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Plastic collapse of a stainless steel pressurized tube

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ABSTRACT

The failure of a stainless steel tube which conducted oil at 300 °C has been analysed. The fracture surface of the broken tube was studied in the scanning electron microscope and the fracture mechanism found was the nucleation, growth and coalescence of voids. This mechanism is characteristic in materials plastically deformed before failure. Specimens for metallographic examination were cut from the damaged tube and from an intact tube to analyse both microstructures. No significant changes which could justify a microstructure's embrittlement were detected. Hardness measurements were performed on the damaged and intact tubes. The broken tube was harder than the intact tube due to plastic deformation accumulated during failure. The pressure which is necessary to reach this hardening was analysed by the deformation theory of plasticity and it was found this pressure is close to that corresponding to the plastic instability. Consequently, the most plausible hypothesis of failure was due to an over-pressure which leads to the tube's plastic collapse.

1. Introduction

A stainless steel tube of 72 mm in diameter and 2 mm thickness, which transports oil at 300 °C failed catastrophically during service. The tube was processed with a DIN 1.4541 stainless steel and was loaded by a nominal internal pressure of 3.6 MPa during service. Several reasons could be considered to explain this failure: an embrittlement process due microstructural changes at high temperature, the presence of critical defects or the plastic collapse due to an over-pressure [1–3]. To analyse all the possibilities the damaged component as well as an intact tube were studied. The damaged and intact materials were characterized, using quantitative metallography, to identify possible microstructural changes which could justify a microstructural embrittlement. In addition, the mechanical properties of the intact and damaged stainless steel were determined to evaluate hardening in the region close to failure. Finally, the fracture surface of the broken tube was analysed to evaluate the dominant fracture mechanisms.

2. Experimental techniques

The fracture surface of the broken tube was analysed in a Philips XL 30 scanning electron microscope (SEM) equipped with energy dispersive X-ray microanalysis (EDX). Secondary (SEI) and backscatter electron images (BEI) were obtained.

Transverse sections were cut on the as-received failed tube at the rupture edges and at some distance away from the rupture region, in order to examine the microstructural characteristics and differences between the regions adjacent to and

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apart from the fractured area. Samples were prepared with standard metallographic procedures [4]. Polished surfaces were etched in Behara's reagent to reveal the microstructure, and then analysed by light microscopy (LM).

HV10 Vickers hardness measurements were performed on both, the failed and intact tubes, using a Vickers hardness tester Wolperttestor Instron 2100. These tests were carried out according to ISO 6507-1 [5]. The purpose is to check if there were indications of different hardness in the analysed areas.

Material tensile properties at room temperature and 300 °C were tested on a MTS Alliance RF/100 universal testing machine following the recommendations of UNE-EN-10002 [6].

3. Failure analysis

3.1. Fractography

The fracture surface of the broken tube was analysed by SEM. A low magnification image of the broken surface is presented in Fig. 1 showing a ductile fracture micromechanism [1]. Higher magnification images, along the tube thickness, are presented in Fig. 2. Fracture was initiated at the internal side of the tube and was propagated through the thickness until failure by a mixture of nucleation, growth and coalescence of voids and a tearing mechanism promoted by the small thickness of the tube. These fracture mechanisms are usually observed in materials plastically deformed before fracture. Features which could indicate neither an embrittlement of the stainless steel nor the presence of critical defects were found. Ti (C, N) precipitates were observed through the fracture surface like the one showed in Fig. 3, which are distributed along the material's microstructure as it will be discussed in the following section.

3.2. Microstructure

Normally, under these service conditions, the lost of properties in austenitic stainless steel is associated with intergranular corrosion sensitization, due to preferential precipitation of Cr-rich phases along grain boundaries, usually $Cr_{23}C_6$. Ti additions favour the precipitation of Ti carbides, reducing the risk of sensitization and the appearance of Cr-poor areas in the vicinity of austenite grain boundaries [1,2,7].

The microstructures (observed after etching) of samples drawn from various locations of the failed tube (apart from and adjacent to the fractured area) are illustrated in Fig. 4. In both cases, the microstructure is composed of equiaxed austenitic grains with deformation bands along the conformation direction. In addition, Ti (C, N) inclusions could be detected in both regions. No evidences of secondary phases precipitation at grain boundaries were detected, even at high magnification (Fig. 4b).

In the vicinity of the broken zone (Fig. 4c and d) the deformation caused by the fracture was extended about 25–35 μm. However, there is no evidence that the presence of inclusions in the deformed zone was able to encourage the cracking propagation. Therefore, the failure does not seem to be caused by deterioration of the tube's microstructure.

3.3. Hardness measurements

Hardness of the damaged tube, close to the fracture surface, and the intact tube were 240 ± 10 HV10 and 193 ± 6 HV10, respectively. These results show that the damaged tube is 1.24 times harder than the intact one. The analysis of the fracture surface as well as the microstructure of the damaged and intact tubes showed no evidences to justify this hardening by microstructural changes during service. Consequently, this hardening around the damaged section should be explained by plastic deformation accumulated up to failure. To analyse this process it is necessary to determine the hardening curves at room and at the service temperature.

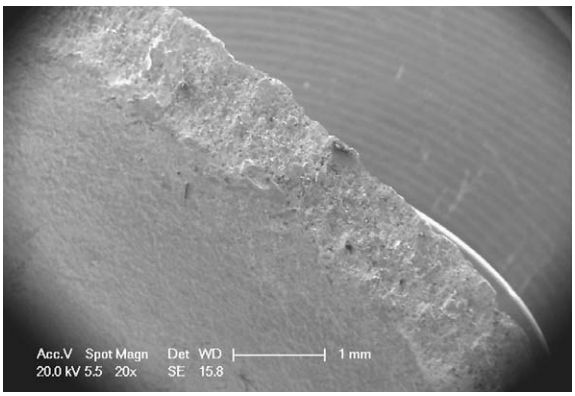

Fig. 1. Fracture surface of the broken tube at low magnification.