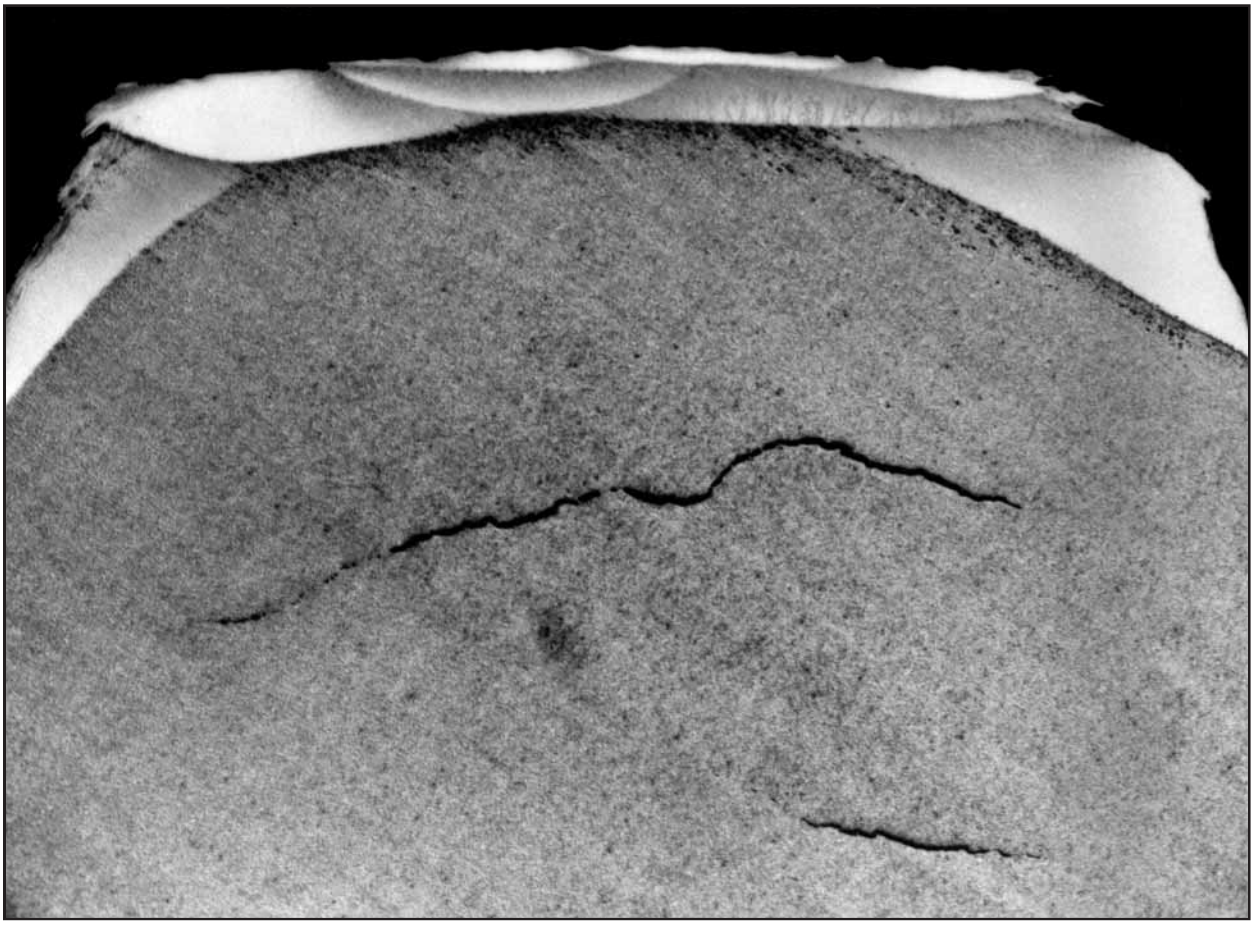


Fig. 63: This outer wire of a rope has been dragged along the edge of a cargo hatch several times when unloading a ship. Each time a new layer of martensite formed, partly tempering the underlying martensite layers. The thickness of the martensite layer is approx. 0.05 mm.

MARTENSITE FORMATION

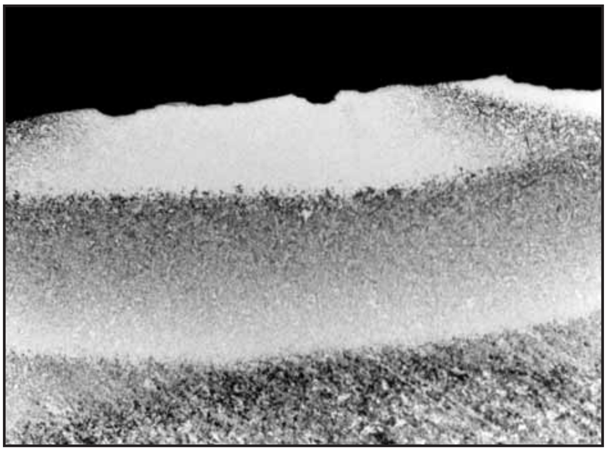


Fig. 64: Detail of Fig. 63. The white structure is martensite, the darker bands are tempered martensite.

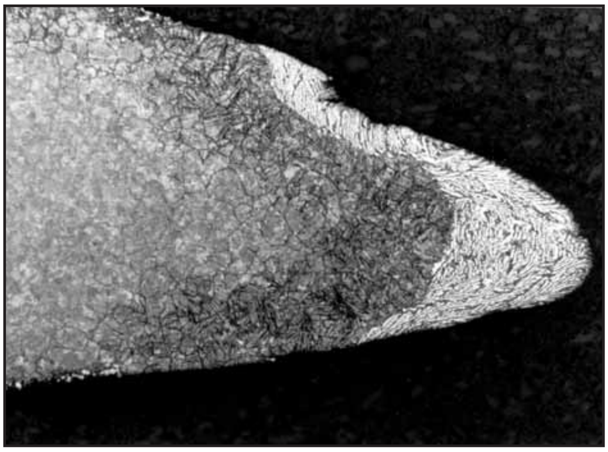


Fig. 65: Martensite (white tip) formed by arcing.

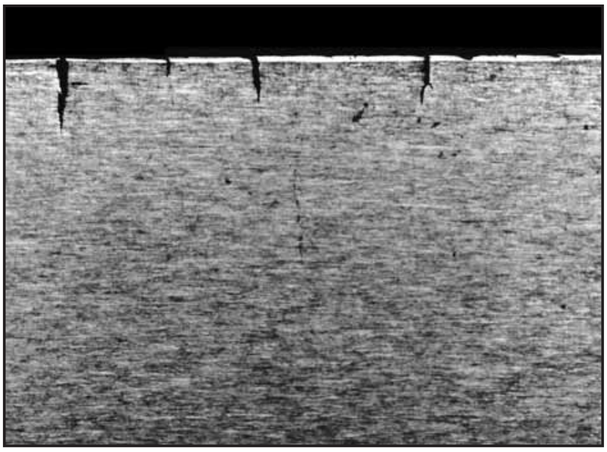


Fig. 66: Layer of martensite on the surface of a rope wire.

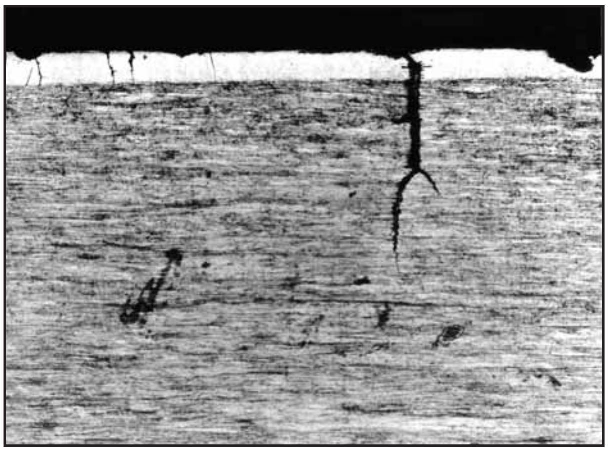


Fig. 67: Detail of Fig. 66 showing the crack formation.

Fig. 68: No, this is not martensite. It is the zinc coating of a galvanized wire flaking off (see also Fig. 111.)

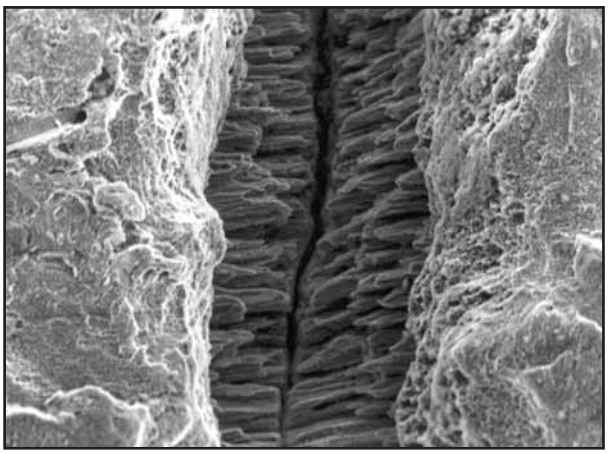


Fig. 69: Detail of the same wire as shown in Fig. 68. A fatigue crack has formed underneath the zinc coating.

DAMAGE CAUSED BY HEAT

Steel wire rope is a very good conductor of heat. Therefore zones of a wire rope can work in a very hot environment for a limited time as long as the heat absorbed by the rope can be conducted away to other, cooler areas of the rope.

If, however, the temperature within the rope wires exceeds approximately 300°C, the microstructure of the cold drawn wires will recrystallize (Figs. 71, 76 and 77), losing about two-thirds of the wire tensile strength in the process.

If the energy input is much higher than the rate at which the rope can conduct or dissipate heat, then the wire rope will heat up very quickly. This will happen for example when lightning or arcing strikes a rope locally, heating up the wire rope to temperatures where the steel will melt (Figs. 70 and 78).

According to EN12385-3, stranded rope with fibre cores may be used up to a maximum of 100°C. Stranded ropes with steel cores can be used up to 200°C. Special attention must also be given to the temperature limitations of the end connection (see e.g. EN12385-3).

Even if the strength of the wire rope is not affected by the temperature, a reduction in fatigue life must be expected when the working temperatures meet or exceed the drop point of the lubricant used.

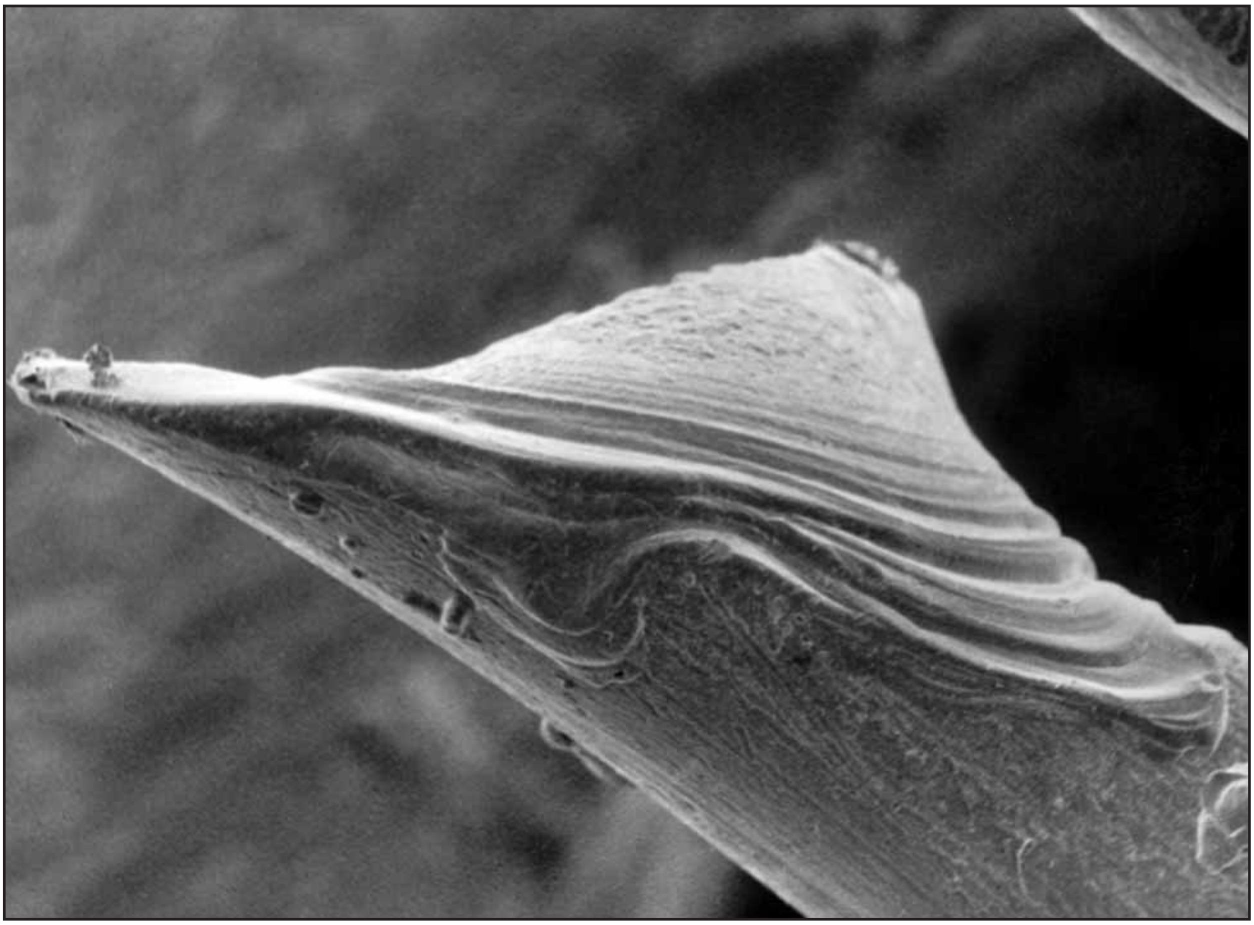


Fig. 70: A lightning strike has subjected this wire to considerable local heat causing the steel to melt.

DAMAGE CAUSED BY HEAT

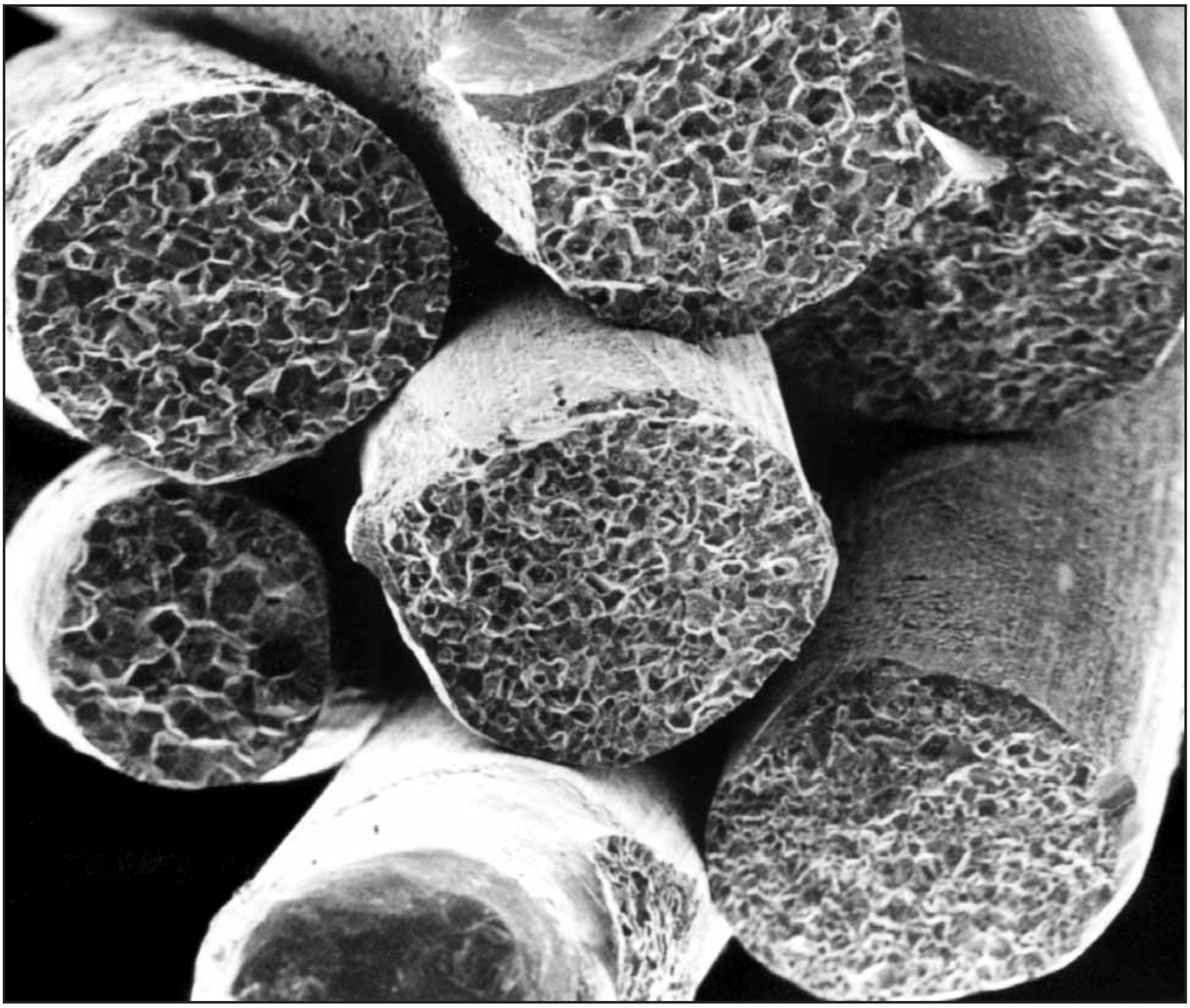


Fig. 71: This seven wire strand has been subject to temperatures greater than approximately 300°C. The microstructure of the wires has undergone a recrystallization from the highly oriented drawn wire structure.

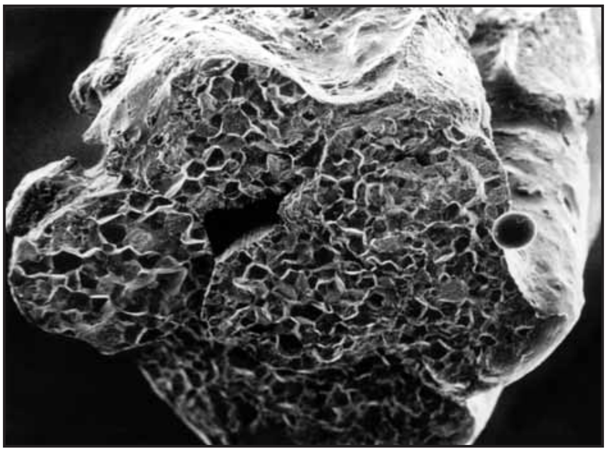


Fig. 72: At even higher temperatures, the steel will melt and the individual wires fuse.

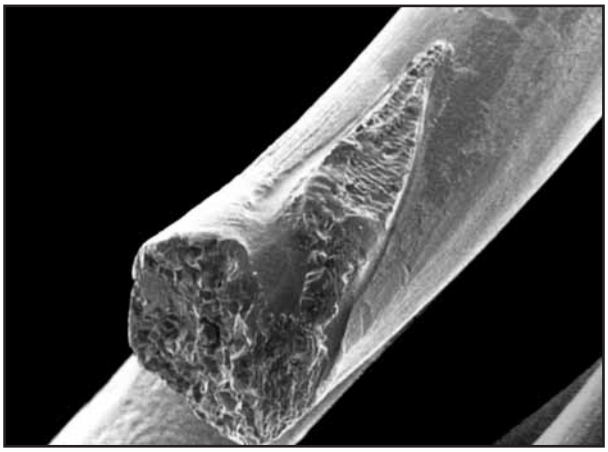


Fig. 73: The recrystallization is accompanied by an increse in volume, causing the wire to crack longitudinally.

DAMAGE CAUSED BY HEAT

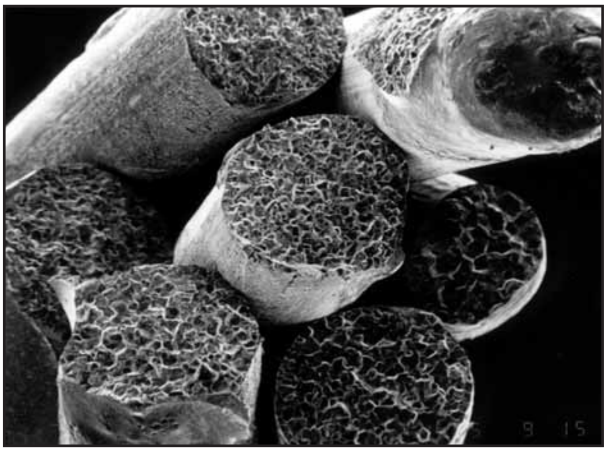


Fig. 74: The microstructure of these wires has undergone a recrystallization from the highly oriented drawn wire structure.

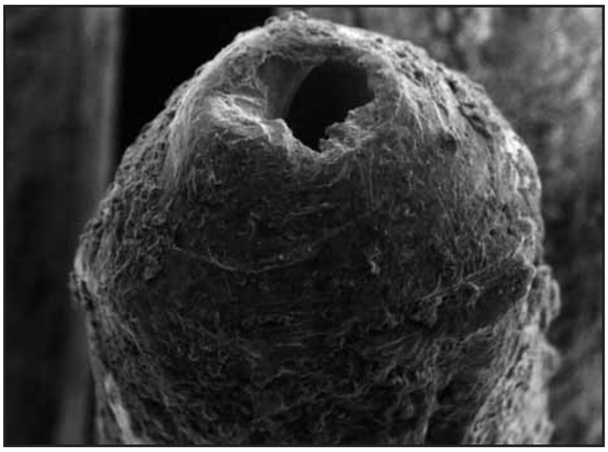


Fig. 75: Detail of wire shown in the top right of Fig. 74. Here, the temperature was even high enough to melt the wire.

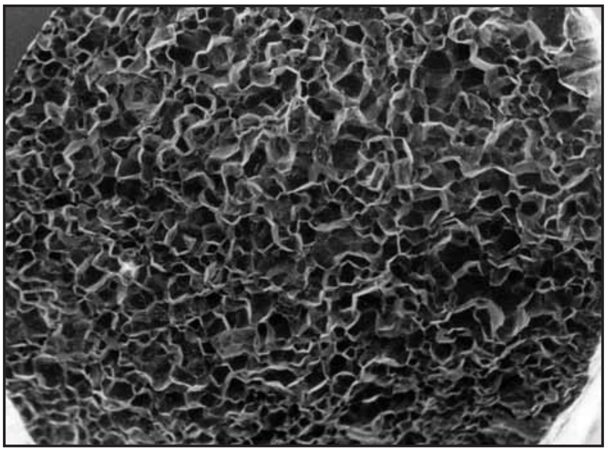


Fig. 76: Recrystallized structure.

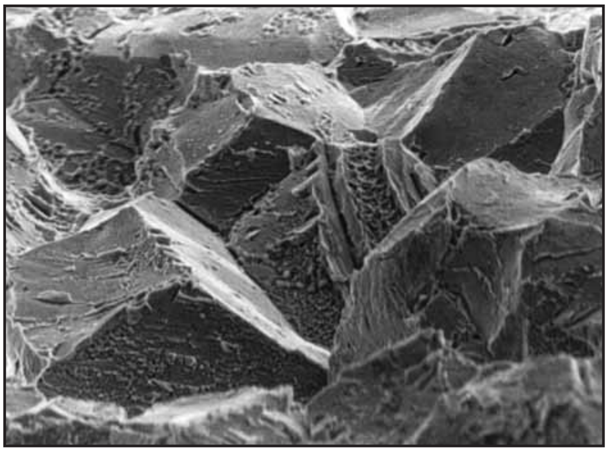


Fig. 77: This detail of Fig. 76 shows the intergranular fracture of the crystalline structure.

Fig. 78: High local temperatures during arcing fused these wire ends.

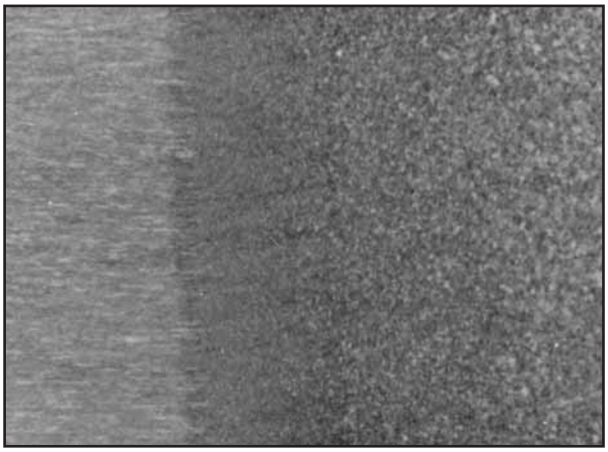


Fig. 79: This etched sample shows the transition from the cold drawn wire structure (left) to the recrystallized structure (right).

DAMAGE CAUSED BY HEAT

Fig. 80: This hoist rope from a ladle crane has been exposed to elevated temperatures for too long. As a result of this the outer wires have annealed, softened and then lengthened in service.

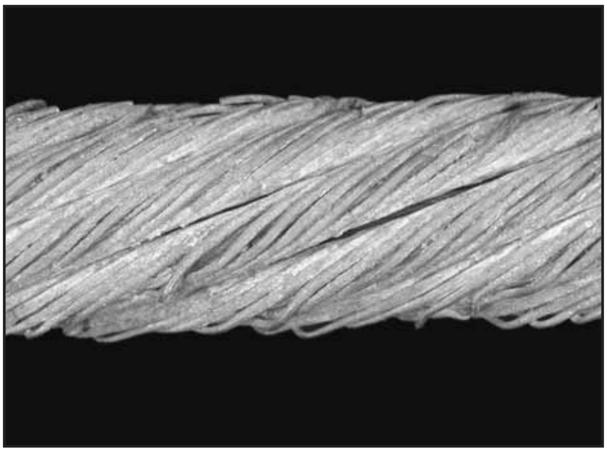


Fig. 81: Another detail of the same rope as shown in Fig. 80. Please note that the lubricant has completely disappeared.

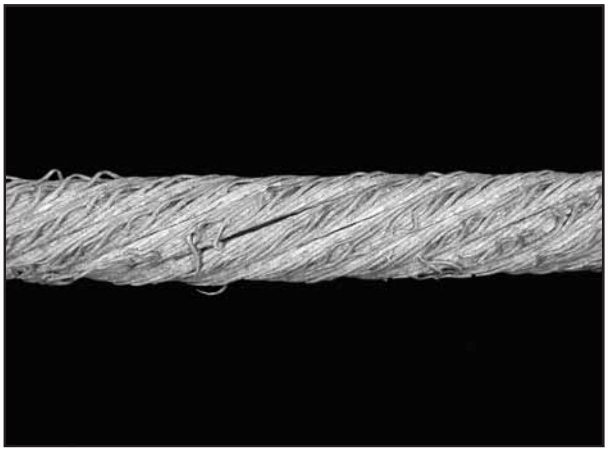


Fig. 82: Another detail of the same rope as shown in Fig. 80.

INTERNAL WIRE BREAKS

A visual and tactile inspection of a steel wire rope will have to rely on the condition of the outer wires. In most ropes, these represent about 40% of the metallic cross section. The outer wires are visible for only about half their length. Therefore a visual and tactile inspection of a steel wire rope will have to rely on the condition of about 20% of the metallic cross sectional area only.

Visual rope inspection =
20% evidence + 80% hope

If the contact conditions between the rope elements inside the rope are worse than the contact conditions on the sheave, the rope wires will fail on the inside first. This is very dangerous because internal wire breaks are very hard to detect. Non-destructive testing equipment can help in the detection of internal wire failures.

Wire ropes working on plastic sheaves are more likely to fail from the inside out than ropes working on steel sheaves.

A steel core too small in diameter will lead to insufficient clearance between two adjacent outer strands and cause interstrand nicking (Fig. 142) and so-called valley breaks.

A plastic layer between the steel core and the outer strands will reduce the local pressure between the layers and therefore reduce the risk of internal wire breaks.

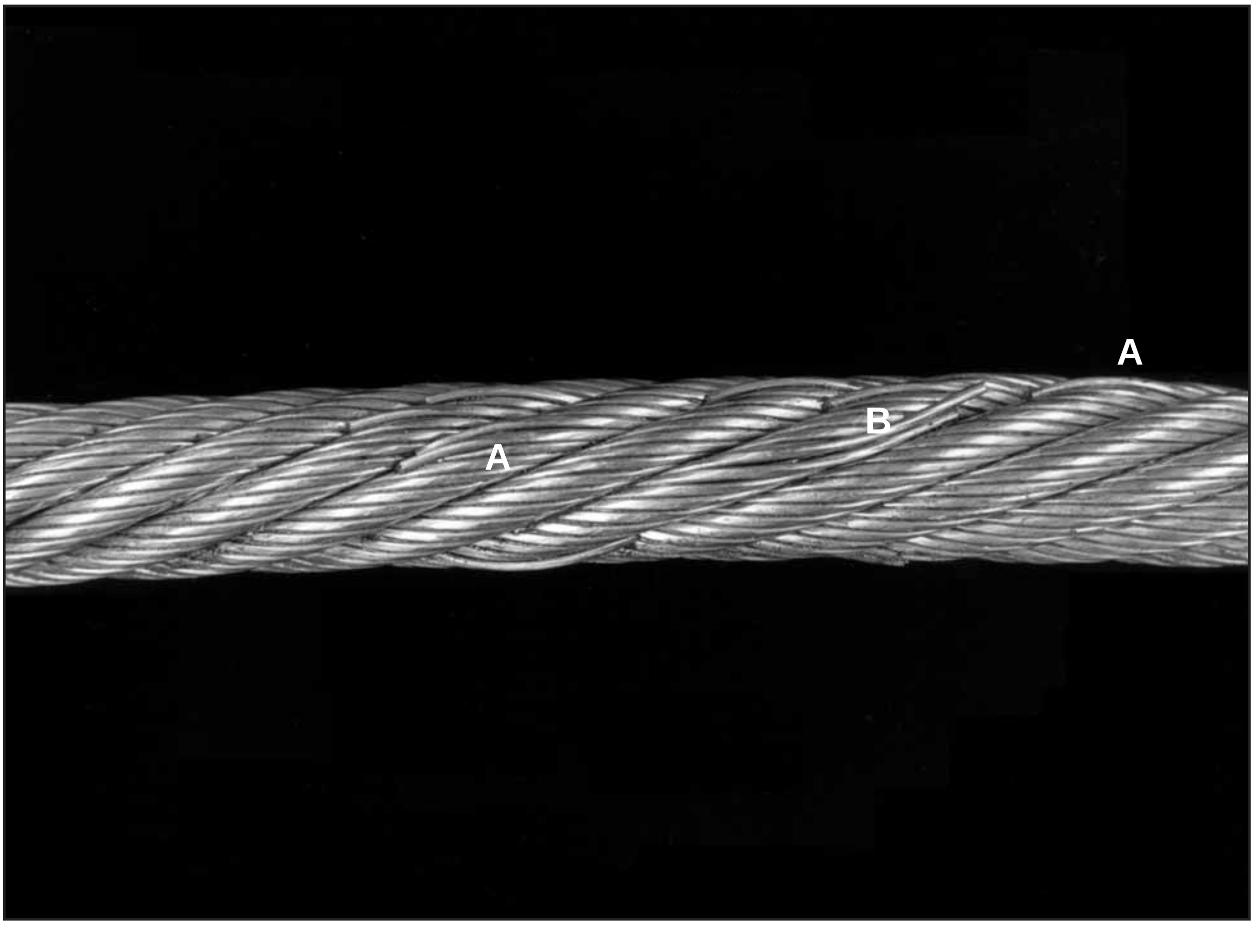


Fig. 83: An eight strand rope showing evidence of internal wire breaks. Please note that the broken wire ends are twice as long (A, broken in the valley) or three times as long (B, broken underneath the outer strand) as they would be had they broken at the crown.

INTERNAL WIRE BREAKS

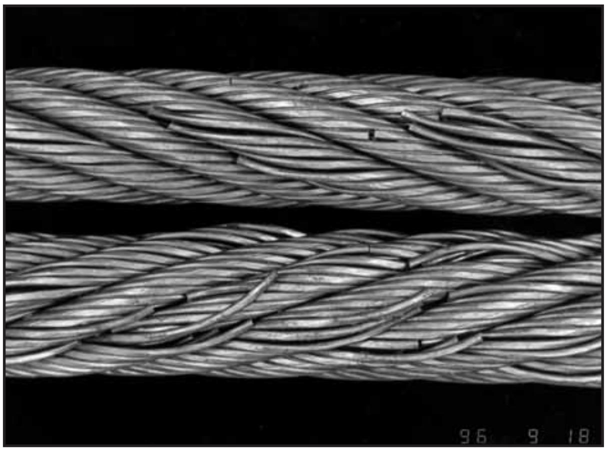


Fig. 84: The great number of internal wire breaks have only been revealed by severely bending the ropes during inspection.

Fig. 85: Opening up this discarded steel wire rope proved that the steel core was no longer in very good condition.

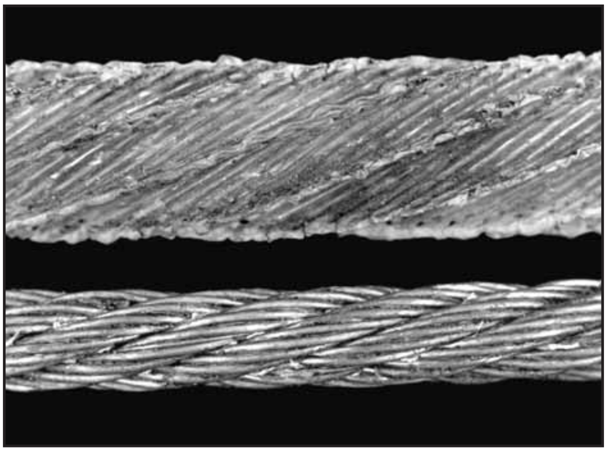
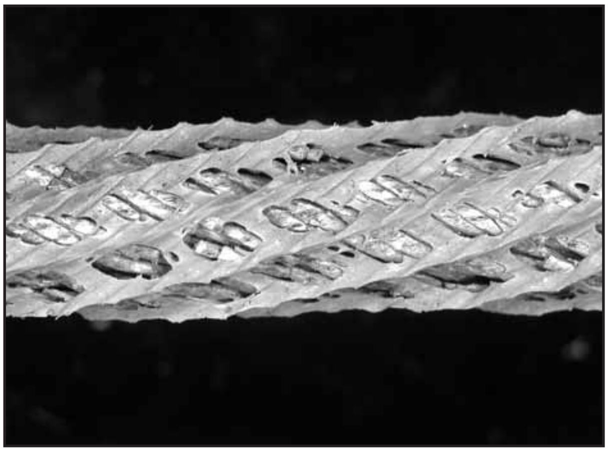


Fig. 86: Undamaged plastic coated steel core of a discarded rope after removing the outer strands and after removing the plastic layer.



Photograph by Frank Loch

Fig. 87: Damaged plastic layer perforated by the outer and inner strands. The hardness of the plastic was insufficient for the purpose.

Photograph by Frank Loch

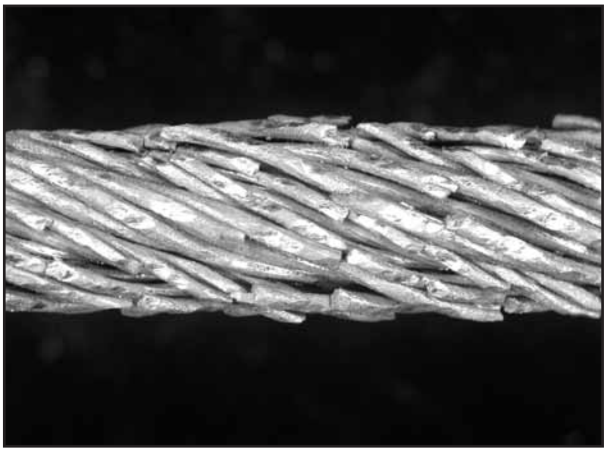
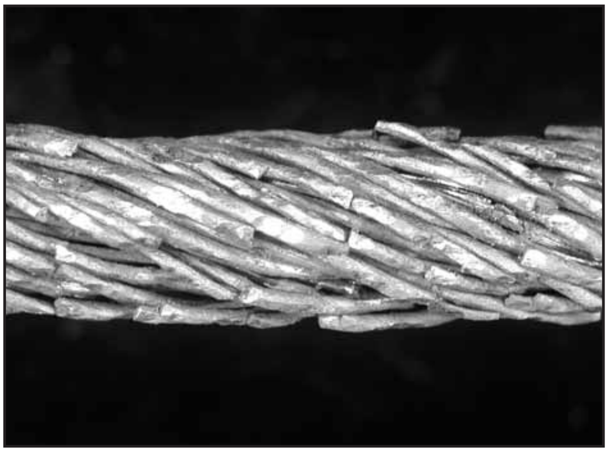


Fig. 88: The rope core shown in Fig. 87 after removing the plastic layer. The outer wires have broken at the crossover points.



Photograph by Frank Loch

Fig. 89: The rope core shown in Fig. 87 after removing the plastic layer. The outer wires have broken at the crossover points.

INTERNAL WIRE BREAKS

Outer wires which have broken at the point of contact with the steel core can be made visible by severely bending the rope during inspection or by trying to lift up the outer wires with the aid of a screw driver.

Internal wire breaks often will display typical fatigue breaks with wire ends twice as long (valley breaks) or three times as long as those occuring at the crown of the outer wire (see Figs. 83 and 90).

Rotation resistant ropes have relatively good contact conditions on the sheaves. Because of the fact that the rope core is closed in the opposite direction to the outer strands, however, there are many wire cross-overs inside the rope. Therefore, rotation resistant ropes tend to develop a great number of internal wire breaks. Rope cores closed in one operation (parallel lay) or internal plastic layers avoid crossovers and reduce this danger.

In cyclic tension condition, the rope must get longer and shorter during every cycle. The sections lying on drums or sheaves are restricted from adapting their length to the line pull. The core will therefore try to get longer while the outer strands are held back by the drum or sheave surface. This will lead to internal wire breaks. A drum surface as in Fig. 95 is always a clue that the rope might fail from the inside out.

As mentioned earlier, NDT will help to detect internal wire breaks.

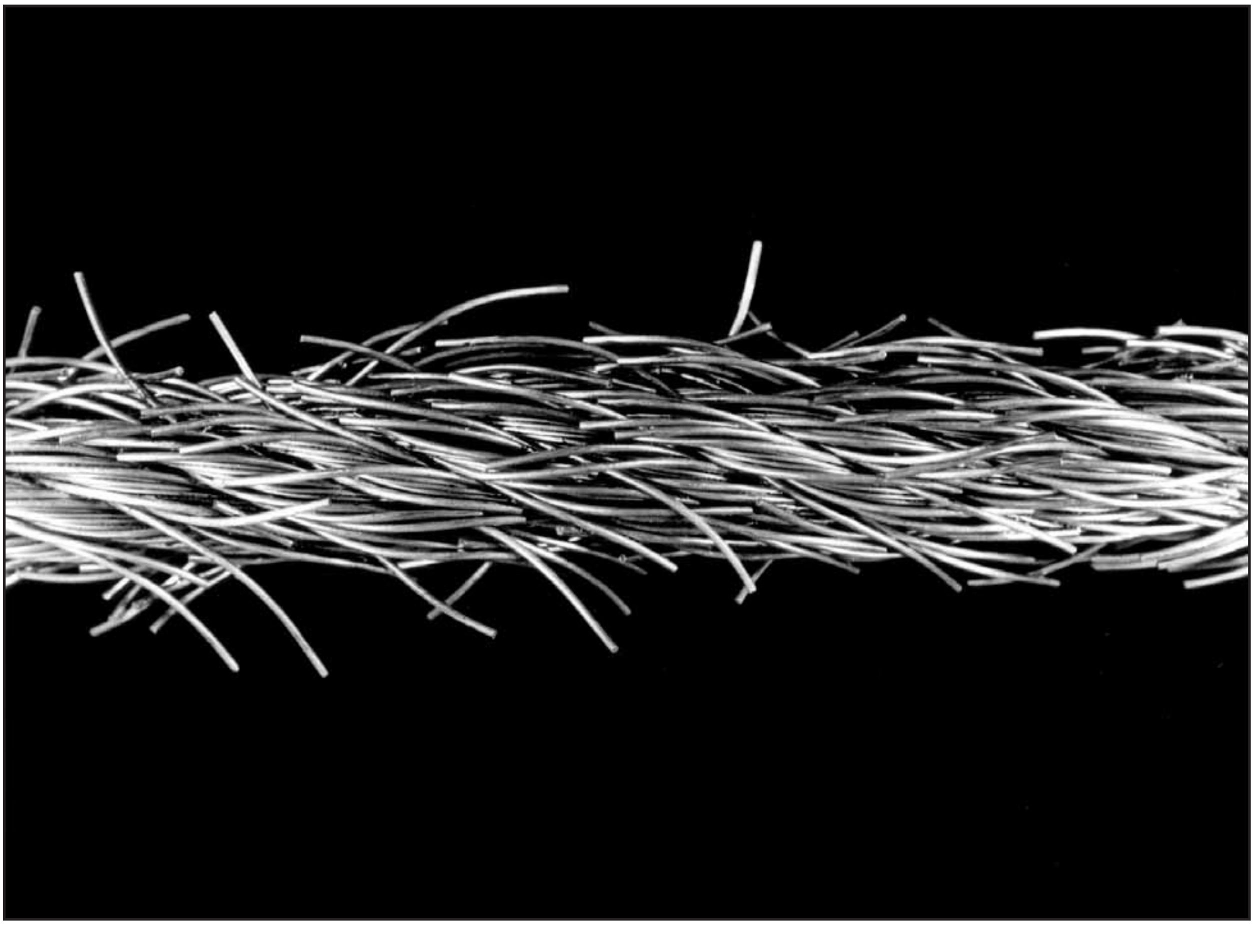


Fig. 90:This rope did not show a single external wire break. Fortunately the inspector severely bent the rope: an incredible number of internal wire breaks became apparent. A plastic layer will help prevent internal wire breaks.

INTERNAL WIRE BREAKS

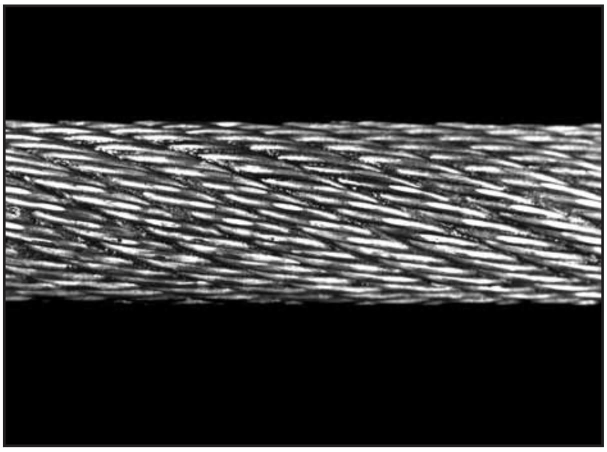


Fig. 91: Outer surface of a 36 x 7 rotation resistant hoist rope. No wire breaks are visible.

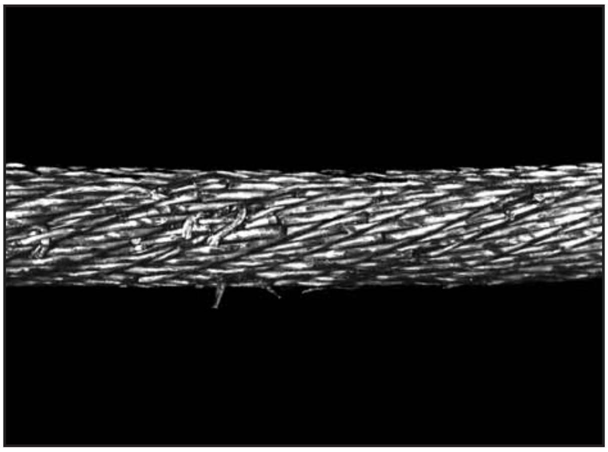


Fig. 92: The same 36 x 7 rope after removing the outer strand layer. Many wire breaks can be found at the crossover points.

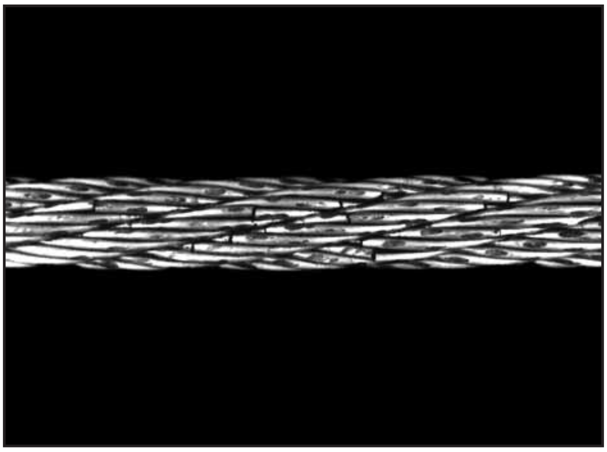


Fig. 93: The innermost strand layer of the same 36 x 7 rope also shows a great number of wire breaks.

Fig. 94: The cross over marks between two strand layers are often the starting points for fatigue cracks inside the rope.

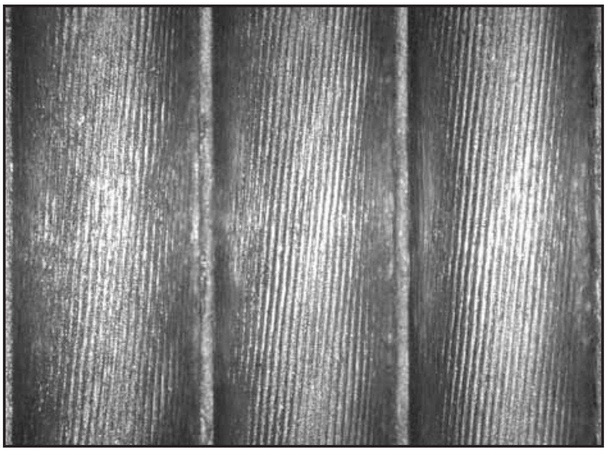


Fig. 95: Longitudinal scratch marks on a drum suggest that the rope might develop internal wire breaks.

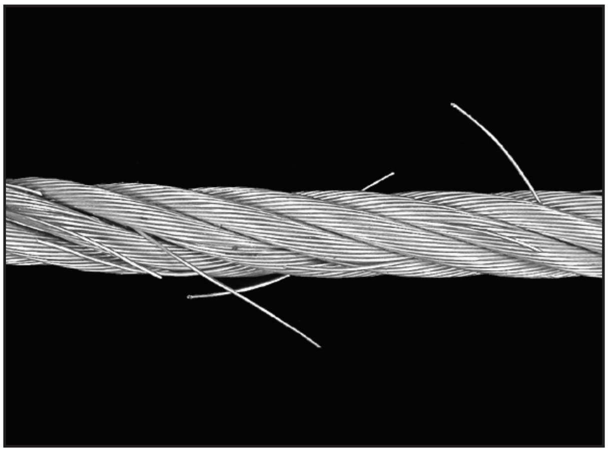


Fig. 96: Internal wire breaks are never alone. If you find one, look for more!

DAMAGE FROM ROTATION

A steel wire rope is made up of helical elements. If the rope is twisted in the opening sense, these helixes will be opened up and lengthened, if it is twisted in the closing sense, the helixes will be closed and shortened. These changes in geometry will change the wire rope properties, sometimes considerably.

In order to prevent unlaying, non rotation resistant steel wire ropes must be fixed with their ends secured against rotation. Rotation resistant ropes, on the other hand, will not have a tendency to unlay under load and can therefore be attached to a swivel. The swivel is even advantageous because it will allow twist caused by other mechanisms to leave the system.

If the rope is travelling over sheaves or a sheave is travelling over the rope, the length differences created between the rope elements might be accumulated at a single point (usually the point where the sheave travel stops), see e.g. Figs. 97, 98 and 101.

Twisted rope sections will have a tendency to get rid of some of their twist by sharing it with previously nontwisted rope sections. This is how twist can travel through a reeving system, causing problems in areas far distant from the point where it originated (Fig. 108).

Because of their helical surface, ropes can also be twisted when pulled through tight sheaves or rubbing along structual members.

Fig. 97: A surplus of strand lengths in the steel core caused by twisting the rope has been accumulated at one point by a sheave. Defects like this are usually found at the end of the motion of the sheave over the rope (or of the rope over the sheave).

DAMAGE FROM ROTATION

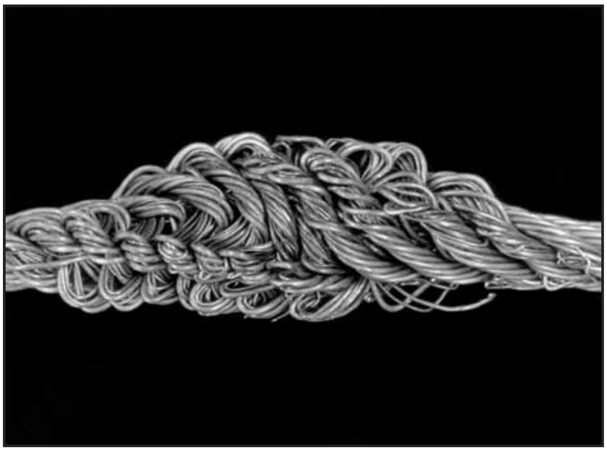


Fig. 98: This shows the rope section from Fig. 97 with the outer stands removed to reveal the surplus length accumulated in the core.

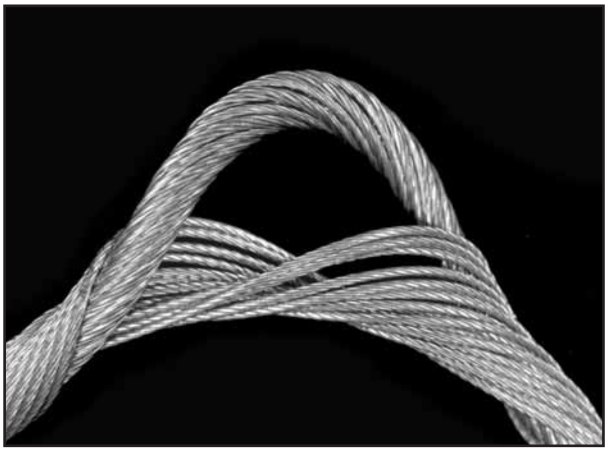


Fig. 99: This rotation resitant rope has been shortened, and its core lengthened, by twisting the rope in the closing sense.

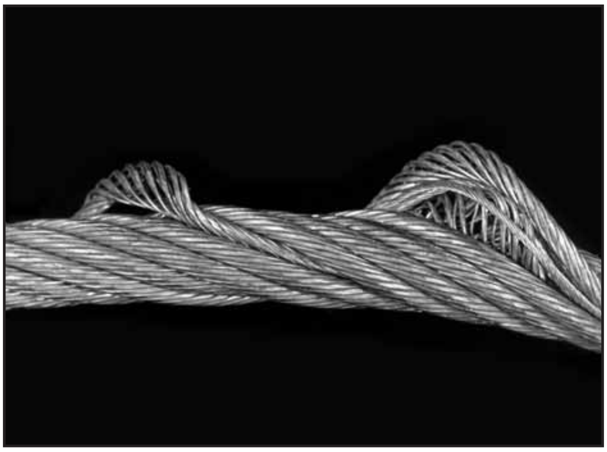


Fig. 100: Double parallel lay ropes are very sensitive to being twisted. Here the inner elements are forced out due to rope twist.

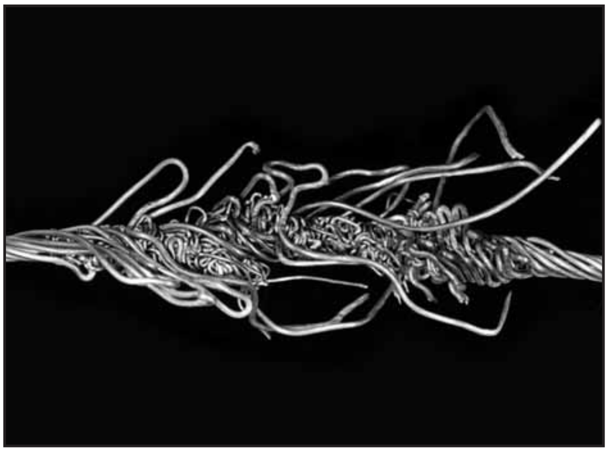


Fig. 101: Sometimes the rope twist only affects the innermost strand which is the shortest and the only straight strand in the rope.

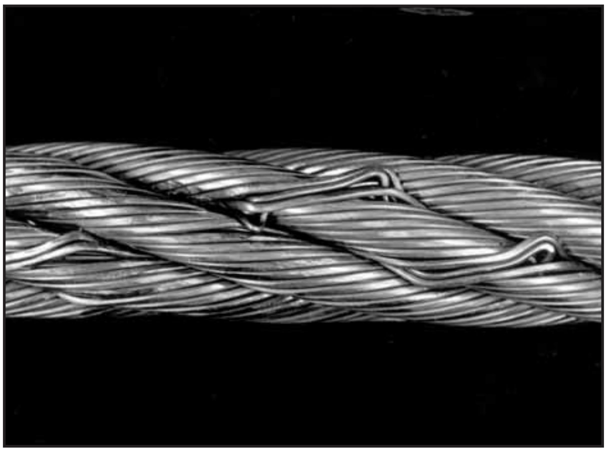


Fig. 102: In this six strand rope, twist has loosened the two outer layers of wires in the outer strands.

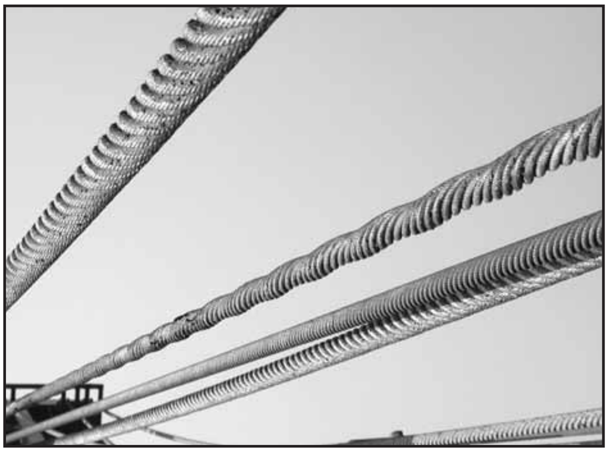


Fig. 103: Corkscrews can be formed if a rope rubs agaist structual members or runs through tight sheaves (a combination of rotation and friction).

DAMAGE FROM ROTATION

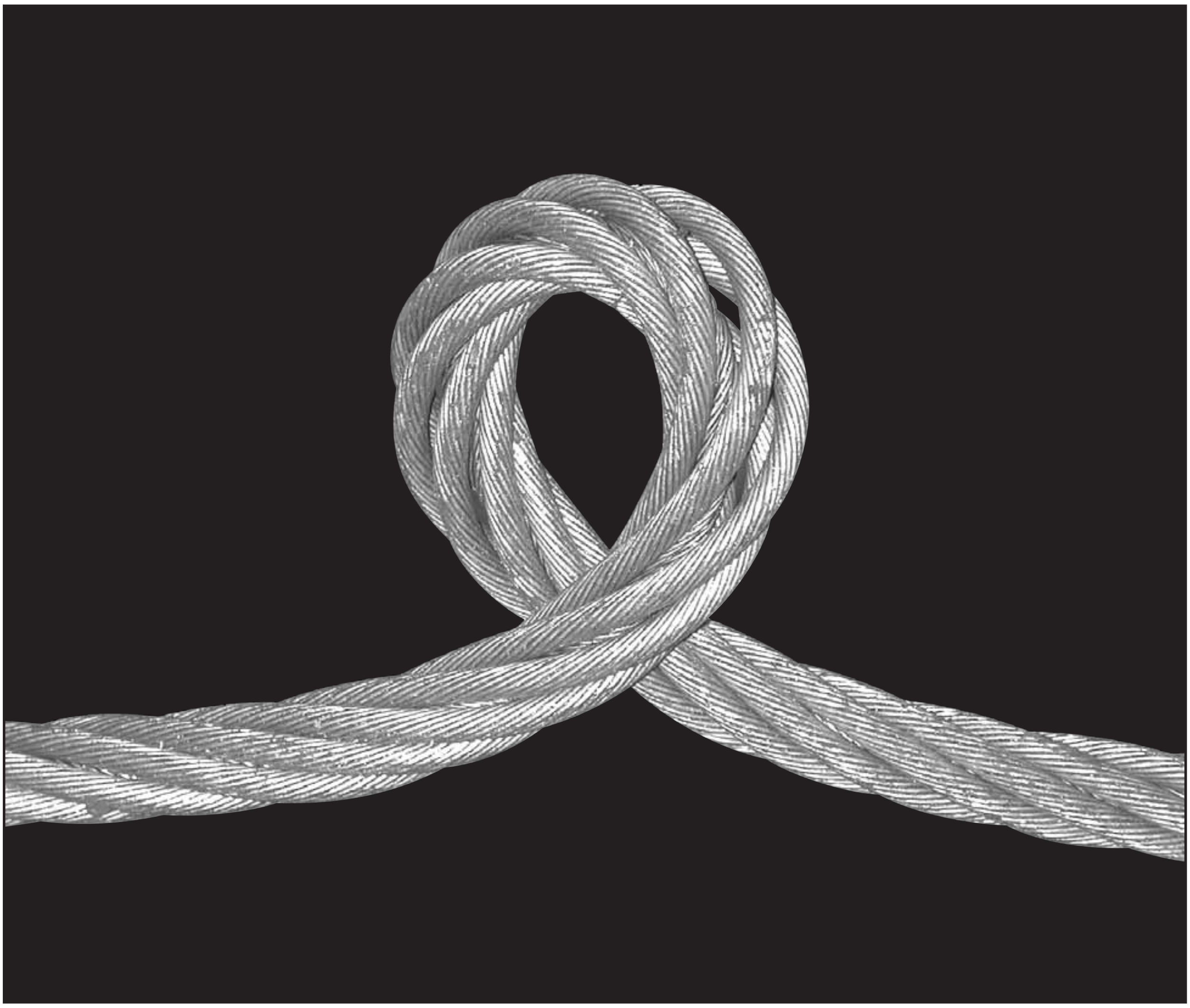


Fig. 104: This rope has been twisted in the opening sense. When slack, it will form a hockle in the closing sense. When hockles are loaded, they might pull tight and permanently deform the rope.

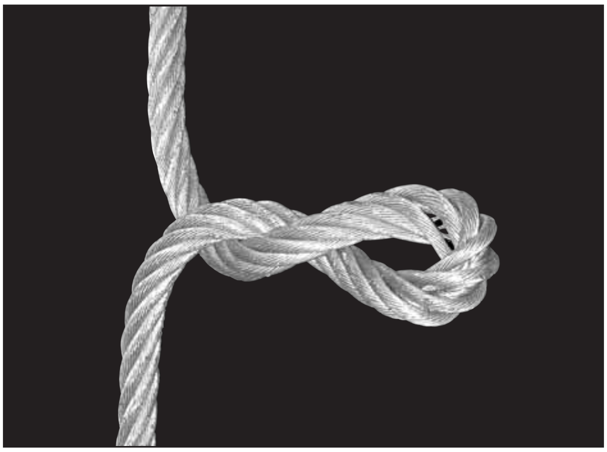


Fig. 105: This rope has been twisted in the closing sense. When slack, it will form a hockle in the opening sense.

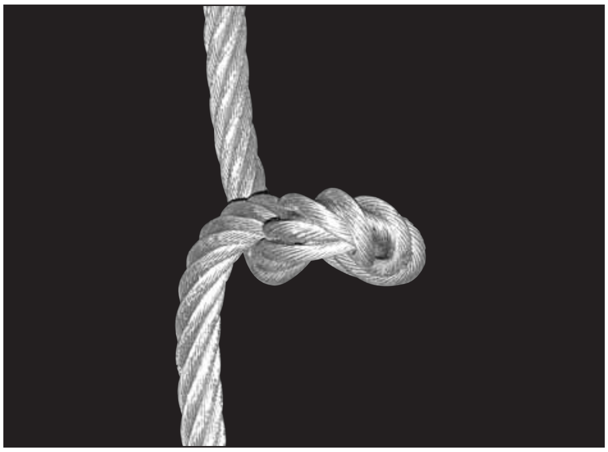


Fig. 106: The same hockle as in Fig. 105. Under load, the hockle pulls tight, causing severe rope damage.

BIRDCAGING

A birdcage is a short section of rope in which the outer strands are much longer than the rope and therefore “stand up”. Birdcages are normally formed when a wire rope is opened up by twisting or by being twisted around its own axis. In an opened up (unlaid) condition, the outer strands are too long for the rope length, and the “superflous” strand length is brought to one point by a sheave (Fig. 107). This is why birdcages are often found at the end of the sheave travel.

A shortening of the rope can also create too much strand length for the inner rope elements (e.g. Figs. 98 and 101).

The worst situation arises if a rotation resistant rope is twisted in the opening sense. This causes a lengthening of the outer layer and at the same time a shortening of the core. This is why rotation resistant ropes are so sensitive to being twisted by external mechanisms (e. g. fleet angles).

Birdcages can also be created by dragging a rope through a tight sheave.

If a non rotation resistant or semi rotation resistant rope is operated with a swivel, the rope will unlay. Unlaid rope sections will then travel over sheaves. The result often is a birdcage or several birdcages at the other end of the rope (see Fig. 108).

Contrary to common belief, 99.5% of all birdcages are not created by shock-loads.

Fig. 107: This steel wire rope has been unlaid. In this state its outer strands are too long for the rope length. A sheave has accumulated the “superflous” strand lengths to a point at the end of its travel.

BIRDCAGING

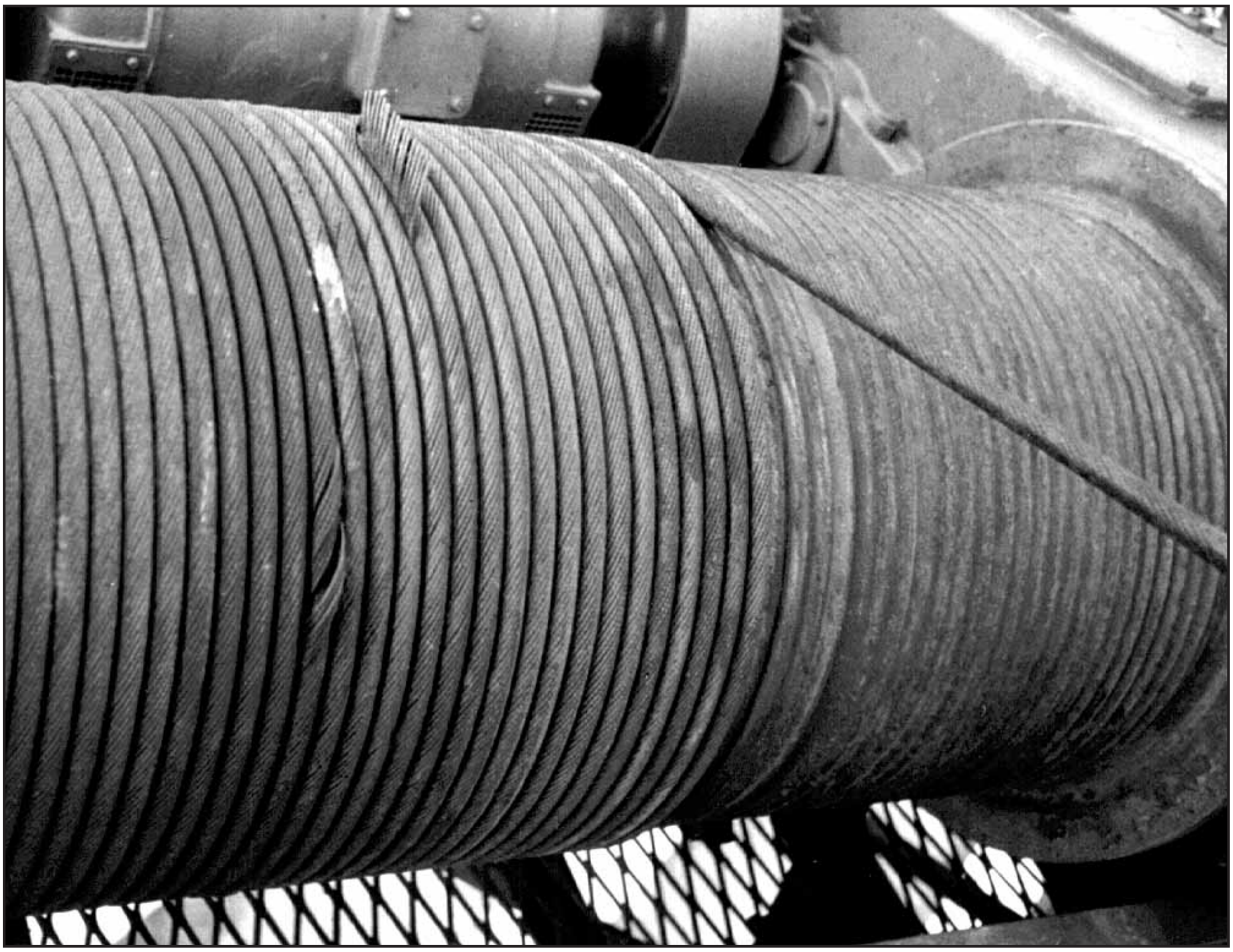


Fig. 108: This semi rotation resistant rope has been attached to a free spinning swivel. Under load, the rope opened up, and twisted rope sections travelled through the reeving system. The sheaves moved the “superflous” strand lengths through the reeving system until they ended up on the drum. This is a typical example of how an action at one end of the rope (the use of swivel) causes a reaction (the creation of birdcages) at the other.

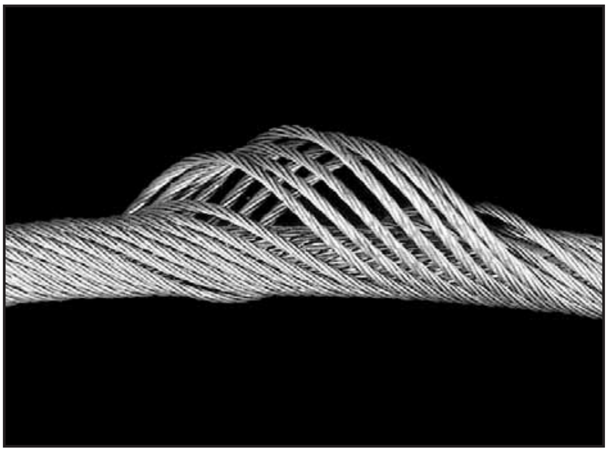


Fig. 109: Birdcage on a rotation resistant rope. If you’ve seen one you’ve seen them all.

Fig. 110: Another example of a birdcage on a rotation resistant rope.

DAMAGE FROM THE SHEAVE

If a steel wire rope enters a sheave under a fleet angle, it will first touch the groove flange. It will then partly roll down, partly slide down into the bottom of the groove. This mechanism will twist the rope, leading to the torsional problems described in the previous sections. It will also lead to increased wear, both on the surface of the wire rope and on the flange of the sheave (Figs. 122 and 123).

Both the amount of twist and the amount of wear can be reduced by lubricating the wire rope and by opening up the groove throat angle (e.g. to 60°). Contrary to common belief, a throat angle of 60° poses less danger of the rope jumping a sheave than a throat angle of 45°.

A tight or stuck sheave might create birdcages or severely deform the outer wires or strands of the rope (Fig. 111). Often martensite is formed on the wire surfaces (see pages 21 and 22). If, on the other hand, the groove diameter is much bigger than the rope diameter, the groove will not support the rope sufficiently and create very high local pressure, leading to premature wire failures (Fig. 121).

If a long end of a broken outer wire catches and is bent across its neighbouring strands, it will easily get caught between the wire rope and the sheave causing nicking damage. This is especially relevant to Langs lay ropes where the exposed wire ends are always long (Figs. 116 and 117).

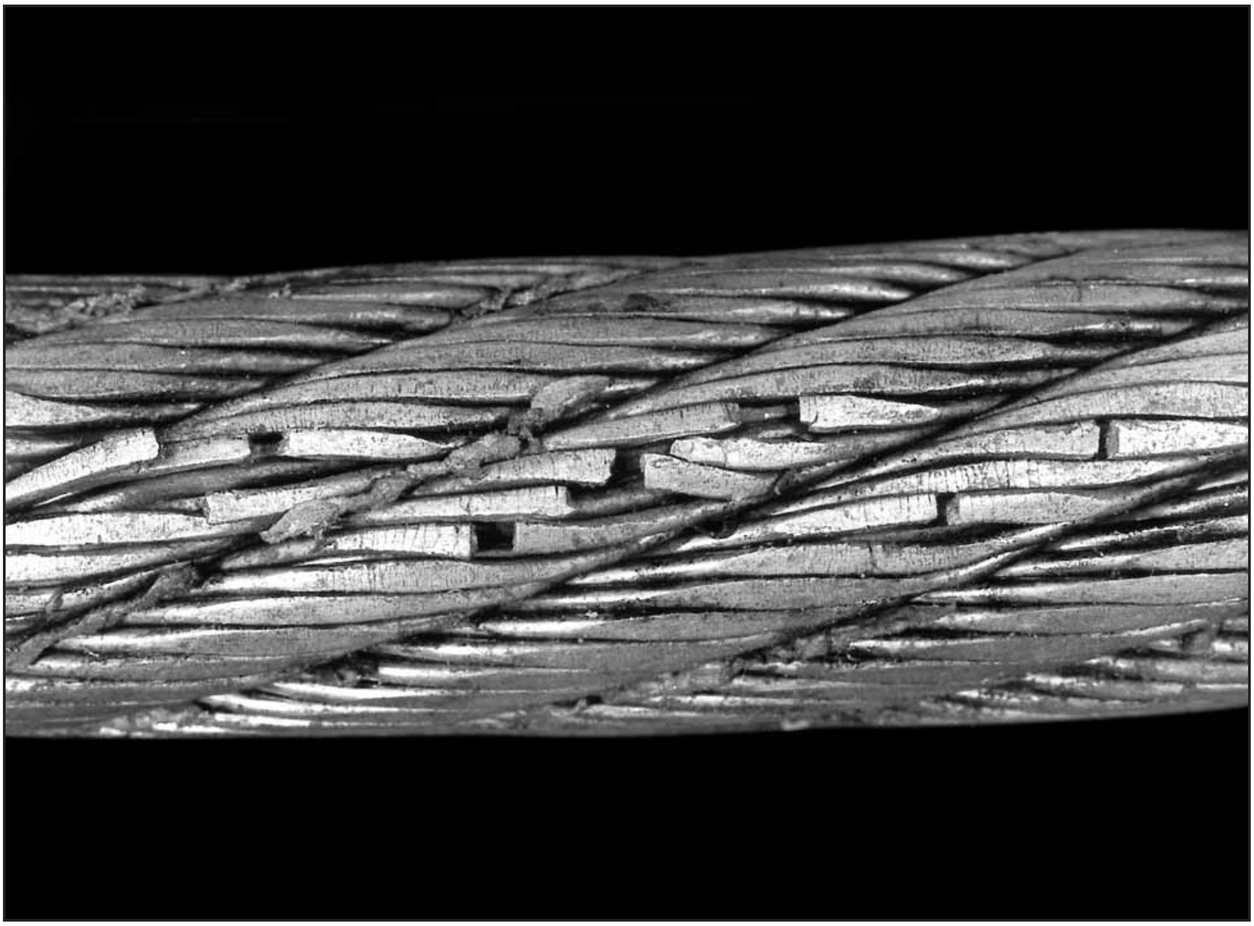


Fig. 111: This eight strand rope has worked in a tight sheave. Its internal plastic layer has prevented the formation of a birdcage, but a lot of cracks have formed in the galvanized outer wires (see also Figs. 68 and 69 from the same rope).

DAMAGE FROM THE SHEAVE

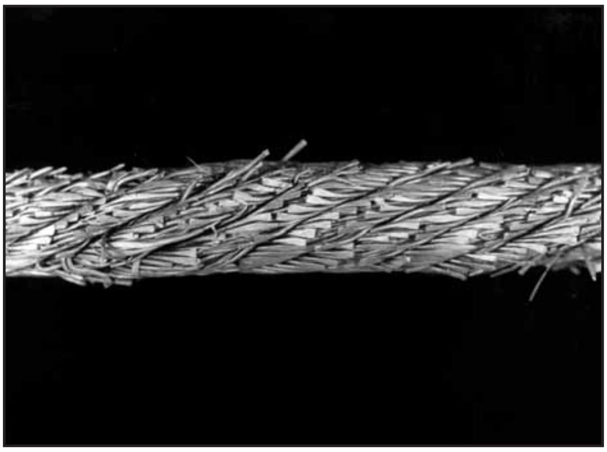


Fig. 112: This rope has been operated in a tight sheave.

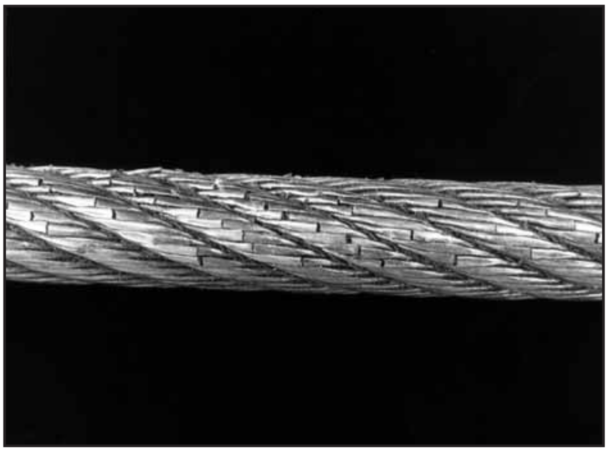


Fig. 113: Another example of a rope which has worked in a tight sheave.

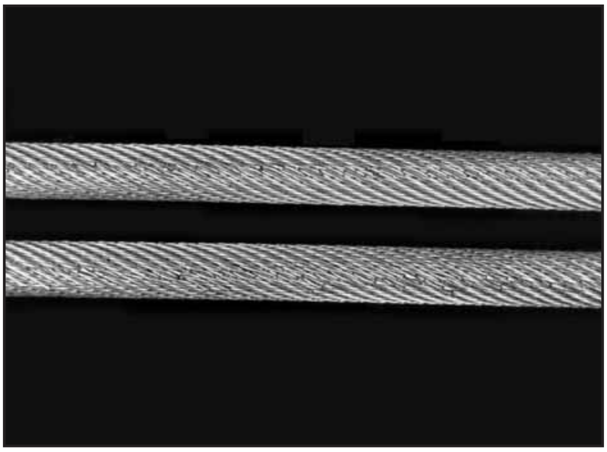


Fig. 114: This rope has operated in a groove which was much too wide, leading to premature wire failure along the line of contact.

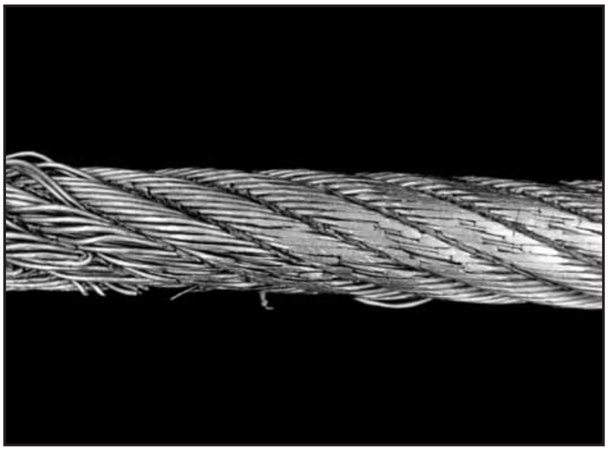


Fig. 115: This rope has been dragged over a stuck sheave. Note severe abrasion to the right and loose wires to the left.

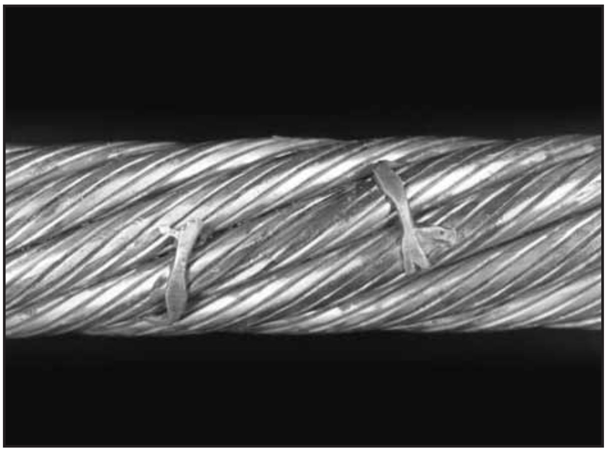


Fig. 116: These two broken wire ends got caught between the wire rope and the sheave causing nicking damage.

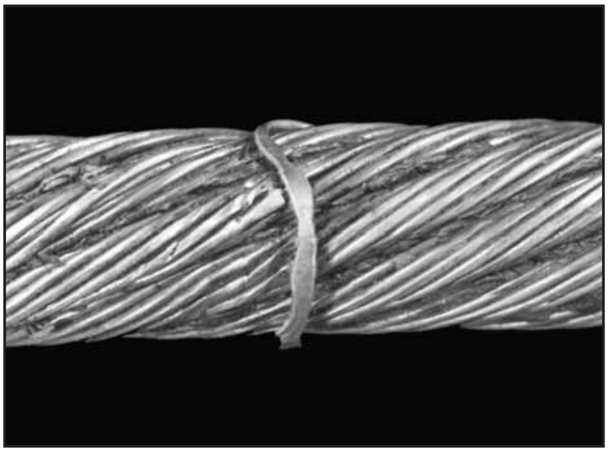


Fig. 117: Across strand nicking damage is espcially relevant to Langs lay ropes where the exposed wire ends are always long.

DAMAGE FROM THE SHEAVE

Negative imprints in sheave grooves can be created by different mechanisms. If, e. g. the circumference of the sheave at the bottom of the groove is a multiple of the strand distance in the bent condition of the rope, then during every revolution of the sheave, the same points in the groove will be hit by strand crowns, whereas the neighbouring zones will not be subjected to any wear.

An indication for such a mechanism is a lubricant deposition at regular intervals on the flanges of the sheave (Fig. 118).

Continuous load changes lead to continuous changes in lay length. Therefore ropes with varying loads are less likely to produce negative imprints.

Imprints will normally not harm the rope that created them. But the replacement rope will be damaged by the imprints, even if it is of the same design.

Imprints can not always be avoided but can be delayed by hardening the grooves. Lubrication and slight rope rotation will also help avoid the formation of negative imprints.

As opposed to conventional steel wire ropes, swaged ropes have no crowns and valleys and will therefore normally not create negative imprints.

Fig. 118: Lubricant deposition at regular intervals on the flanges of a sheave as opposed to a continuous coating often indicate the formation of negative imprints.

DAMAGE FROM THE SHEAVE

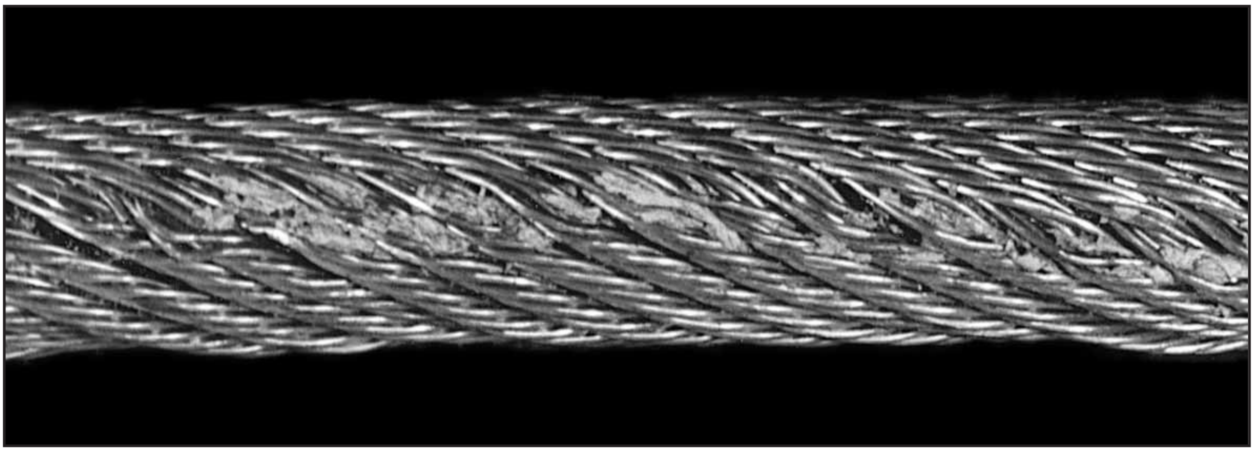


Fig. 119: This rope has “jumped” a plastic sheave. Please note the plastic particles in between the outer wires. Due to the higher coefficient of friction, under otherwise similar conditions, a rope will “jump” a plastic sheave earlier than a steel sheave.

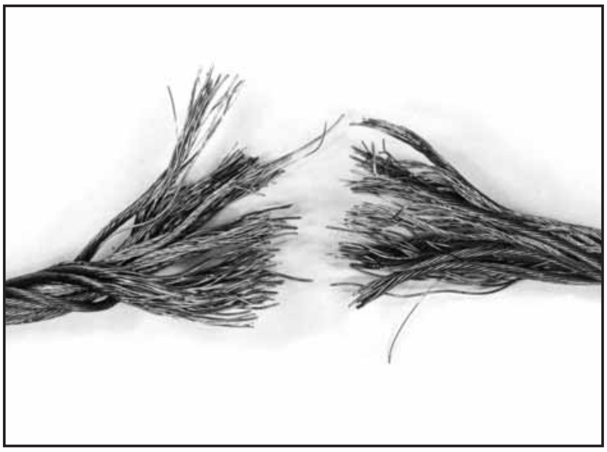


Fig. 120: A rope which has failed having “jumped” a sheave will often look as if it has been cut by an axe (shear and tensile failures).

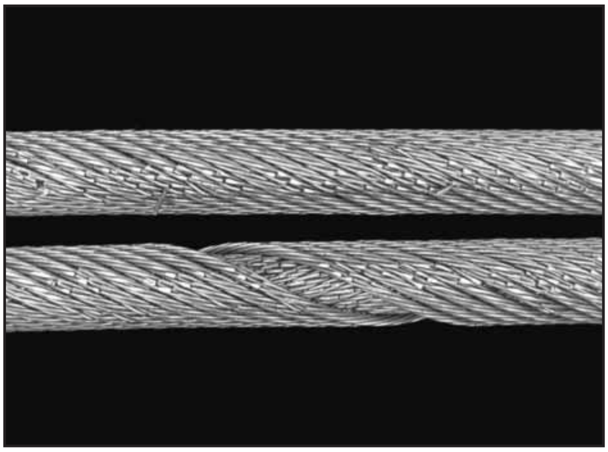


Fig. 121: This rope has operated in a groove which was much too wide, leading to premature wire failure along the line of contact.

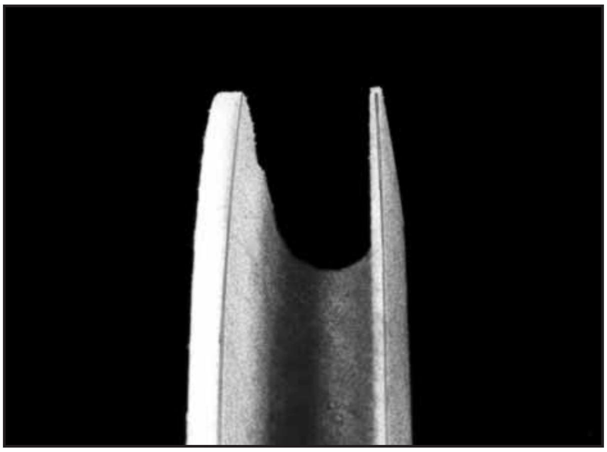


Fig. 122: Severe fleet angles will lead to rope twist and increased wear, both on the wire rope and on the flange of the sheave.

Fig. 123: Extreme wear on the flange will one day cause it to collapse. During inspection, the material thickness must be measured.

DAMAGE FROM THE DRUM

Left hand drums should operate with a right hand rope. Right hand drums should operate with a left hand rope. A violation of this rule might lead to rope twist and structural damage.

On a multi layer drum with special grooving, the crossover zones are arranged parallel to the drum axis. If the wear pattern shows that the crossover zones are inclined (Fig. 124), the rope diameter is either too big or too small with respect to the drum pitch. Under these conditions, the rope will always cross over a bit earlier or later with every consecutive wrap.

If the fleet angle of the rope versus the drum groove is too big, the rope will either be pulled against a neighbouring wrap (Fig. 128) or against the flange of the drum groove (Fig. 130). In both cases, the rope surface will be damaged.

Damage caused by multi layer spooling can be reduced by using Langs lay ropes with compacted outer strands. Hammered (swaged) ropes are especially suitable.

In multi layer spooling, drums with Lebus type grooving have proven to be far superior to drums with helical grooving.

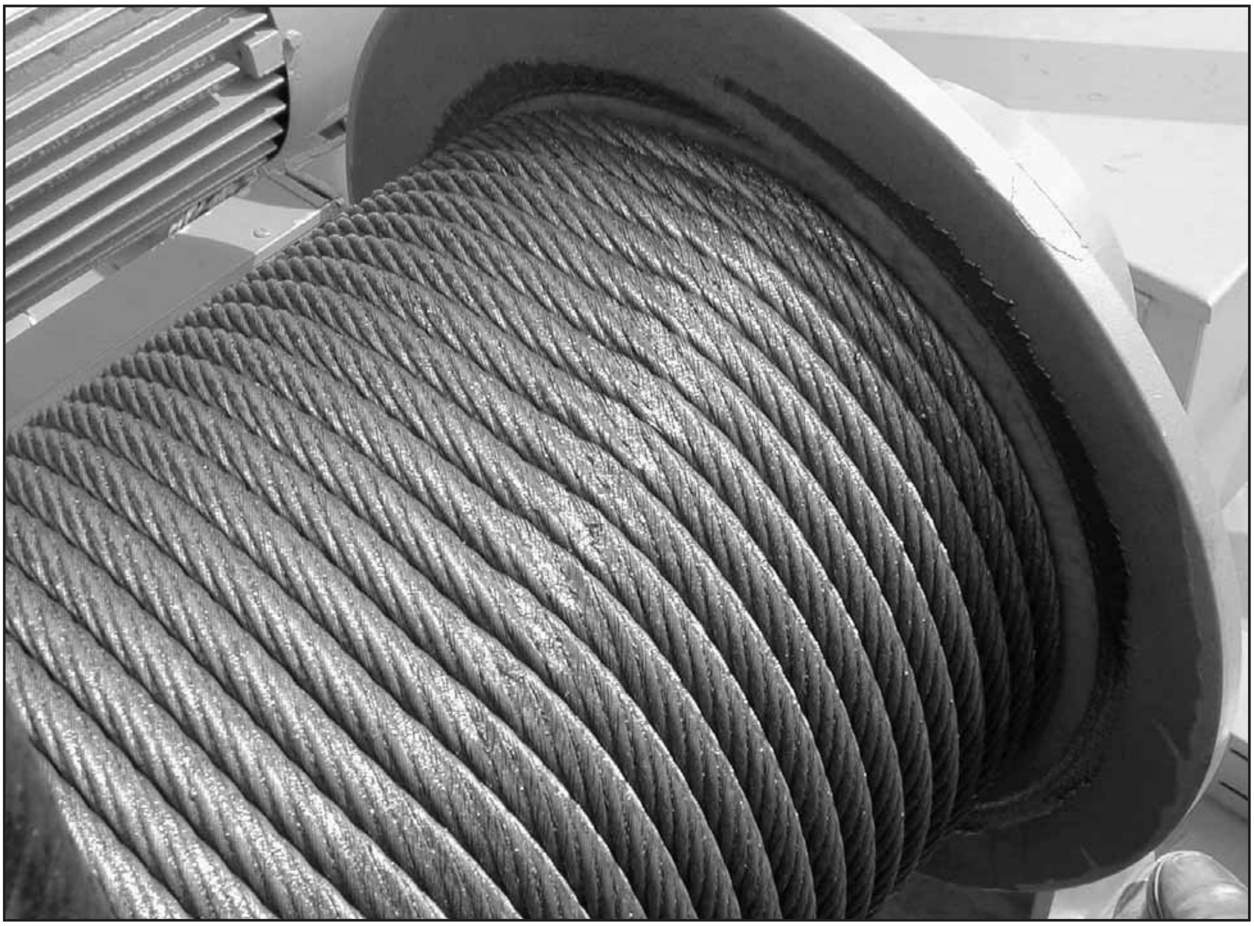


Fig. 124: The inclined wear pattern (cross over zone) shows that the rope is too small for the drum pitch. If it was inclined in the opposite sense, this would be an indication that the rope diameter is too big.

DAMAGE FROM THE DRUM

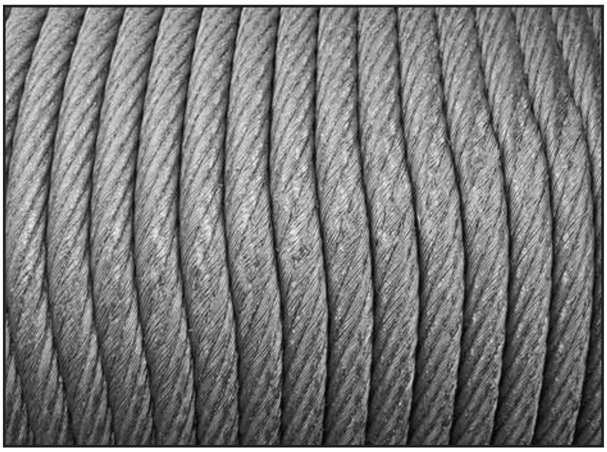


Fig. 125: Inclined wear pattern in multi layer spooling normally indicates an incorrect rope diameter.

Fig. 126: This rope is spooling onto a multi layer drum with special grooving. The rope is about to cross over one wrap.

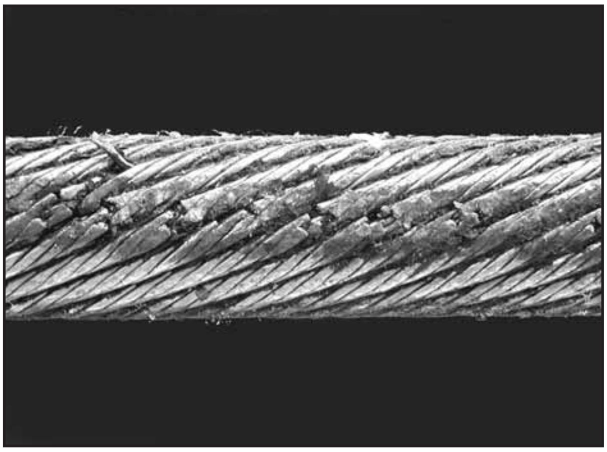


Fig. 127: Typical rope damage created in the cross over zone.

Fig. 128: The fleet angle forces the rope fall entering the drum to rub against its "neighbour", causing severe abrasion and rope twist.

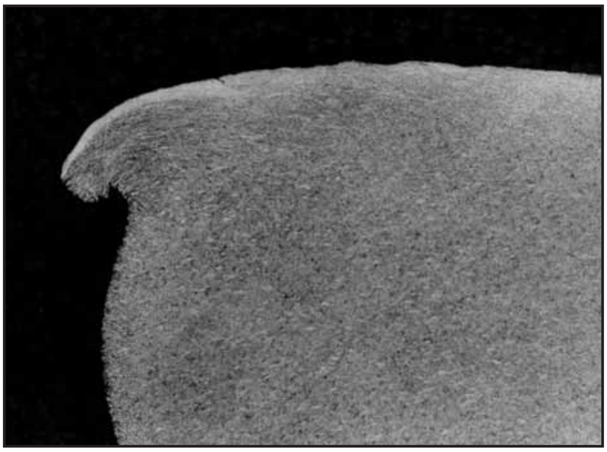


Fig. 129: Abrasion and plastic wear (see page 4) caused by rubbing against a neighbouring rope wrap (see Fig. 128).

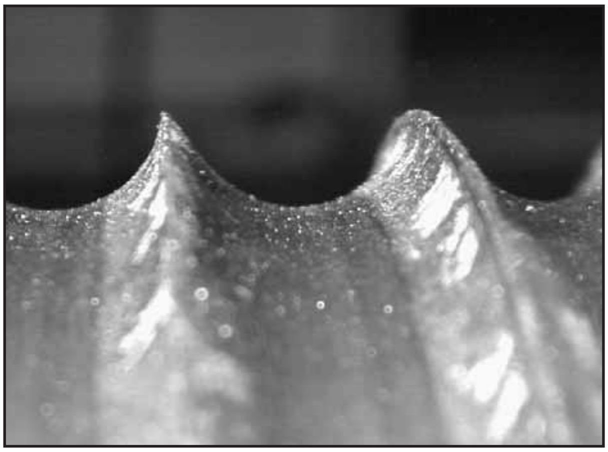


Fig. 130: If a fleet angle forces the rope fall entering the drum to rub against the groove flanges, both rope and flange might be worn.

DAMAGE FROM THE DRUM

In multi layer spooling, a good pretension of the lower rope layers on the drum is essential. Lack of pretension can lead to severe wire rope damage.

In the worst case, the rope might be pulled in between the lower layers during lifting. During subsequent lowering of the load, the rope might not spool off the drum, thereby reversing the load movement (Fig. 131).

Under high tension, a rope tends to be as round as possible. With no load, a rope can be deformed and flattened muchmore easily. Highly tensioned upper layers will therefore severely damage loose (and therefore vulnerable) lower layers (Figs. 132 and 133).

If a load is applied to a steel wire rope, the rope will get longer. It will therefore slip on the first wraps of the drum, creating wear both on the rope and on the drum. If the load is always applied at the same location, the wear will concentrate in one spot (Fig. 134). Shortening the rope (drum crops) or lengthening the rope will spread the wear and improve the situation.

In multi layer spooling, small diameter differences between two ropes might add up to considerable length differences being spooled onto otherwise identical drums. Therefore, steel wire ropes operating together should be ordered as a “matched pair”. They should have only very little differences in diameter.

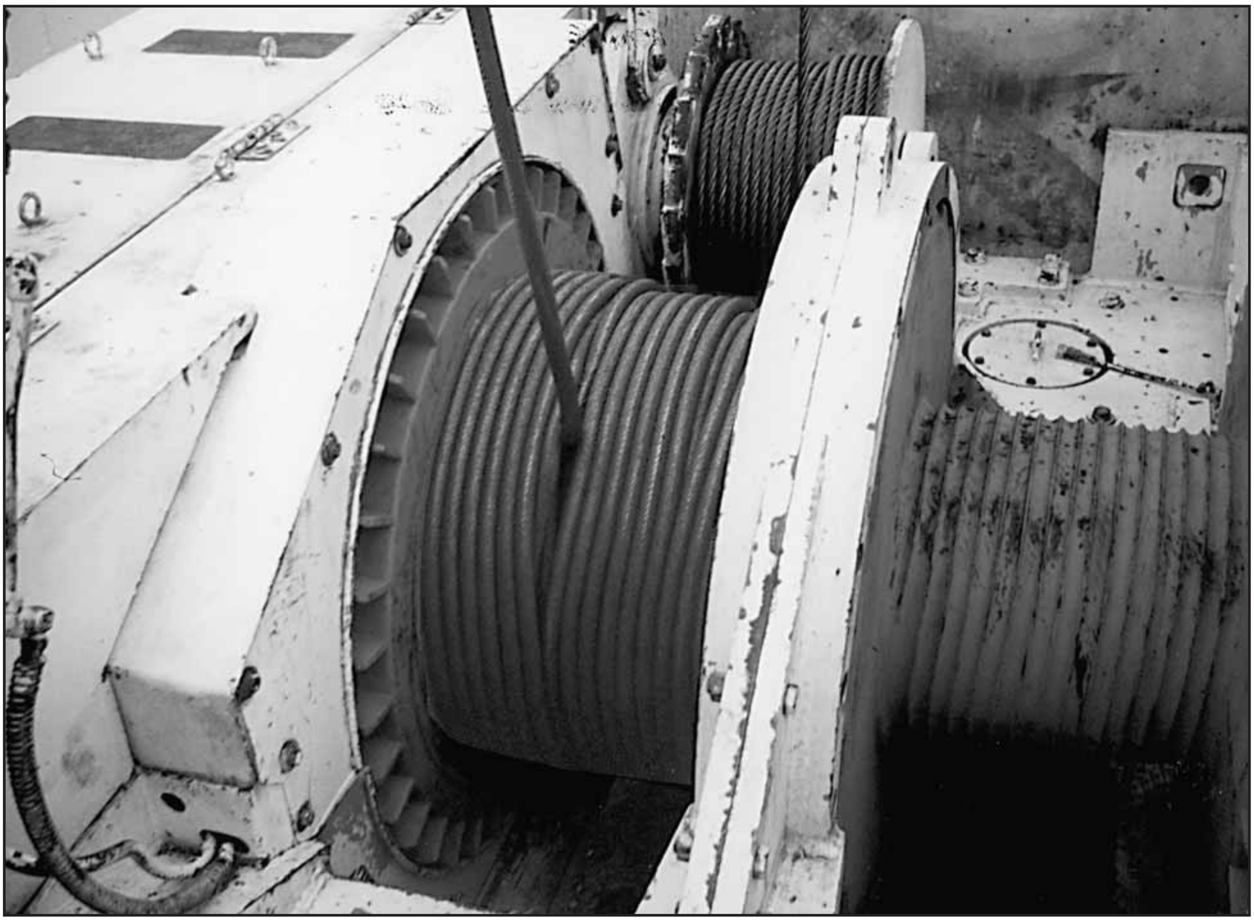


Fig. 131: This rope has been pulled into a lower, non tensioned layer during lifting. During subsequent lowering of the load, the rope got stuck and did not spool off the drum, thereby reversing the load movement.

DAMAGE FROM THE DRUM

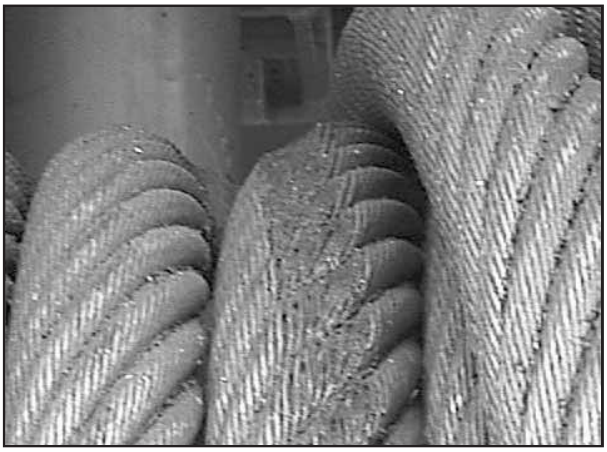


Fig. 132: This rope has made only one lift! The highly tensioned rope has cut into and deformed a lower, non-tensioned layer.

Fig. 133: This rope, too, has only made one lift! Again, lack of pretension caused the rope damage.

Fig. 134: If the load is always picked up at the same location, always the same sections on the drum and on the rope will be worn.

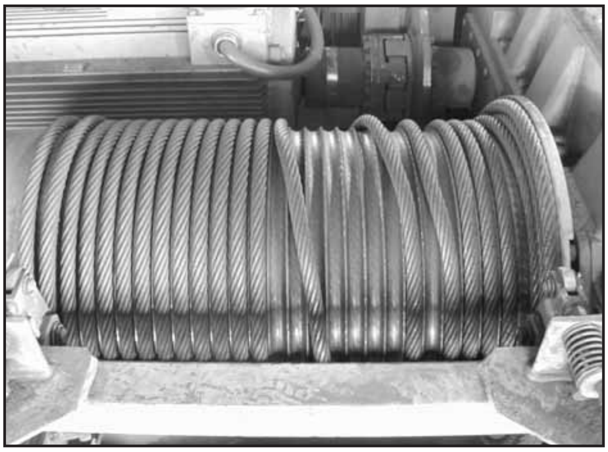


Fig. 135: Steel wire rope and drum damage caused by spooling over the groove flanges.

Fig. 136: Rope damage on a multi layer drum. It took one of the authors a considerable time to convince the user that...

Fig. 137: this rope was ready for discard (see Fig. 136). Further examination showed that <u>every</u> outer wire was broken every 3 cm.

OTHER PHENOMENA

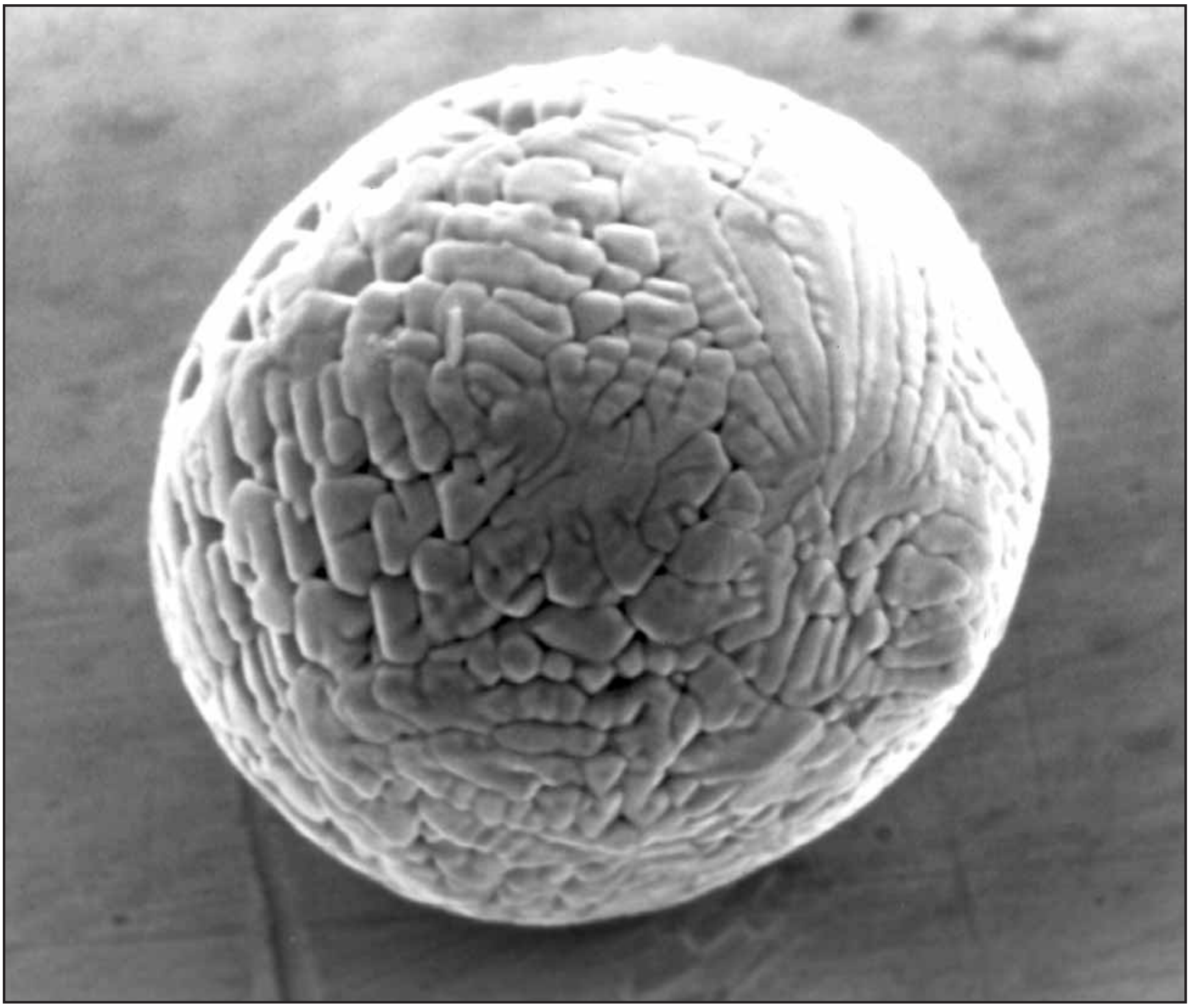


Fig. 138: Manganese- Sulphite balls in the wire structure are extremely hard and do not deform in the wire drawing process. They often appear on the surface of fatigue breaks because wires will trend to fail in sections already weakened by such inclusions.

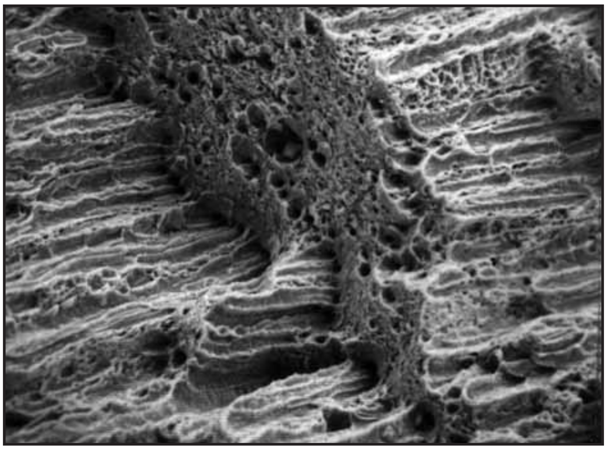


Fig. 139: The fracture zone of a wire destroyed through severe bending (very low cycle fatigue) will look like split wood.

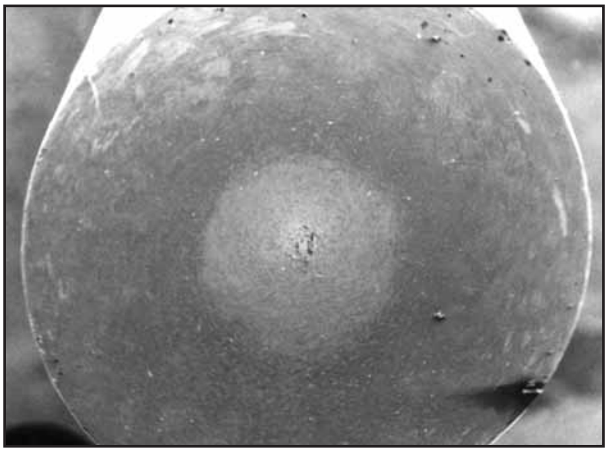


Fig. 140: The fracture surface of a rope wire destroyed by pure torsion will look like an old 33 rpm LP record.

ROPE GEOMETRY FAULTS

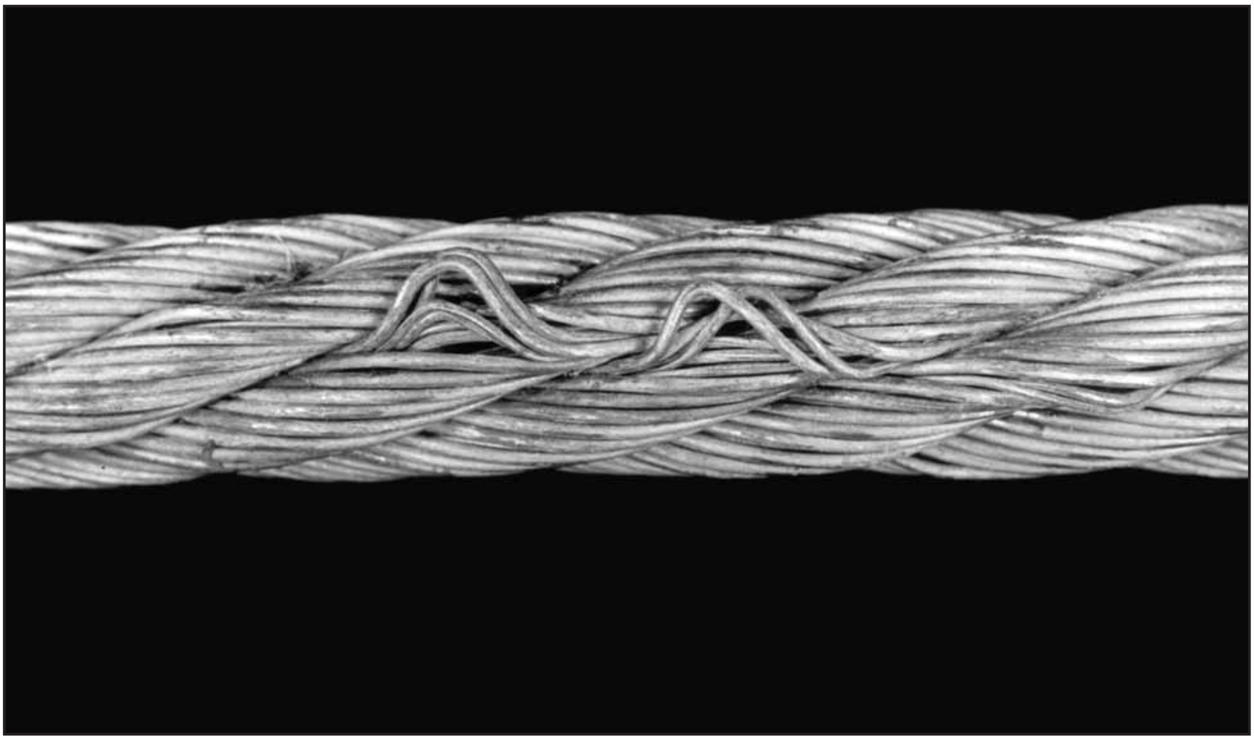


Fig. 141: Loop formations can be (but may not be) caused by insufficient clearance between the wires in the strand. Lack of clearance will prevent these wires from moving relative to their neighbours, causing overloading and yield.

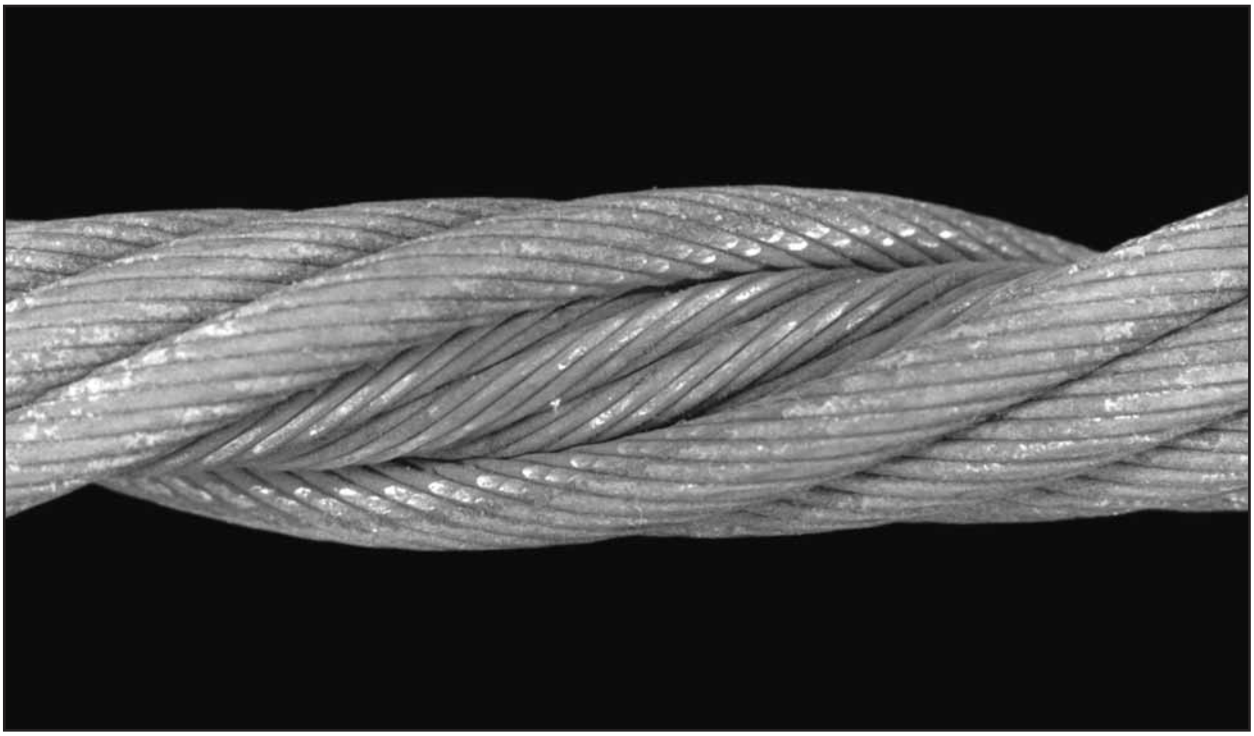


Fig. 142: If the diameter of the steel core of the rope is too small, the outer strands will not have sufficient clearance. Interstrand nicking will occur. Lack of clearance will considerably reduce the rope’s fatigue life.

ROPE PRODUCTION FAULTS

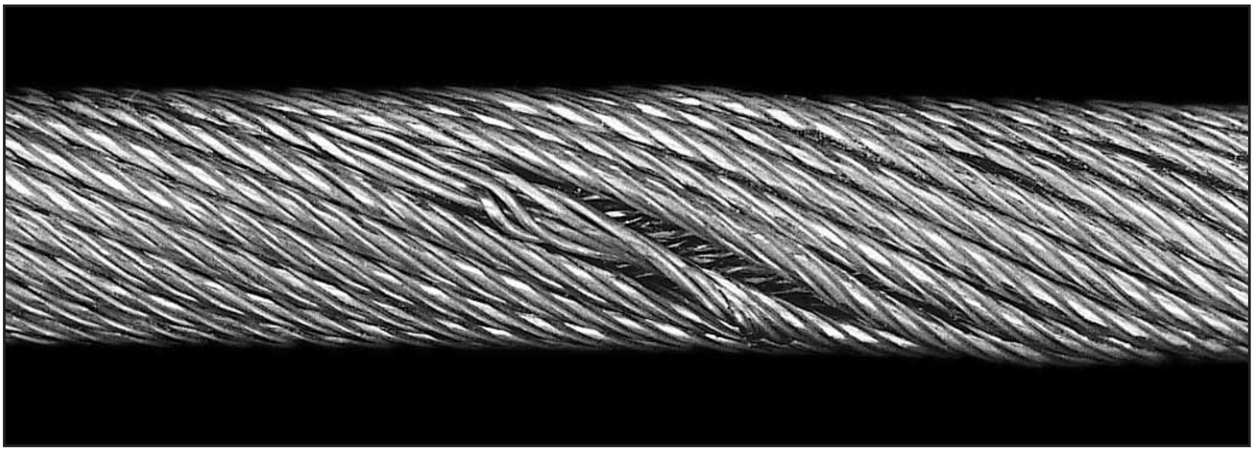


Fig. 143: During stranding, one strand obviously had slipped on the capstan, locally creating a long lay length. This stranding defect was not detected before the faulty strand was closed into the rope.

Fig. 144: A strand serving was not removed during rope closing and ended up as an unpleasant decoration of the finished rope.

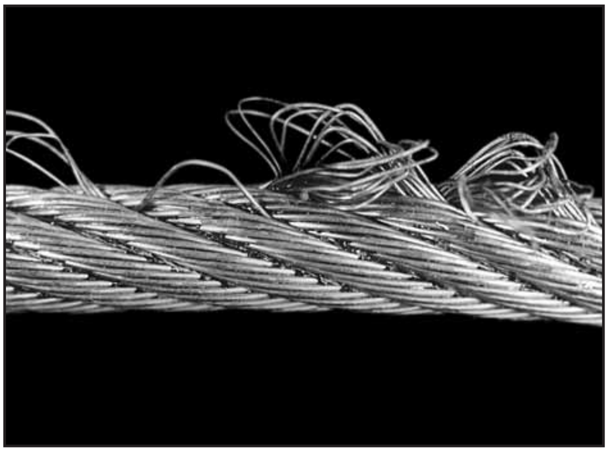


Fig. 145: An incorrect backtwist in the rope closer has shortened the strands. The inner wires were then be under compression and later popped out.

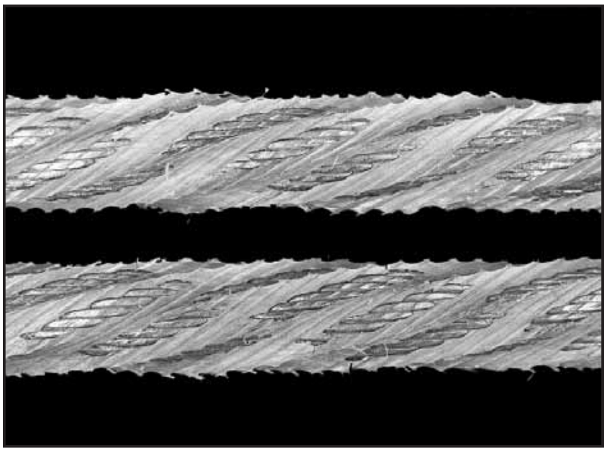


Fig. 146: An unsuited plastic material will not give sufficient support to the outer strands. It will wear and lead to premature rope failure.

Fig. 147: In multi layer spooling, small diameter differences of two ropes will lead to big differences in the spooled rope lengths (see p. 42).

FURTHER READING

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