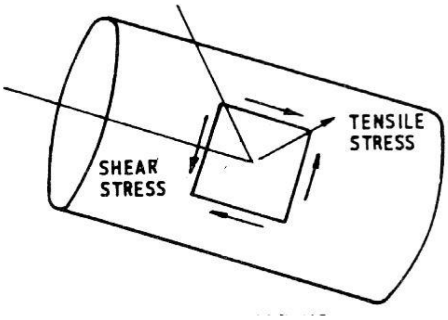
Cautionary Tale XXXVII The Shape of Fractures in Compression Springs

During training courses that the author gave in 2007, delegates requested that a description of the shapes of fracture be presented for Compression Springs.

Whether fracture is due to fatigue or stress corrosion cracking, the position of maximum stress ought to be at the inside surface of an active coil in an axially loaded compression spring. Hence fracture will generally initiate close to the inside coil position where the applied stress will be torsional and maximum. The state of applied stress at this position is illustrated theoretically by the following diagram.



Torsional stress acts at 45° to the principle axis of the wire. This stress may be resolved into a longitudinal and transverse shear stress of equal magnitude.

The net stress on a loaded compression spring is the sum of the applied stress and any residual stress. The residual stress in compression springs will be a relatively low tensile bending stress after low temperature heat treatment. The subsequent springmaking process of shot peening will impart a surface residual compressive stress equal in all directions and so this will not greatly influence the shape of fractures, although the effect of the peening may be visible near the surface. Prestressing will impart a residual torsional compressive stress and so this will no alter the fracture shape either.

It might be expected that compression spring fractures would be at 45° to the wire axis from initiation to final overload failure as a response to the net torsional stress. This is sometimes the case, as shown in Figure 1.

Figure 1 Helicoidal shaped fatigue and overload fracture.

The position where the fatigue fracture stops and the overload fracture starts is just visible in this example at about one third through the wire section.

Sometimes the fatigue crack is at 45°, but the final overload fracture is by ‘torsioning’ an example of which is shown in Figure 1b.

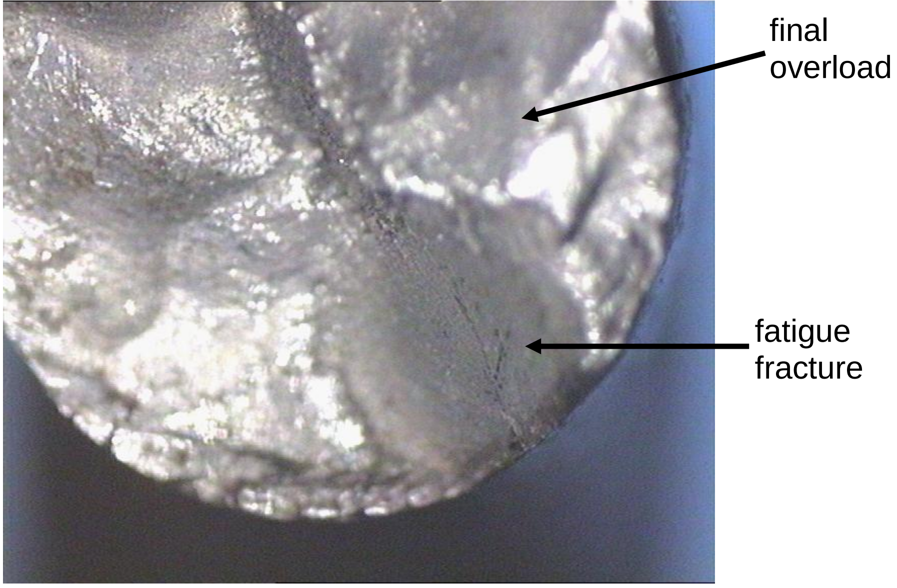


Figure 1b **x 25**

The higher the applied stress, the smaller the fatigue fracture will be and the larger the overload fracture.

Sometimes the resolved shear stresses influence the first part of the fracture as shown in Figures 2 and 3.

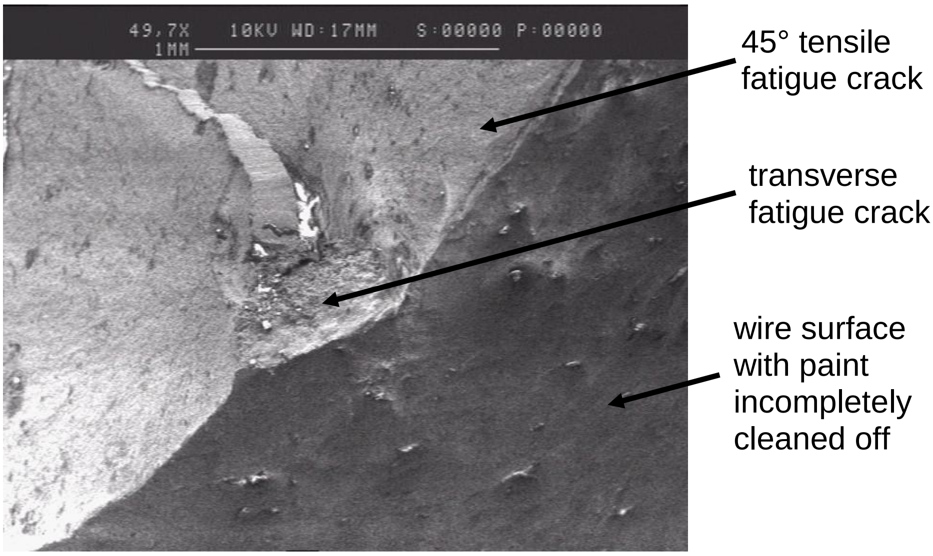


Figure 2 transverse shear crack at origin with the 45° fatigue cracking initiated either side of the transverse shear fatigue crack

This shape of fracture is often observed in springs made by hot or cold coiling when the material has an equiaxed tempered martensite microstructure. It is almost never seen when the spring has a drawn microstructure – this leads to a longitudinal shear fatigue crack, as shown in Figure 3. This fracture shape is also seen in springs with a tempered martensite microstructure – for which there is a 50% chance that the initial fatigue crack will be longitudinal and 50% that it will be transverse.

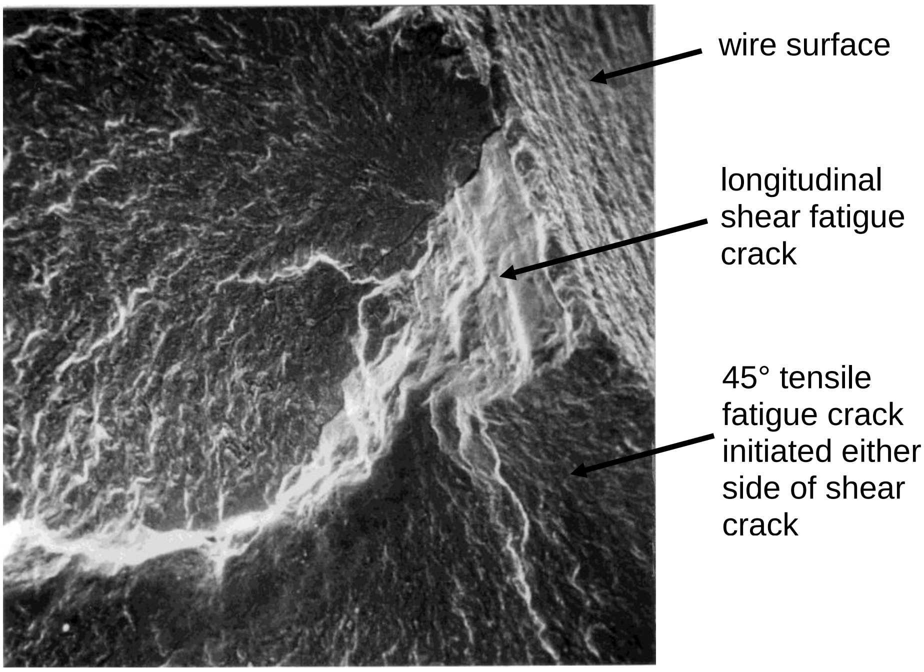


Figure 3 longitudinal shear crack at origin

Sometimes the final overload fracture is helicoidal in shape as shown in Figure 1, but it is equally possible that this overload will happen by torsioning, as shown in Figure 1b. In nickel alloys and occasionally in stainless steels both the fatigue and overload fractures may be transverse in direction as shown in Figure 4.

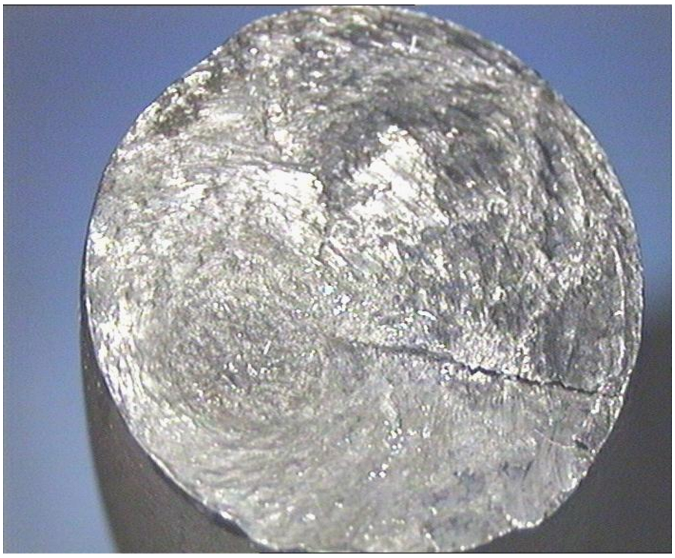


Figure 4 torsioning fatigue and overload x 6

For all spring materials there is a history of hot work on the steel, and so inclusions and any segregation will be considerably elongated. This often causes longitudinal splitting during the final overload fracture, as shown in Figure 5. This type of fracture is more likely in drawn carbon steel springs, but is often seen in SiCr springs above about 7mm diameter and occasionally in 302 stainless steel springs. It is important to recognise that the splitting is a consequence of failure and is not its cause.

Figure 5 A longitudinal split is a consequence of the fatigue crack and not its cause.

Pre-existing cracks will alter the fracture shape. The most likely types of crack are coiling cracks, which are always transverse in direction, quench cracks, which are largely longitudinal, and stress cracks (particularly in 17/7PH) which are always longitudinal. Since these crack types will be present prior to spring stress relieving or tempering they will be covered in oxide, and this should still be clearly visible unless post-fracture corrosion is extensive.

The moral of this cautionary tale is that much can be learnt from looking at the shape of fractures, but there is a wide range of possible shapes, and it is intended that this tale will provide useful and practical guidance to help readers to interpret what they see.

Mark Hayes is the Senior Metallurgist at the Institute of Spring Technology (IST) in Sheffield, England. He manages IST's spring failure analysis service, and all metallurgical aspects of advice given by the Institute. He also gives the spring training courses that the Institute offers globally.

Readers are encouraged to contact him with comments about this cautionary tale, and with subjects that they would like to be addressed in future tales, by telephone at (011) 44 114 252 7984, fax (011) 44 114 2527997 or e-mail m.hayes@ist.org.uk.