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Analysis of Helical Shaft Fracture during Exploitation of Rotary Screw Compressor

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Abstract

This paper describes the results of laboratory analyses – metallographic specimens and strength tests – performed in order to evaluate the causes that determined the fracture during exploitation of a component of the rotary screw compressor (the helical shaft), compressor that accumulated a total number of 24928 hours in service.

The performed analyses (macroscopic examination, chemical composition determination, strength determination, microstructural analysis, and microfractographic analysis) led to the hypothesis that the main cause of the failure during exploitation of the Helical Shaft part was the presence of macro and microcavities from the start ingot used to manufacture the analysed part.

Key words: *screw compressor, helical shaft, friction, cavity*

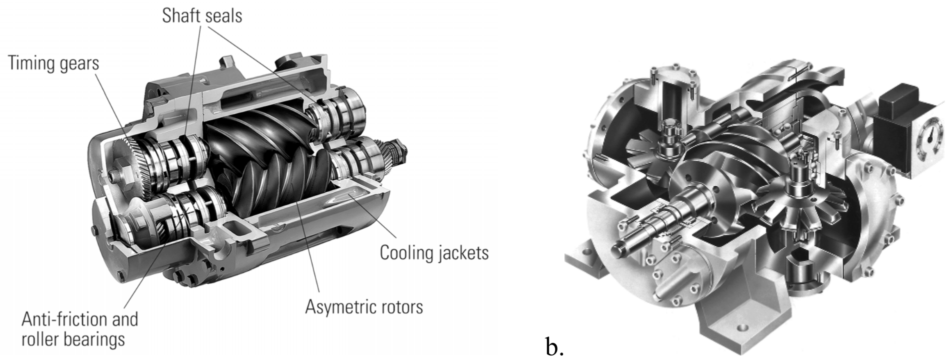
Introduction

The screw compressor is a rotary, positive displacement machine that continuously compresses gas in a near constant motion. It contains only two moving parts called rotors that resembles a screw, hence the name rotary screw compressor. Each rotor has multiple helical grooves, sometimes called lobes, which spiral along the longitudinal axis. One rotor called the main rotor, is machined with large grooves that protrude outward. The other rotor, called the secondary rotor, is machined with grooves that protrude inward. The two rotors are contained in a housing with an inlet port at one end and a discharge port at the other [7, 8].

The rotary screw compressors are made in two configurations: dry (or oil-free) and oil-flooded, presented in Figure 1. The basic principle is the same (the rotors 'push' the air to one side), but they are quite different machines. The big difference is the design of the compressor elements, the part where the actual compression takes place. The oil-flooded version needs oil to operate properly; the oil-free version doesn't need oil.

There are two common methods of preventing excessive slippage. The first is called a “dry screw”. The dry-type screw compressor has no sealing media between the two rotors and the housing, hence the name dry screw compressor. Since the rotors are in close proximity to each other and are not permitted to touch each other, it is necessary that the rotating shafts be linked together with a timing gear. Axial and thrust bearings keep the rotors in position and timing gear keeps them synchronized. Oil is still used, however to lubricate and remove heat from the shaft bearings and timing gear [6].

Normally, dry screw compressors are selected for application that cannot tolerate oil in the process gas supply. Typical applications include, instrument air, food processing and some chemical processes. Another consideration in selecting dry screw compressor is the cost. They tend to cost more because of the higher manufacturing cost necessary to maintain the close tolerances.



a. b.

Fig. 1. Compressor element
a. Oil-free double-screw compressor b. Oil-injected single-screw compressor

The other method of preventing excessive slippage is called a “flooded or wet screw”. Oil is injected directly into the gas stream where it fills the clearance between the rotors, and the clearance between the rotors and housing, the work principle is presented in Figure 2. The flooded screw not only prevents gas slippage but removes some of the heat from the process gas as it is compressed, and provides a lubricating film between rotor surfaces. Consequently, flooded screw compressors do not require timing gears to synchronize the rotors [1, 2, 8].

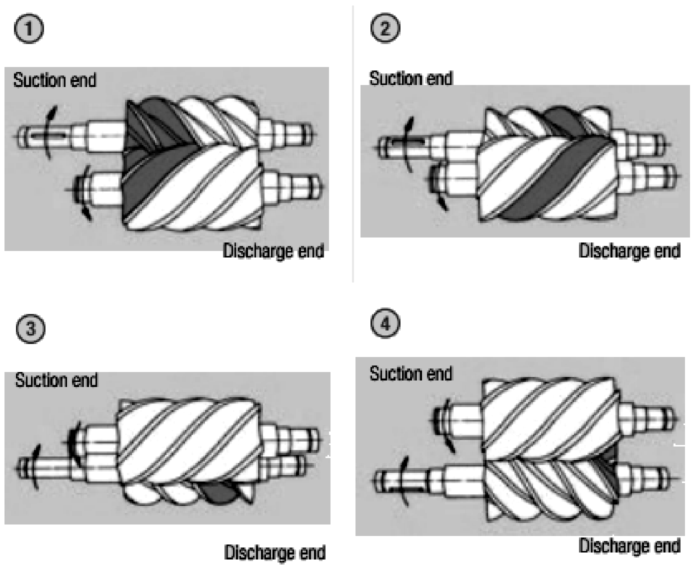


Fig. 2. Working phases of rotary screw compressor:
1) Intake: Gas enters through the intake aperture and flows into the helical grooves of the rotors which are open. ***2) 3) Compressing:*** As the screw rotates the air intake opening closes. The volume in the chambers is reduced and pressure increases. During this procedure, oil is injected to lubricate the rotor bearings, to seal the rotors, and to dissipate the heat of compression. ***4) Discharge:*** The compression process is completed, the final pressure attained, the discharge commences [1].

Maintenance Requirements

Screw compressor servicing includes cleaning, inspecting or replacing modular components on site. Any damage to the rotors normally requires new parts, hence the normal practice is to fit new or factory refurbished elements after either a specified service life or based on condition monitoring trends. The main aim of this replacement is to re-establish the performance to "as-new" values. The clearances inside compressor elements are very small, considering this fact, the ingression of dirt or scale can cause major breakage, and intrusive materials can seize the rotors. The correct inlet filters must always be fitted and maintained, although minor scratches and dents can be ground and polished out [3, 4, 5].

Screw compressors are typically made with high quality carbon steel rotors and cast iron housings. Oil flooded machines are based on oil films to prevent corrosion, while dry machines usually use PTFE coatings. In-service corrosion tends not to be serious as the heat keeps the surfaces dry, and the rust particles are removed immediately. Considering the corrosion process, standby machines should be regularly brought into service for a minimum of 24 hours, and the out of service machines should ideally be sprayed inside with a light coating of lubricating oil, protected from the weather and purged with a small flow of dry air [10].

Case Study - Analysis of Helical Shaft Fracture during Exploitation of Rotary Screw Compressor

This case study concerns laboratory investigations that were performed in order to establish the causes that lead to the fracture during exploitation of the helical shaft, made out of a bar that suffered plastic deformation, material type C35+N (W 1.0501). The shaft is part of a rotary screw compressor and is shown in Figure 3 [1, 9].

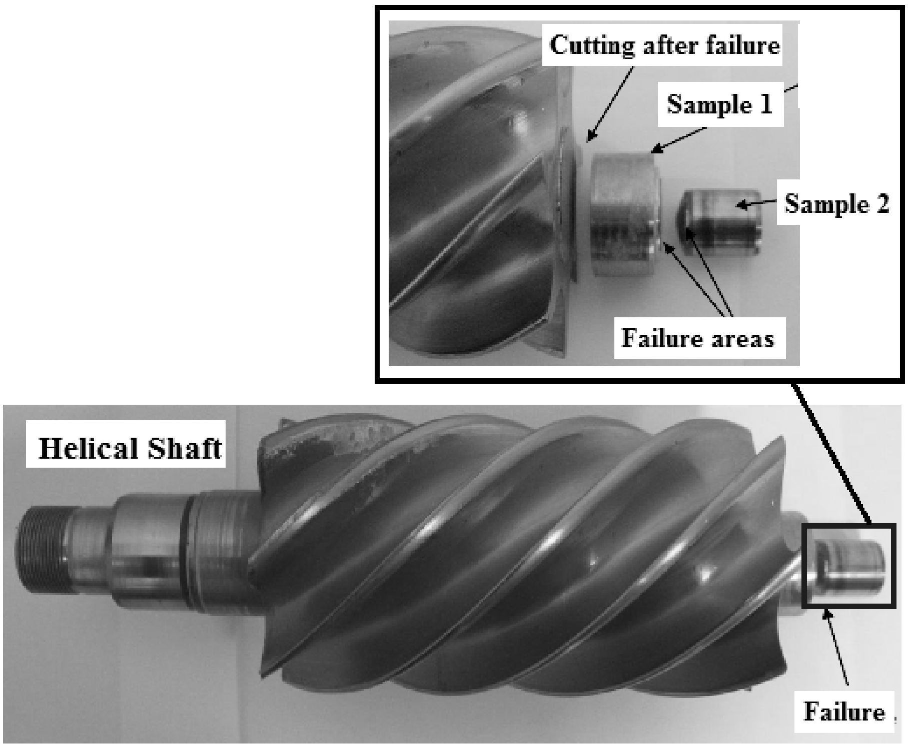


Fig. 3. The Helical Shaft fracture areas – sample used in analysis

Investigation procedures and equipment

The experimental investigations pursued to establish the causes of the deterioration of the helical shaft as a component of the rotary screw compressor consisted of:

➢ macroscopic examination of samples 1 and 2 (see fig. 4) using the stereomicroscope, with magnifications of up to 10x; the examination was performed on both the fracture surfaces, as well as on the exterior surfaces of the samples;

➢ determination of the chemical composition, using the optical spectrometer, performed on sample 2 (on the surface opposite to the fracture surface);

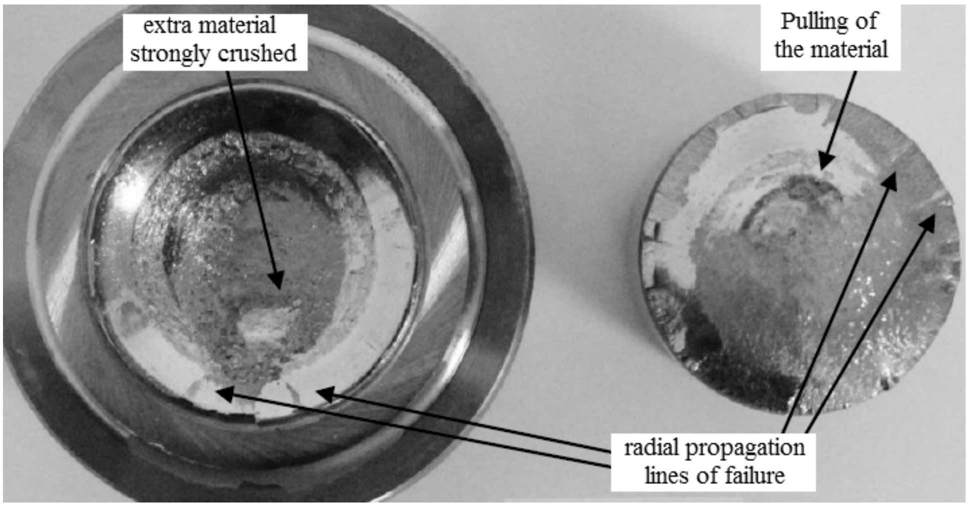


Fig. 4. Analysed samples: sample 1 – right, sample 2 – left

➢ hardness determination through the Brinell method, using the universal hardness tester, with 187.5 kgf of force and 2.5 mm ball;

➢ microstructural analysis of metallographic samples, on sample 1, on a surface cut at a distance of approximately 15 mm from the fracture surface; the examination was performed using the field emission, scanning electron microscope, which has an X ray energy dispersive microanalysis system;

➢ microfractographic analysis of the fracture surfaces, on samples 1 and 2, using the same microscope mentioned above.

Macroscopic examination

The fracture of the part occurred in the minimal section area, at the end of the bearing mounted on that section. The visual and macroscopic with small magnifications examinations were performed after the bearing was removed and revealed the following aspects [9]:

- the bearing removed from sample 1 did not show signs of abnormal behaviour during usage;
- the exterior surface of sample 1 (on generators) showed small abrasion areas, that probably formed during the installation of the bearing, but with no fractures visible to the naked eye, towards the fracture surface; these area will be the studied using the scanning electron microscope;
- the exterior surface of sample 2 (on generators) showed friction marks that were probably produced after the fracture occurred; there were no cracks visible to the naked eye;

- from a macroscopic point of view, the fracture surfaces are destroyed in proportion of 70% by calking due to the friction between them, after the occurrence of the fracture; there were no straining grooves and a specific rupture point could not be identified because of the advanced degradation state of the surfaces;
- on the fracture surface of sample 1 we could observe a material loss of macroscopic dimensions, that corresponds to a material excess on sample 2, strongly calked (see fig. 4); both areas will be examined at large magnifications using the electron microscope.

Chemical composition determination

The material's chemical composition, determined through optical spectrometry, on the face opposite the fracture surface of sample 2, is shown in Table 1. We can notice that the material is a type of carbon-steel, which corresponds to the SR EN 10083:2007 material standard for the C35 brand.

Table 1. Results of the tests on the chemical composition

Chemical composition, % by mass									
	C	Si	Mn	P	S	Cr	Mo	Ni	Cr+Mo+Ni
Sample 2	0.35	0.20	0.71	0.015	0.015	0.09	0.02	0.10	0.21
SR EN 10083:2007	0.32 – 0.39	< 0.40	0.50 – 0.80	< 0.045	< 0.045	< 0.40	< 0.1	< 0.4	< 0.63

Hardness determination

The material hardness determined on sample 1, through the Brinell method, according to SR EN ISO 6506-1:2006 was found to lie in the interval 152-155 HBW 2.5/187.5, which corresponds to a resistance to traction of 510 MPa. This values is above the minimal value imposed the by the SR EN 10083:2007 standard for the normalized state of the material.

Microstructural analysis of metallographic samples

Evaluation of the microstructure was performed on sample 1, after a filing, polishing, and Nital 2% treatment. The examination using the scanning electron microscope showed the following:

- The general aspect of the microstructure is normal for a carbon-steel that suffered normalized plastic deformation; the microstructure consists of ferrite and lamellar perlite grains, constituents found in equal proportions; the structure is extremely fine, with a grain size of score 6-7 according to ASTM E112 (see fig. 5);
- We could not observe non-metallic inclusions, especially silicates, nitrates, and sulphates, extremely fine and uniformly spread on the examined surfaces; the inclusion level was normal for steel under normal conditions;
- We could not observe signs of material overheating during the plastic deformation and thermal treatment procedures.

Microfractographic analysis

The investigation using the scanning electron microscope were performed on sample 1 (exterior and fracture surfaces) and on sample 2 (fracture surface), with the obtained images shown in Figure 6. The examination was performed at an electron bean acceleration potential of 30 kV, in images of secondary electrons.

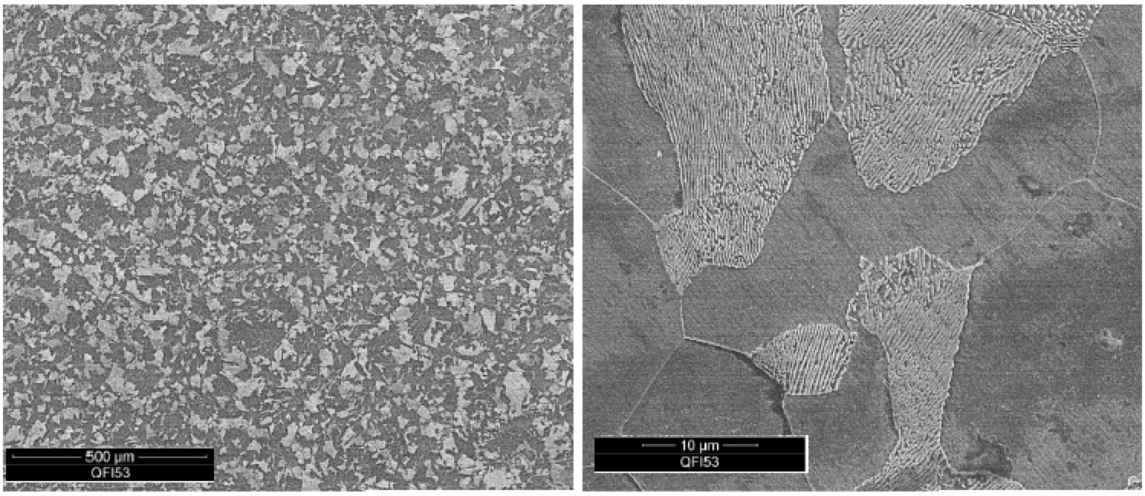


Fig. 5. Microstructure on sample 1, in two images (x200; x600), ferrite and perlite grains, extremely fine structure and high uniformity level.

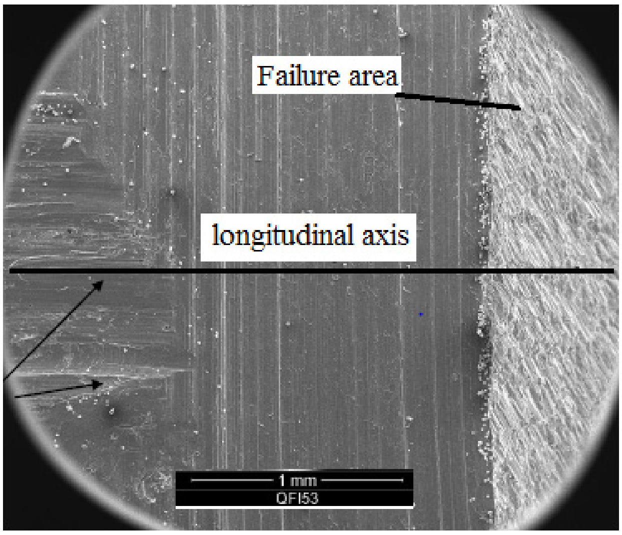


Fig. 6. Secondary electrons image (x100) of the exterior surface of sample 1. Superficial material deformations at about 2 mm from the fracture surface.

The small geometric irregularities observed on the exterior surface of sample 1 (during the macroscopic analysis) were examined using the scanning electron microscope, and we observed that the general aspect of the affected areas suggests a superficial deformation of the material that occurred, most likely, during the installation of the bearing, and no cracks on either the slightly deformed areas or on the spaces the separate them from the fracture surface, which shows that they did not contribute to the fracture [9].

Analysis of the fracture surfaces

Examination of the fracture surfaces using the scanning electron microscope was performed on the areas that showed fewer signs of deterioration and that were signalled as relevant during the macroscopic analysis. The following aspects were observed:

- the area marked on Figure 2 as a macroscopic fracture crater (a material loss of a couple of cubic milometers, on sample 1) turns out to be, after examinations at high magnifications, a material defect, specifically a cavity; around this macroscopic defect we observed a multitude of such microscopic defects, some of them obstructed by material pressed immediately following the fracture (see Figure 7); we also noticed material micro volumes surrounded by contraction holes;

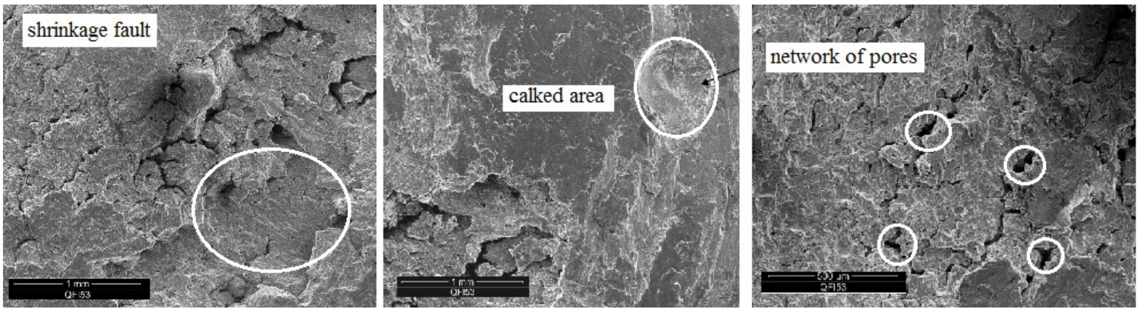


Fig. 5. Examining the fracture surfaces using the scanning electron microscope

- the deterioration level of the fracture surfaces was approximately 90%; even in areas where the macroscopic analysis revealed the presence of fracture craters, these turn out to be flat and deformed due to the friction between the two parts separated by the fracture; we cannot establish the ductile-fragile character of the fracture; the defect is positioned at approximated half a radius from the centre.

Conclusions

The part that represents the subject of this investigation report (the helical shaft of a rotary screw compressor) is in conformity with the execution documentation as far as material characteristics are concerned. The chemical composition and hardness correspond to the SR EN 10083:2007 standard for the normalized C35 class of materials. The material microstructure (ferrite - perlite) is extremely fine and has a high uniformity degree.

The advanced deterioration degree of the fracture surfaces, due to the intense friction of the parts that resulted after the fracture, allowed for a microscopic examination on extremely small areas. Even in these conditions, areas with material defects could be observed, and were found at a distance of half a radius from the centre of rotation.

The defects are macro and microcavities, the biggest one measuring approximately 4x3x4 mm. Surrounding these macroscopic cavities we observed areas with contraction pores that form networks around the material microvolumes, thus favoring the formation of radial cracks as a result of operation strains. Even though the dimensions of the whole area of defects cannot be precisely estimated, because of the advanced stage of deterioration of the fracture surface, it is certain that the fracture started from these defects, and propagated rapidly towards the edges of the part. The radial propagation lines, macroscopically observed on both samples, support this idea.

Regarding the material defects described in this report, they probably come from the start ingot that presented a central cavity, thinned by the ulterior plastic deformation procedures. In these conditions, it is very likely that the analysed part may present other areas with such defects, but unaffected during exploitation due to their bigger width. In the analysed case, the fracture was favored by the presence of the defect in the minimal section of the part.

Considering all of the above, we conclude that the fracture during exploitation of the analysed part occurred due to the presence of a material defect in the minimal section, under mechanical strain due to normal exploitation.

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Analiza ruperii în serviciu a arborelui elicoidal din componența unui compresor cu șurub

Rezumat

Lucrarea prezintă rezultate analizelor de laborator – probe metalografice şi încercări de duritate – efectuate pentru evaluarea cauzelor care au determinat ruperea în serviciu a reperului arbore elicoidal, din componența unui compresor cu şurub, compresor ce a acumulat un număr total de 24928 ore de funcționare.

Analizele efectuate (examinare macroscopică, determinare compoziție chimică, determinare duritate, analiză microstructurală si analiză microfractografică) au condus la formularea ipotezei conform căreia, principala cauză care a determinat cedarea in exploatare a piesei tip arbore elicoidal este reprezentată de prezența unor defectelor de tip macro şi microretasuri provenite de la lingoul de pornire, utilizat la realizarea piesei analizate.