Fractographic analysis of failures

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Fractography with the scanning electron microscope (SEM) has proved to be a versatile method for materials research and also for failure analysis, from which four some unusual examples are given in our paper (stress relief cracking, hot cracks in welds, hot cracking during forging, stress corrosion cracking in manganese austenitic steel).

1. Stress relief cracking in a steam pipe

A few days after starting-up, a superheated steam pipe burst along the longitudinal welding seam. The fracture originated at cracks in the heat-affected zone near the weld fusion line (coarse grain zone). On the other side of the weld seam cracks could also be detected (Fig. 1). The surface was partly hot tinted but in some areas we could see by means of the SEM (scanning electron microscope) that the structure was intergranular with very fine dimples on the grain boundaries (Fig. 2).

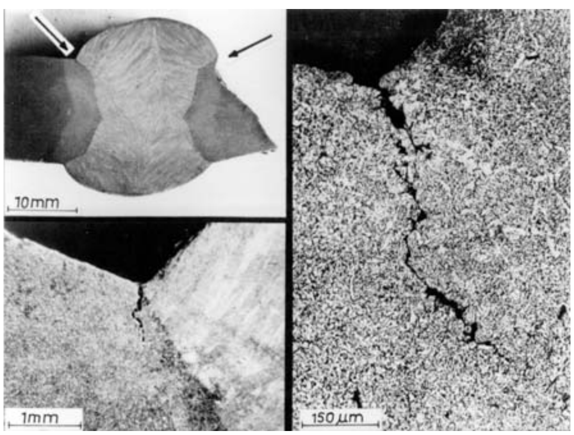

Fig. 1: Intergranular crack near the fusion line; strong reinforcement of the weld

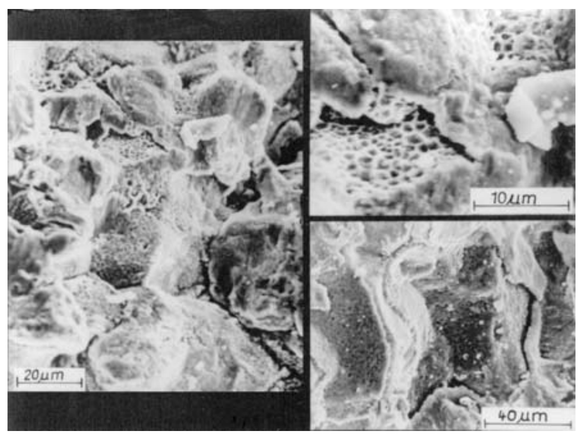

Fig. 2: The opened intergranular crack with very fine dimples on the grain boundaries (right above)

The position and surface of these cracks are typical of stress relief cracks (reheat cracks). Such cracks normally originate during post-weld heat treatment. It is supposed that during welding a solution of carbides occurs in the austenite grains followed by reprecipitation during relief treatment [1, 2]. The primary austenite grains are hardened, and creep during stress relief is confined to a narrow soft, precipitation-free zone along the grain boundaries. Cavities are nucleated and link to a crack network.

It is known that stress relief cracks are associated with stress raisers, such as changes in the cross-sections of pipes. In our case the strong reinforcement of the weld acted as a stress raiser. Moreover it was proved that stress relief treatment had not been performed. Therefore stress relief and crack nucleation can be considered to have occurred during the first days of high-temperature service, until bursting.

2. Hot cracking caused by melting of sulphides during welding

Intergranular cracks in high-strength construction steels were found extending from the heat-affected zone over the fusion line into the weld seam.

The cracks were opened for further investigations. In the parent plate accumulations of flat inclusions could be observed in the SEM (Fig. 3). The inclusions were determined by EDAX (energy dispersive microanalysis) to be mainly sulphides (Fe, MnS). In the region of the fusion line the sulphide inclusions had been completely or partly molten. The sulphide melt had formed fern-like structures on the austenite grain boundaries (Fig. 4). Such „sulphide splashing" and the crack nucleation only occur under the action of stresses (shrinking stresses) [3].

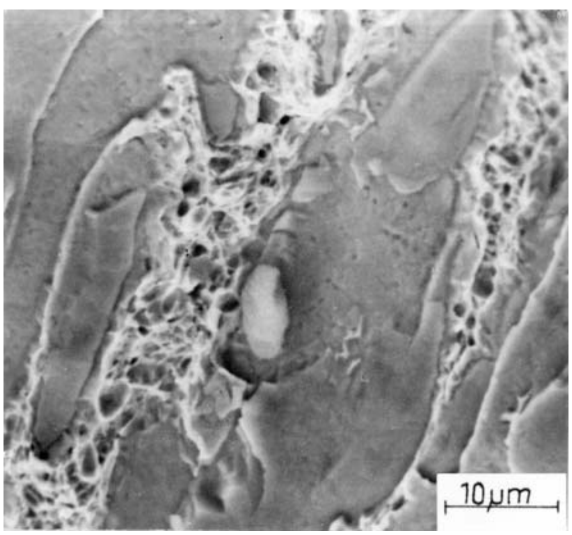

Fig. 3: Sulphide inclusions in the parent plate

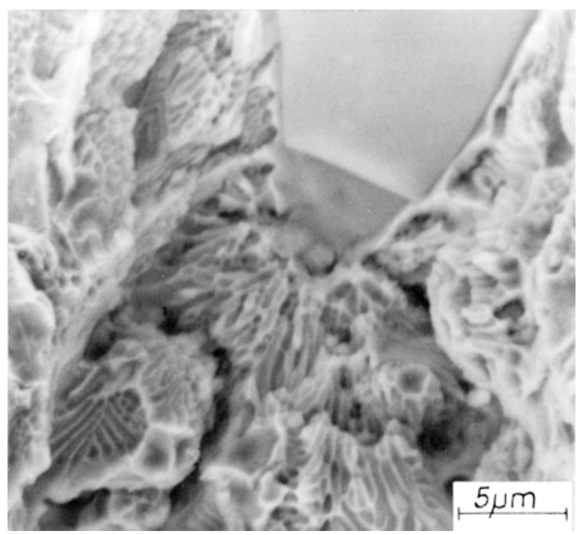

Fig. 4: Partially molten sulphide inclusion with fern-like structures in the region of the fusion line

3. Hot cracking during forging (heading)

Porosity and cracks were detected in forged steel parts. In the most strongly forged zone, the fracture surface appeared to be very coarse grained already for the naked eye (Fig. 5). In the less forged region the surface was glittering and here cleavage fracture could be viewed with the SEM. In the coarse-grained area the fracture was intergranular with strongly oxidized grain boundaries, which had been partly molten (dendritic structure) thus being the cause of cavities. In some areas the shells on the grain boundaries peeled off.

Furthermore fern-like structures of sulphides (Fe, MnS) could be detected on the grain boundaries (Fig. 6).

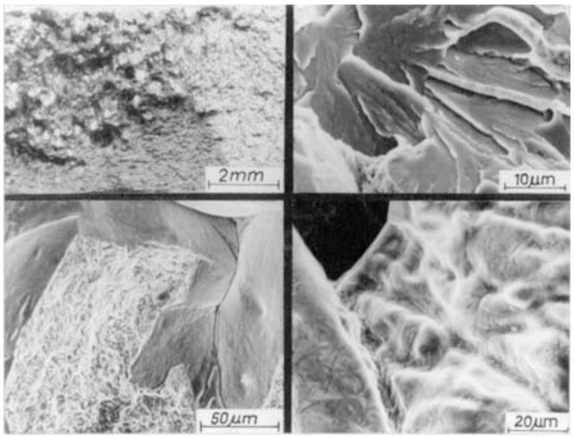

Fig. 5: Headed steel part: coarse grains in the strongly forged region; grain boundaries with dendritic structure

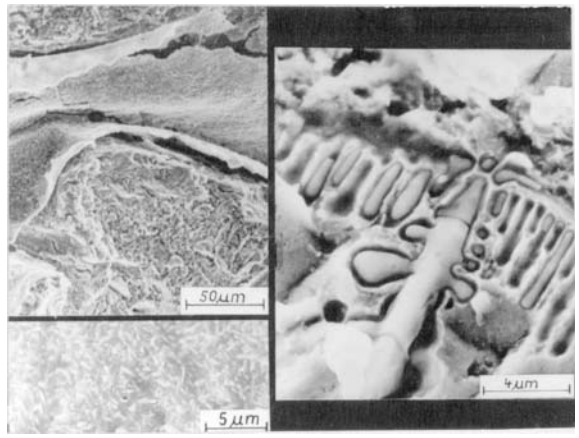

Fig. 6: Peeled off oxide shells (left) and fern-like structure of low melting sulphides (right)

It is assumed that in the case of strong overheating sulphur segregates to the grain boundaries and fluid sulphide films are produced there [4]. Sulphide splashing then occurs during forging.

After this investigation we could state mainly based on the occurrence of sulphide splashing: The parts had been forged in a temperature range existing near a weld fusion line (about 1300 °C, see section 2).

4. Failing of a generator end ring

The end ring of an air cooled generator failed during service. The end ring was produced from austenitic manganese chromium steel and supported at two positions on the rotor shaft. Extensive shear lips could be seen on the fracture surface (Fig. 7), with the exception of the first third. Shear lips characterize a ductile fast fracture. Thus the first third of the fracture surface must be considered to be the zone of slow crack propagation.

Viewing this area with the SEM we found complete intergranular fracture with secondary cracks (Fig. 8).

Fig. 7: Macrograph of fracture surface of the end ring

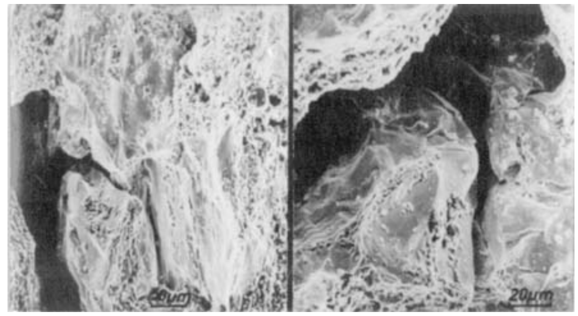

Fig. 8: Intergranular fracture in the slow-fracture zone

The fast fracture showed dimples and extensive ductile tearing, giving the fracture surface a lightly intergranular character (Fig. 9). The crack had started from a locking groove in the outer one of the two shrink fits. On this shrink fit and also on the groove surface areas of fretting corrosion with many short cracks were found (Fig. 10, [5]). The cracks went transgranular to the first grain boundary and then they propagated intergranularly (Fig. 11). Moreover strong work hardness could be detected under the grooves [5].

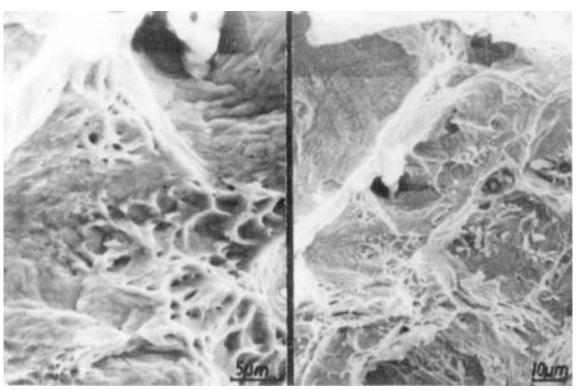

Fig. 9: Dimples and tearing in the fast-fracture zone

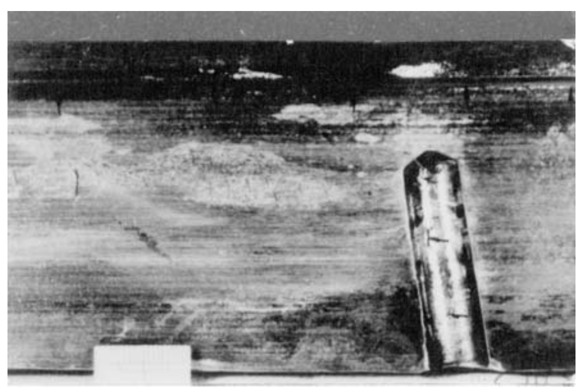

Fig. 10: Shrink fit surface with groove, both with areas of fretting corrosion [5].

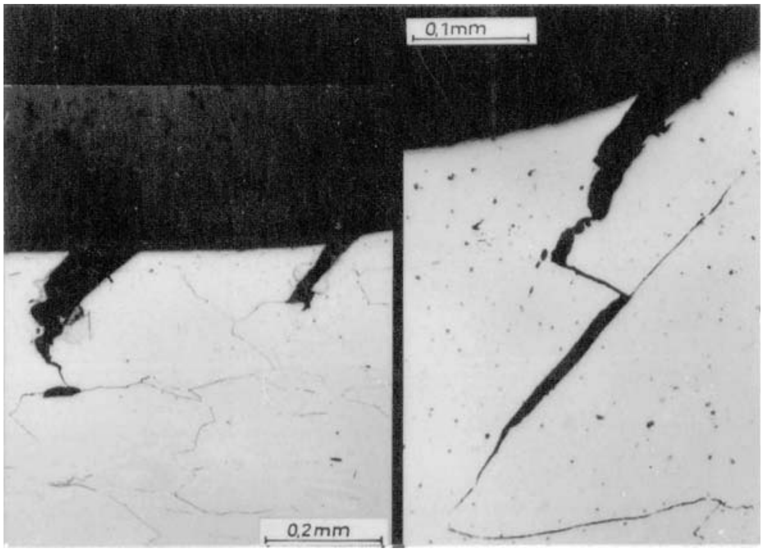

Fig. 11: Cracks (here under the groove) go transgranular to the first grain boundary, then they are intergranular [5].

It is known that in nitrate solution austenitic manganese steels have a great susceptibility to intergranular stress corrosion cracking [6, 7], and even in distilled water if the steel is in the sensitized state [8]. Therefore we assume as in [6, 7] that the failure is due to stress corrosion cracking. It is supposed, that the stress corrosion was caused by humidity from (industrial) atmosphere possibly acting together with nitrates from corona discharge [6, 7].

Stress corrosion had been favoured by two facts:
– Cracks were present caused by fretting.
– Strong workhardness was existing around the grooves induced by their manufacturing.

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