Cautionary Tales Part XXI Hydrogen Embrittlement again

By request, I return again to the much misunderstood topic of hydrogen embrittlement. One reader asked how I could be so certain that hydrogen embrittlement was the cause of the failure of his springs without even examining them. Another has asked for clarification of the fracture appearance when a SiCr spring has failed by this mechanism because his customer believed that the fracture had to be intergranular – it does not.

To provide the information requested, I have now examined the spring that I was sure had failed by hydrogen embrittlement and the results are presented in a simplified format similar to that of one of *IST*'s failure analysis reports.

Three broken extension springs without hooks were supplied to *IST,* and it was understood that they had been made from 4.0mm diameter (0.160") ASTM A401 (SiCr) wire that had been coiled, stress relieved in-line at 400°C (750°F) for 10 minutes, and ground. The corrosion protection specified was chemical blacking and oiling, a process that was sub-contracted. Chemical blacking is an alkaline process that would give no risk of hydrogen evolution. An occasional broken spring had been found in one or two batches over the years, but these were sorted out. Now though, the end user had reported that three springs from one batch had been found broken within one day of assembly, and so the cause had to be investigated.

Visual examination revealed that all the fractures were within central coils, and the fracture shape was indicative of a combination of bending and torsional stress with fracture initiation at the inside surface. On a binocular microscope it could be seen that 80% of the fracture surface had been chemically blacked, and that there was another crack in one of the springs, as shown in figure 1, that was initially at about 60-70° to the wire axis.

Optical metallography revealed that the wire had a structure of tempered martensite and the surface defects and partial decaburisation were slight, being less than 1% of the wire diameter. The hardness was 560Hv10,which is as expected for this size and grade.

Scanning electron microscopy confirmed that the fracture was covered in chemical blacking, which was cleaned off electro-cathodically. Then the fracture mechanism was observed to be intergranular initially (figure 2), with gaping grain boundaries. Traversing across the fracture surface, away from the origin, it became gradually more ductile with quasi-cleavage and microvoid coalescence fracture (figure 3) appearing in ever increasing proportions until the final overload failure, which had no blacking on it to start with, was mostly ductile microvoid coalescence, but still with some quasi-cleavage (figure 4). To plagiarise a famous lager advert, "Only hydrogen embrittlement can do this" i.e. cause a progressively changing fracture appearance from brittle through quasi-cleavage to ductile.

So, how could I be so sure that the spring had failed by hydrogen embrittlement without examining it? The spring failed after a short time delay without having been used – this is characteristic of this fracture mechanism. There was another crack in one of the springs, and it was in a direction consistent with a combination of initial tension and residual bending stress. (If this crack had been; at 90° to the wire axis, half way through the wire section, and covered in temper oxide, then it may have been a coiling crack arising due to an undue delay between coiling and stress relieve, but it was not in the correct orientation and no temper oxide was observed.) Finally I could see blacking on most of the fracture surface, and what I haven't disclosed so far, is that the process sheet for the chemical blacking included a brief dip in hydrochloric acid – an ideal process to induce hydrogen embrittlement, and there is no spring material more susceptible to it than SiCr.

The other question raised at the start of this cautionary tale concerned the fracture mechanism. The final overload here was by a mixture of quasi-cleavage and microvoid coalescence – hydrogen was still influencing the failure. The fracture mechanism of SiCr that is broken in a tensile test is 100% microvoid coalescence. Whilst it is usually the case that this grade fails by an intergranular mechanism when embrittled by hydrogen, it is also possible that in cases of slight embrittlement that the fracture will be mostly quasi-cleavage, much as it is when drawn pearlite structures are embrittled by hydrogen. The reader who wanted this confirmation was also certain that his customer's SiCr springs had failed by hydrogen embrittlement because they had all the characteristics described herein, and the only fact that left uncertainty was the absence of intergranular fracture.

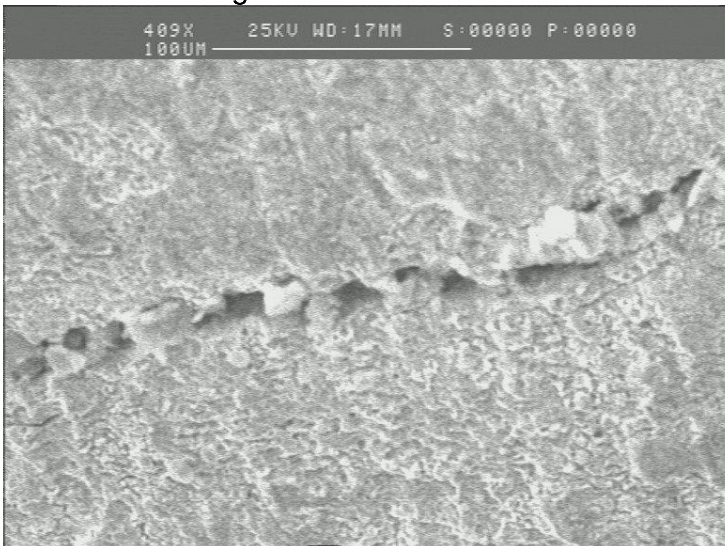

Figure 1 Crack observed one coil from the fracture x 340

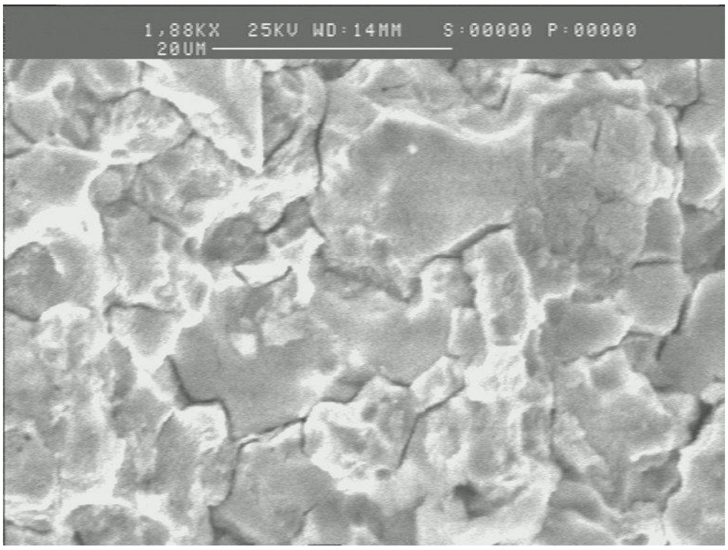

Figure 2 Intergranular fracture near the origin x 1,600

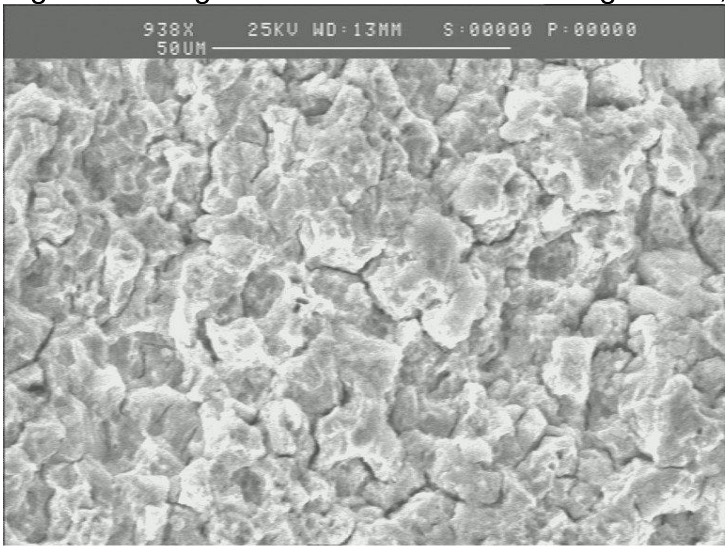

Figure 3 Appearance half way across the fracture, some intergranular, some quasi-cleavage, some microvoid coalescence x 780

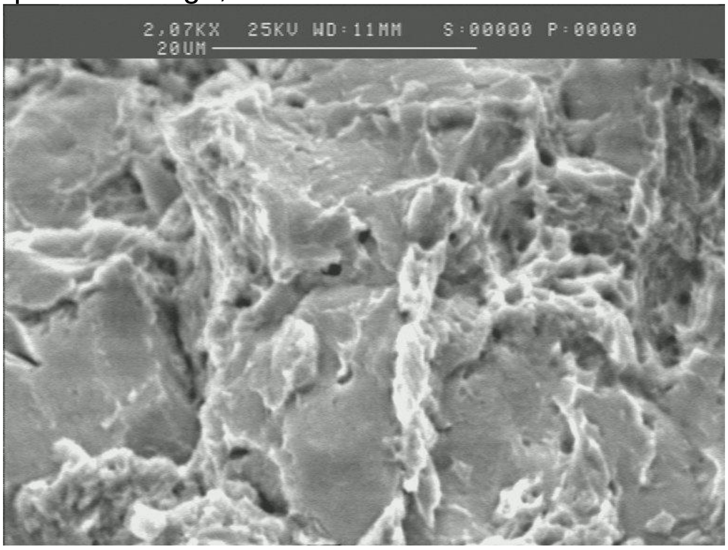

Figure 4 Quasi-cleavage and microvoid coalescence fracture at the opposite side to the origin x 1, 700

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