

FATIGUE FAILURE OF CENTRIFUGAL BOMB AXIS

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Abstract. Among the factors that can cause the premature failure in metallic components are the use of inadequate materials, the presence of defects that appeared during the production and errors of project, assembly or maintenance. Failure analysis allows the identification of causes, contributing to improve the operation and performance of similar equipments, concerning both functionality and safety requirements and also to avoid the repetition of the same failure type. In this work it is made a study of fatigue analysis failure in a centrifugal bomb axis fabricated in duplex stainless steel and used in petroleum industry. This study comprises fractographic observation in a scanning electron microscope, microstructural analysis in an optical microscope and hardness tests. The results thus obtained allow determining the cause of the failure as fatigue of the material.

Keywords: Failure analysis, fatigue of materials, duplex stainless steel

1. Introduction

Petrochemical industry is one of the most dynamic segments of the world economy and its growth in the last years has led to the development of new materials which can fit to requirements which are getting more demanding. Duplex stainless steels (DSSs), which were firstly proposed as a new material in 1927, were further developed in the following decades until the 1990s and have been mentioned as a possible option to the use of more traditional stainless steels. A NACE/ISO standard describes the requirements for such application (NACE MR0175 / ISO 15156-3, 2003). DSSs have a two phase microstructure, composed by expressive fractions of austenite and ferrite and have some advantages, mainly higher strength, higher resistance to intergranular corrosion and lower cost, together with comparable resistance to uniform corrosion, when compared with austenitic stainless steels. On the other hand, DSSs have some disadvantages like difficult thermomechanical processing and low resistance to pit corrosion (Reick, Pohl and Padilha, 1992).

In order to reach some requirements of toughness, strength and corrosion resistance, the presence of some phases, like σ phase, for instance, must be minimized (Lee, Cho and Choi, 1999; Chen, and Yang, 2001; Chen, Wing and Yang, 2002). Another deleterious phase, formed during thermomechanical processing of DSSs, is Cr_2N , the main precipitate found in the heat affected zone (HAZ) of welded joints. This phase presents a competitive behavior with the austenite phase, so that the conditions which favor the formation of austenite, such as high nitrogen content and low cooling rate, are exactly the ones which minimize the formation of Cr_2N precipitates (Liou, Hsieh and Tsai, 2002). On the other hand, σ phase is formed as a consequence of the decomposition of ferrite, which also increases the volume fraction of austenite. This reaction is favored by aging at higher temperatures (650-900°C) and longer periods (30 min – 8 h). However, the kinetics of the reaction of formation of σ phase is slower than the one of Cr_2N precipitation (Lee, Cho and Choi, 1999; Chen, Wing and Yang, 2002).

The basic mechanical properties of any material are obtained through a stress-strain test. A certain load is applied to a standard specimen until the rupture of this one, and these loading conditions are known as almost static ones. However, frequently stresses vary between certain values of tension and compression and this kind of loading is called cyclic loading.

Fatigue failure is consequence of cyclic loading. When a crack nucleates and propagates in the material, this one will undergo rupture at a stress level much lower than the one necessary to cause fracture under static loading. The main factors which can cause fatigue failure are the range of variation of applied stresses, the number of cycles, stress risers,

corrosion, temperature, overloading, residual stresses and combined stresses. According to Fernandes and Castro (2002) fatigue is a kind of local, progressive and accumulative mechanical failure, or in other words, a partial loss of functionality of some component, as a result of nucleation and progressive propagation of a crack due to cyclic loading. Fatigue failure is a local problem which depends on details of geometric characteristics of the piece, on the material and on the loading at the most stressed point of the piece.

According to Suresh (1991) the phenomenology of fatigue cracks can be analyzed as a problem of local plastic deformation and it can be explained by the appearance of shear bands. When there is dislocation movement certain grains, with main slip direction which coincides with the maximum shearing direction, help the dislocations to be grouped in cells, forming persistent slip bands, which appear mainly on the surface of the piece.

Failure analysis uses several kinds of techniques for the investigation of the causes of the defects which lead to the collapse of an equipment or structure. Generally these causes are related to: the use of inadequate materials, the presence of defects which appeared during fabrication and errors of project, assembly or use. The knowledge about these causes and the correction of these anomalies allow improving the performance of similar equipments and avoid the reappearance of the same kind of failure, concerning both functionality and safety requirements (Azevedo, 2004). Usually failure analysis attempts to correlate the visual aspect of a fracture surface to its possible cause and with this purpose it can use microscopy techniques, mainly scanning electron microscopy (SEM) (Wouters and Froyen, 1996).

In this work it is carried out a fracture analysis of a centrifugal bomb axis used in petrochemical industry, by using techniques such as SEM fractography, microstructural observation of duplex stainless steel in an optical microscope and hardness tests. These techniques complement each other and thus, in an efficient way they allow the identification of the cause of the component failure.

2. Methodology

The chemical composition of duplex stainless steel, obtained through X-ray fluorescence analysis, is presented in table 1.

Table 1. Chemical composition of duplex stainless steel.

C	Si	Mn	P	S	Cr	Ni	N	Mo	V	Cu	W	Co	Fe
0.02	0.52	1.85	0.02	0.001	23.00	5.7	0.19	3.28	0.07	0.13	0.02	0.02	Bal.

The centrifugal bomb axis was partially cut for obtaining samples for microstructural analysis in optical microscope, SEM fractographic analysis and hardness tests. Samples for microstructural analysis were subjected to standard metallographic preparation: grinding (100 to 600 meshes), diamond paste polishing (6 to 1 μm) and etching with a 30 ml nitric acid, 10 ml cloridric acid and 60 ml distilled water etchant. Samples for fractographic analysis were observed and photographed in equipment operating at 20 kV. Rockwell C Hardness test (load: 1471.01 N) comprised 5 measurements at different points of the sample, and the average value was calculated and considered as representative of the sample hardness.

3. Results and Discussion

Figure 1a shows the fractured centrifugal bomb axis as received, while figure 1b, obtained in a stereo-microscope, presents the macroscopic overview of the fracture surface. Figure 2 shows the microstructure of the duplex stainless steel, with austenite delineated in a ferritic matrix, which is in accordance to the NACE/ISO standard (NACE MR0175 / ISO 15156-3, 2003). Through optical microscopy it was not found σ phase. Figure 3, obtained in a scanning electron microscope (SEM), presents detailed aspects of the fracture surface, in which striations are clearly visible. These striations indicate failure by fatigue of the material (Metals Handbook, 1986). Figure 4 shows detailed aspects of other regions of the same fracture surface. Table 2 shows results of Rockwell C hardness test.

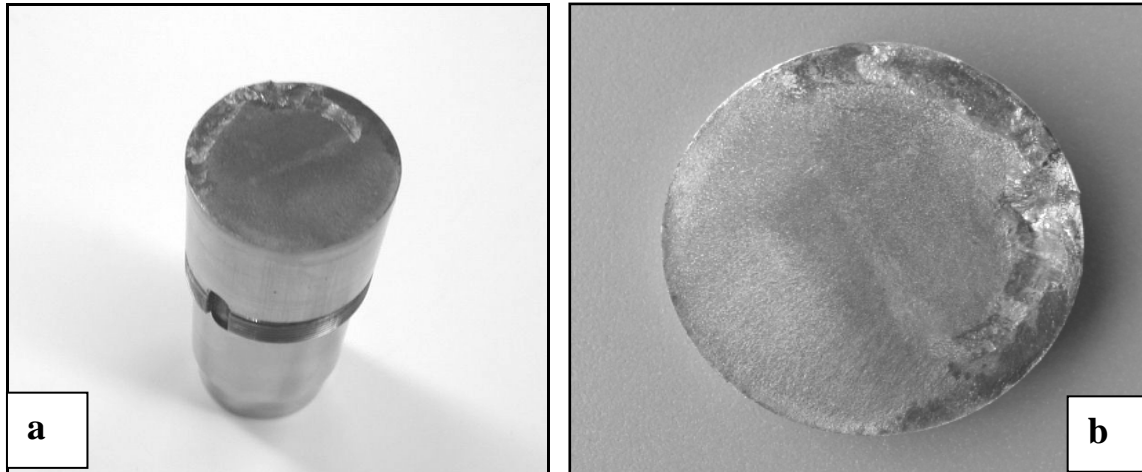


Figure 1. (a) Fractured centrifugal bomb axis (b) Fracture surface: macroscopic overview.

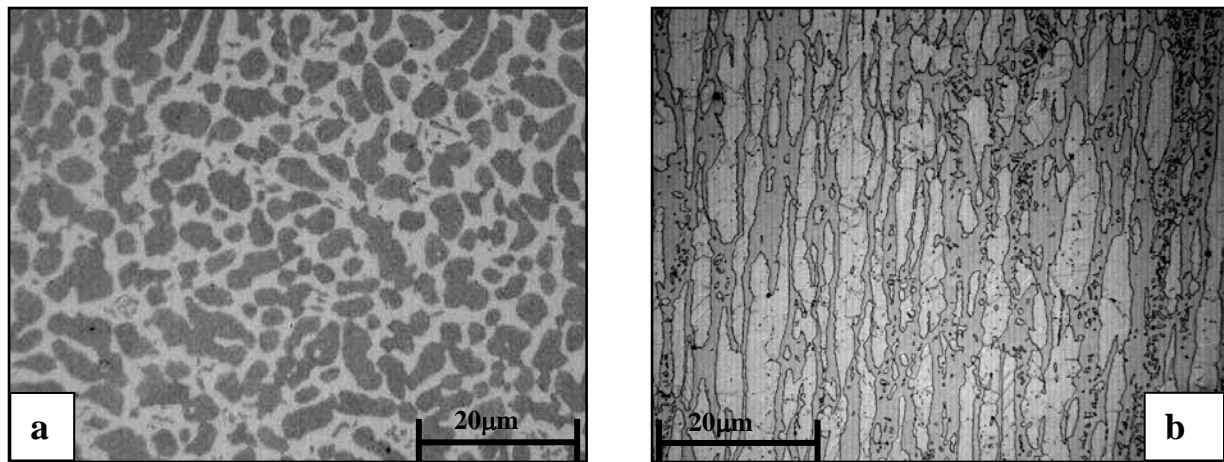


Figure 2. Duplex stainless steel microstructure: (a) transverse section; (b) longitudinal section.

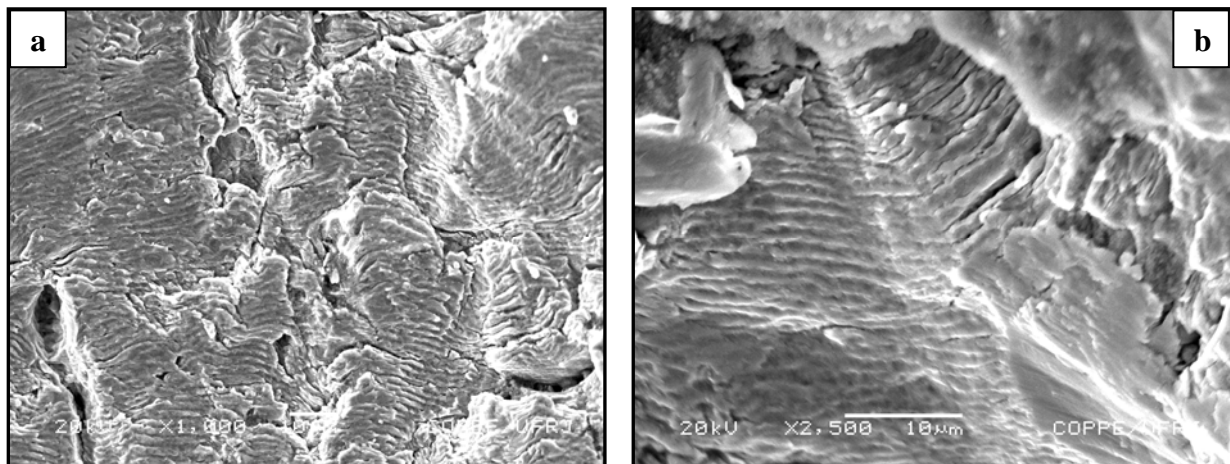


Figure 3. SEM images: (a) Fracture surface presenting fatigue striations. (b) Detailed aspect of the same region.

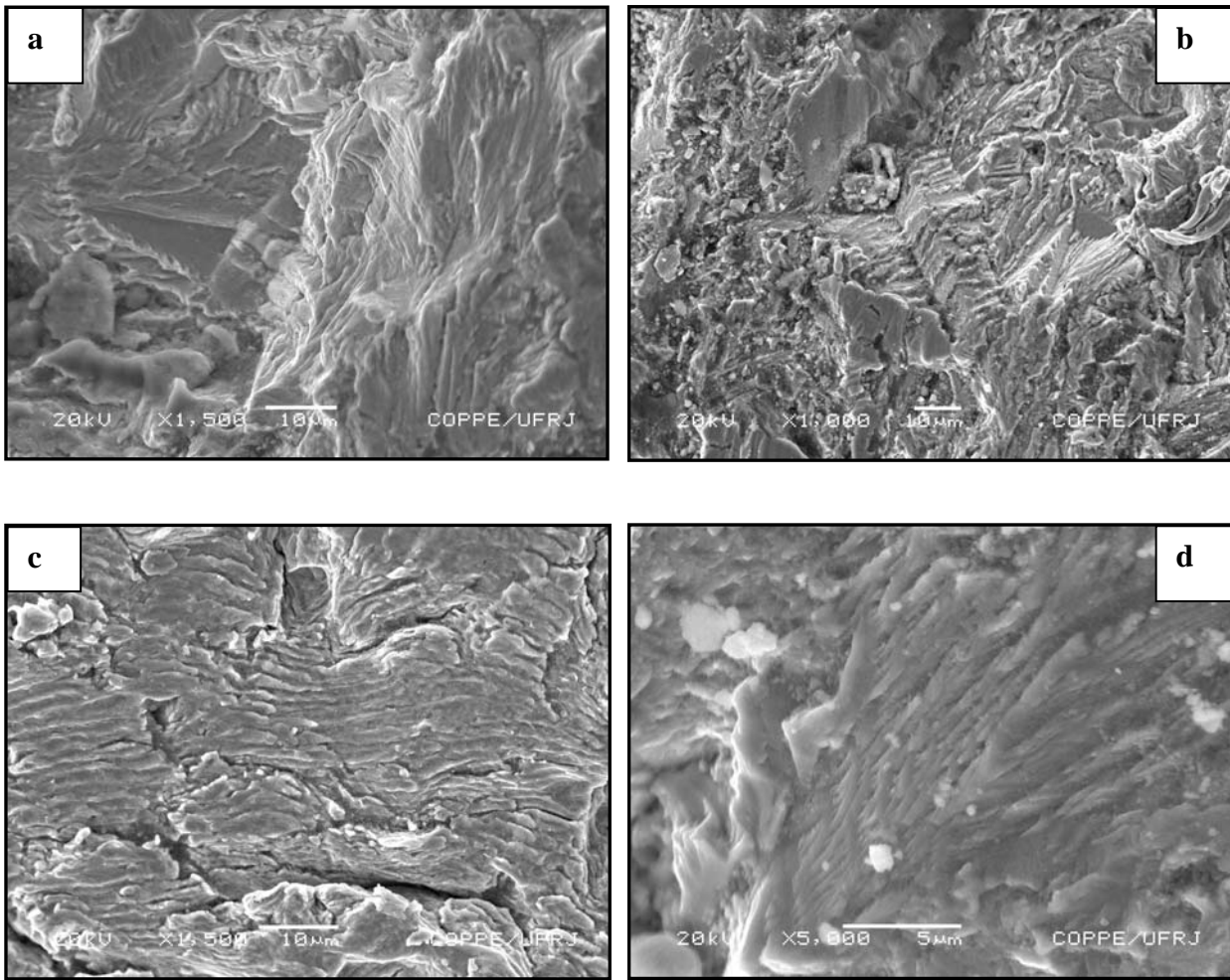


Figure 4. (a) ,(b), (c), (d) Detailed aspects of other regions of the same fracture surface

Table 2. Hardness values of the duplex stainless steel sample.

Points	Hardness (HRC)
1	22
2	22
3	23
4	23
5	22
Average (Rockwell C)	22,4

The average hardness value (22.4 HRC) is lower than the upper limit (25 HRC) prescribed by the NACE/ISO standard for the application of this component and thus it can be considered acceptable (NACE MR0175 / ISO 15156-3, 2003).

According to Reick (1992), duplex stainless steels, with chemical composition very similar to the one analyzed in this study, have tensile strength around 640 to 750 MPa, yield strength between 400 and 450 MPa and total elongation around 25 %, being these values compatible with the kind of application defined for this material in the present case.

If one considers the results with different techniques, which eliminated the possibility of the causes being related to inadequate material (chemical composition and microstructure), one realizes that misalignment harmed the operation of the equipment leading to fatigue failure.

4. Conclusion

The present study on failure analysis of a centrifugal bomb axis made of duplex stainless steel, based on optical microscopy, scanning electron microscopy and Rockwell C hardness tests, led to the following results:

- Microstructure, composed by austenite in a ferritic matrix, which is in accordance to the standard, and no σ phase was observed in optical microscope.
- The hardness of the duplex stainless steel sample (22.4 HRC) also meets the specified values (lower than 25 HRC).
- There is no evidence of corrosion neither any other kind of degradation in the material.
- SEM images reveal evident presence of fatigue striations on the fracture surface.

The previous results suggest that the fatigue failure was probably caused by misalignment during the assembly of the equipment.

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