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# Fracture analysis of a flow control device used in the petrochemical industry

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**Abstract**

This paper presents a service failure analysis of a steel control device assembled in a petrochemical industry division which resulted in a great fire. The purpose of this analysis was the determination of the reasons that caused fractures in the fixation screws of the body/cover of the valve during operation. The failure caused the leakage of hydrogen ($H_2$) and sulfide gas ($H_2S$), being responsible for an accident in Fortaleza, Brazil. Techniques such as visual inspection, electronic microscopy, optical microscopy, determination of mechanical properties, design analysis by computational simulation and spectrometry were used in this investigation. Several factors influenced the failure mechanism, such as: design failure, environmental cracking, device components out of fatigue and fracture specifications.


*Keywords:* Petrochemical; Stress analysis; Environmental cracking; Valve failures; Heat treatment

## 1. Introduction

Failure analysis in metallic components is an extremely important aspect in engineering. Establishment of failure causes supplies information to improve designs, operational procedures and the use of components. According to Brooks [1], determination of the causes of failure can play an important role in establishing liabilities in litigations.

The aim of this work was the determination of the probable reasons for the failure of the flange screws of a valve operating in a petrochemical industry. The failure caused the leakage of hydrogen ($H_2$) and sulfide gas ($H_2S$), being responsible for a serious accident.

The valve was a sphere type, Ø (diameter) $\frac{1}{2}$", pressure class 1479 psi, operating with 1925 psi @ 50 °C. The valve was sent to The Laboratory for Fracture Mechanics and Fatigue Analysis—LAMEFF (Fortaleza, Brazil) after being removed from the plant with fractured screws and in a condition to be analyzed.

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The analysis effort consisted of scanning electronic microscopy, hardness testing and chemical analysis, to verify the failure causes. Computational analysis was run in ANSYS software with the aim of analyzing the stresses acting in the flange.

## 2. Experimental procedure

The experimental procedure consisted of visual inspection, macroscopic and microscopic characterization using a Phillips XL30 electron scanning microscope equipped with energy dispersive spectrometer (EDS), and chemical composition using a Shimadzu X-ray fluorescence spectrometer.

## 3. Results

### 3.1. Visual inspection

Superficial corrosion was observed on the first two fractured screws on the flange (see Fig. 1). The rupture initiated at these two screws.

### 3.2. Fractography

The components were cleaned with 0.1 wt.% alconox solution, and observed in the scanning electron microscope (see Fig. 2).

The geometry of the flange is presented (see Fig. 3) as well as the distribution of the fixing screws, duly enumerated for the analysis.

### 3.3. Chemical analysis and mechanical properties

In the analyzed sample (see Tables 1 and 2), the composition follows the chemical specification of SAE 5140. The determination was carried out in accordance with ASTM E 30-85 [2].

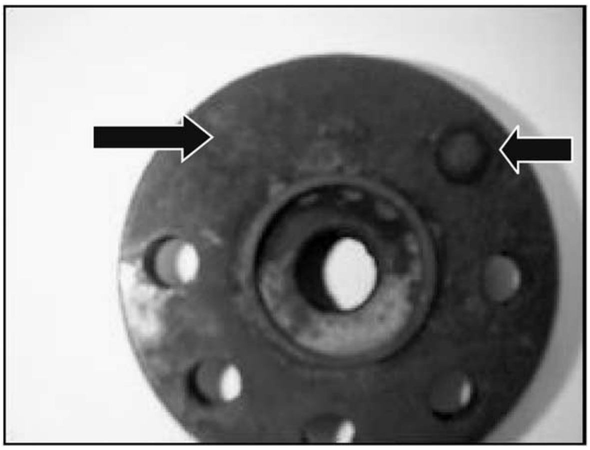

Fig. 1. The arrows show the superficial corrosion of the first two fractured screws.

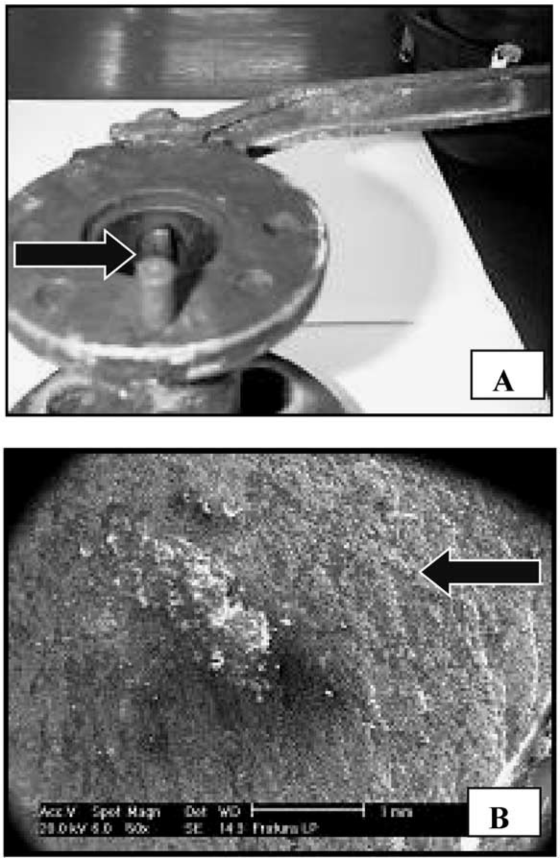


Fig. 2. (a) Fractured screw that remaining fixed on the valve. (b) Striations observed at the top of the fixed fractured screw in the valve flange.

### 3.4. Computational simulation

For this analysis only one type of finite element, SOLID92 (tetrahedral SOLID), was used (see Fig. 4); that element shape is appropriate to model 3D structures and consisted of three degrees of freedom in each node and displacements at x, y, and z nodal positions.

The 3D geometry of the flange was built in CAD software and then exported as an IGES file to be analyzed in the ANSYS program (see Fig. 5). The finite element mesh was generated automatically (see Fig. 6). The holes of the flange were constrained at x, y and z to simulate the fixation screws (see Fig. 7). Finally, the pressure loads were applied in a direction normal to the screws holes surface (see Fig. 7). The solution was done with the ANSYS linear solver. The Von Mises Stress contour plot was obtained with the ANSYS post-processor (see Fig. 8).

## 4. Discussion

In the visual inspection of the flange, surface corrosion was evident (see Fig. 1). The corrosion also happened in other components of the valve.

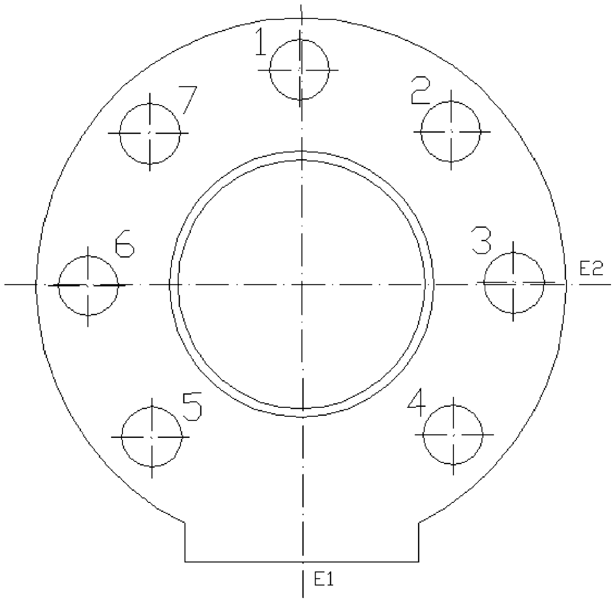


Fig. 3. Flange surface drawn with the screw holes numerically identified.

Table 1
Chemical analysis of the screws

| Components | C | Si | Mn | P | S | Cr | Ni | Mo |
|---|---|---|---|---|---|---|---|---|
| Results | 0.38 | 0.25 | 0.90 | 0.023 | 0.013 | 0.80 | 0.03 | 0.01 |

Table 2
Hardness (Brinell)

| Sample | Hardness (avg.) |
|---|---|
| Screw 3/8″ | 257 HB |
| Screw 5/16″ | 610 HB |

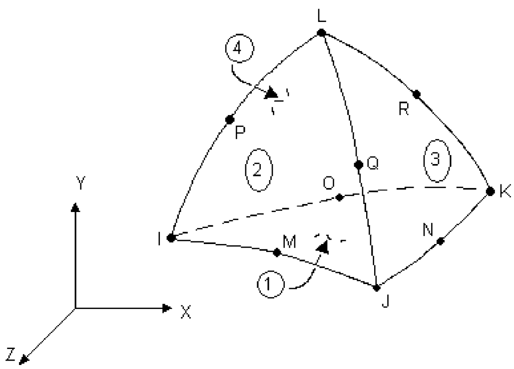


Fig. 4. SOLID92 (tetrahedral solid).

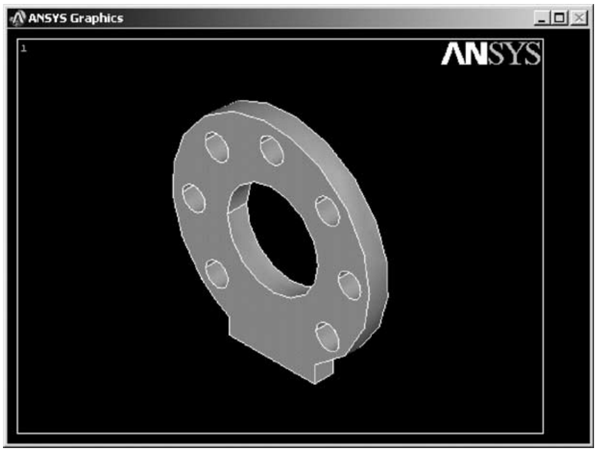


Fig. 5. Flange 3D geometry.

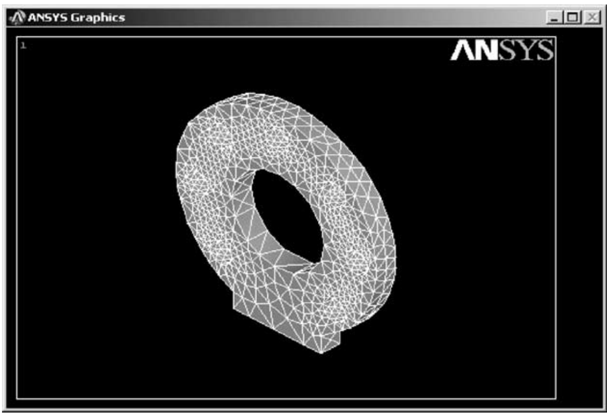


Fig. 6. 3D automatic mesh generation.

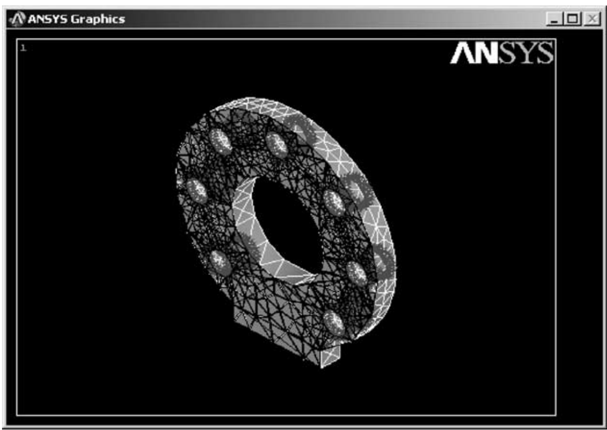


Fig. 7. Constraints and pressure loads applied to the flange model.

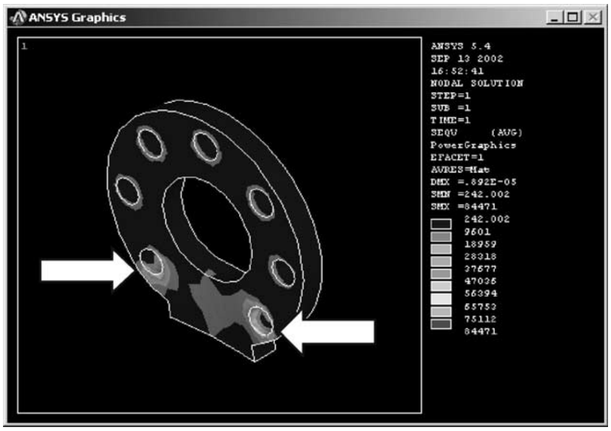


Fig. 8. Von Mises Stress contour plot. The arrows point to the stress concentrations caused by the non-symmetry of screw positions.

It was also observed, that the flange holes possess a pattern that contributed to an irregular stress distribution. The flange did not present symmetry in relation to axis E1 (see Fig. 3). This irregular stress distribution contributed to cause an overload in screws 4 and 5 (see Fig. 3), as the computational simulation shows (see Fig. 8).

According to JONES [3], intergranular crack propagation usually shows grain boundary facets free of ductility (see Fig. 9).

Chemical analysis of the screw showed that molybdenum composition was less than the values specified for ASTM A 193/A 193 M-86 [4]. Annealing should be done right after quenching to remove residual stresses. Residual stresses originated in Martensite formation (on quenching) had probably encouraged cracks. Cyclic loads like pressure oscillations on the plant had contributed to fatigue crack propagation. The analyzed values of the hardness were above the specified ones for ASTM A 193/A 193 M-86 [4] and the hardness reduction is a consequence of annealing that increases material toughness. The screws used for fixing the flanges were not in accordance with ASTM A 193/A 193 M-86 [4].

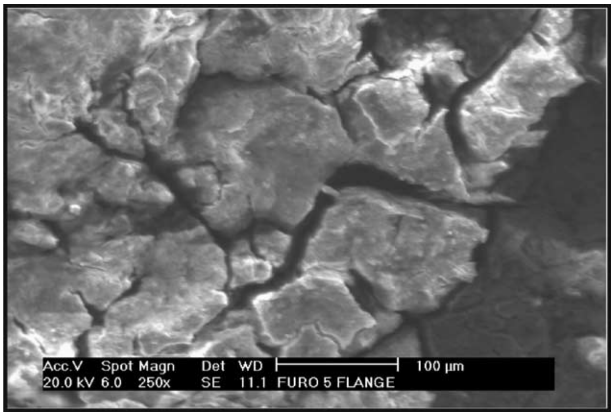


Fig. 9. Grain boundary facets free of ductility caused by environmental cracking.

## 5. Conclusions

The valve failed first by environmental cracking in screws 4 and 5 (see Fig. 3), promoted by the flange screws pattern, hostile environment and use of screws out of specification. Later, fatigue crack propagation caused gas leakage from the valve with the loss of screws 4 and 5, consequently, cyclic loads in the remaining screws led to the failure. The use of inadequate material diminished screw life. Finally, the main causes that had contributed to the failure were: the design of the valve that allowed an irregular stress distribution in the screws, overloading screws 4 and 5; use of screws out of specification that led to environmental cracking (inadequate composition and high hardness) and reduction of fatigue life.

## References

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