

FAILURE ANALYSIS: TRIBOSORPTION AS THE BASIS OF MEDIUM-INDUCED FRACTURES

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INTRODUCTION

Some media such as hydrogen, sulfides and carbides but also metals are known to be able to embrittle and to crack steel and other metallic materials.

The existing concepts used to explain these phenomena are mainly based on the classical form of the Griffith-Equation:

$$\sigma = \sqrt{\frac{2E \cdot \gamma_s}{\pi \cdot a}} \dots \dots \dots (1)$$

The medium should reduce the surface energy (γ_s) and therefore promote cracking. In this connection, the TROIANO-ORIANI-Theory should be mentioned for hydrogen cracking, and the REHBINDER-Effect for liquid-metal embrittlement.

However, relative to the true fracture work itself the surface energy is very small.

Therefore, Orowan extended the Griffith equation by introducing the real fracture energy (γ_{eff}) as the sum of surface energy (γ_s) and plastic deformation work (γ_{pl}).

In hydrogen cracking of steel, for instance, the fracture work is at least a hundred times greater than the surface energy. Accordingly, the reduction of plastic deformation work has to be explained rather than that of surface energy. The latter should be confined to describe the action of wetting agents.

THE TRIBOSORPTION CONCEPT

For metals, an embrittlement is usually caused by the formation of very fine precipitates impeding the movement of dislocations. The question arises in which way a foreign medium can produce the same effect.

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The medium has to enter the matrix. As medium-induced cracking may reach considerable velocities, normal diffusion can be excluded as transport mechanism; instead, a certain kind of pumping should occur. Solely atoms but not molecules can certainly penetrate the metal lattice. Whenever the medium is a compound, the molecules have to be dissociated a priori.

Embrittling media, which exist in the solid state at room temperature, have their main activities in the range of their melting points or slightly below, i. e. partially in the solid state. The latter fact points out that solely the vapour phase is responsible for embrittlement.

Those elements have an embrittling effect which are almost insoluble in the matrix. But the reverse case occurs in regions of current flow (slip bands), i. e. where the solubility is high. The reason may lie in the fact that moving dislocations are small regions of very high temperatures, thus being able to carry foreign atoms.

When the movement of dislocations is locally stopped the solubility of the foreign atoms drops resulting in a strong oversaturation.

Now, the foreign atoms tend to agglomerate and to rebuild the compound (recombination) as far as former compounds (hydrogen, sulfides, carbides) are concerned. The places of agglomeration (accumulation) and recombination should be supplied by voids induced by the reaction of dislocations carrying the foreign atoms. The media accumulating in voids should remain in the gaseous state to form pressure bubbles as a kind of short-time precipitates inhibiting further gliding.

Due to its mechanical activation the process of fast uptake and transport of foreign atoms is termed TRIBOSORPTION.

This hypothesis may be supported by two examples of hot cracking, where regions of intergranular embrittlement were found ahead of the cracks. A dispersion of fine carbides (Fig. 1) and sulfides (Fig. 2) along the grain boundaries represents the frozen state of the distribution of the embrittling medium.

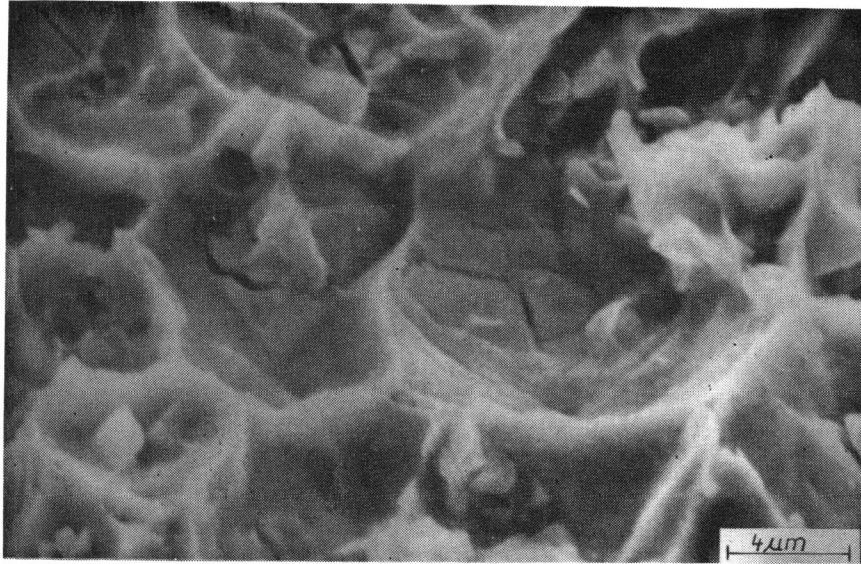


Figure 1: Hot cracking of a Ni-alloy: small carbide particles at the grain boundary.

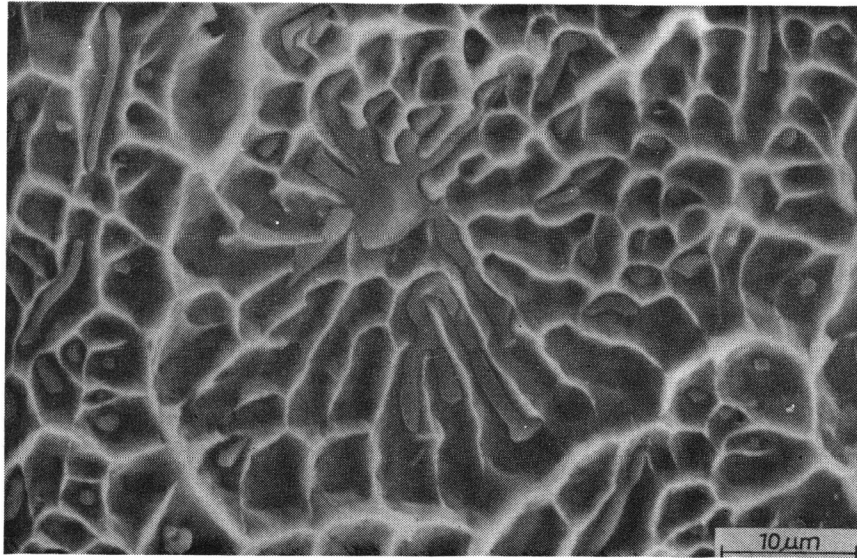


Figure 2: Hot cracking of construction steel: a grain boundary covered with a sulfide dispersion.