FAILURE ANALYSIS AND PREVENTION OF METALLIC STRUCTURES AND COMPONENTS FROM NPP: CASE STUDY

ANALIZA DE DEFECTARE ȘI PREVENIRE ÎN CAZUL STRUCTURILOR ȘI COMPONENTELOR METALICE DINTR-O CENTRALĂ NUCLEARĂ

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Abstract: *The goal of the current study was the analysis of one threaded rod from the elastic suspension of the raw water pipelines from CNE Cernavoda to identify the causes that led to its breakage. For the failure analysis, fracture surface of the threaded rod was investigated using laboratory techniques: optical microscopy, scanning electron microscopy, energy dispersive X – ray spectrometry(SEM-EDS) and mechanical tries (Brinell hardness) .*

The conclusion was the failure of the threaded rod was caused by improper mounting, the presence of a hard impurity in material and the usage of a material with greater hardness than the one specified in the project.

Keywords: failure analysis, threaded rod, elastic suspensions of pipelines

Rezumat: *Scopul studiului a fost analiza unei tije filetate din suspensia elastică a conductelor de apă brută de la CNE Cernavodă pentru a stabili cauzele care au dus la ruperea acesteia. Pentru analiza defecțiunilor, suprafața de rupere a tijei filetate a fost investigată folosind urmatoarele tehnici de laborator: microscopie optică, microscopie electronică de scanare / dispersie energetică - spectrometrie cu raze X (SEM-EDS) și încercări mecanice (duritate Brinell).*

Concluzia finala a fost că ruperea tijei filetate s-a datorat montarii necorespunzătoare, prezenței unei impurități dure in material și utilizarii unui material cu o duritate mai mare decât cea specificată în standard.

Cuvinte cheie: analiza defectelor, tijă filetată, suspensii elastice ale conductelor

1. Introduction

A failure analysis procedure, or methodology for evaluation, is necesary to be made step by step. This includes developing a logical plan for the investigation,

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collection of background information, laboratory testing and analysis, formulation of final report based on relevant data, analysis, and recommendations.

A failure analysis investigation is much like the work of a detective. Relevant facts pertaining to the investigation must be gathered, analyzed, and studied with attention to solve the problems. After the point of origin is found, the investigator may proceed to study possible causes or factors involved in the failure (design, method of manufacturing, service history, environment conditions or a deficiency in the material) and possible means of preventative measures.

The first question of an evaluation is why a failure occurs. The answer can be find separating the failure into “mode of failure” and “cause of failure”. Mode of failure can be revealed by fractography, while the cause of failure can be identified through metallurgical and mechanical testing, chemical and surface analysis. [1].

The goal of the current study was the analysis of one threaded rod from the elastic suspension of the raw water pipelines from Cernavoda NPP to identify the causes that led to its breakage.

This elastic support of pipelines (included in class 6 according to NC 2-83) is mounted in the classical path of the nuclear station. Normally, this type of suspension is composed of two main parts: the load bearing element, which distributes the load to the bearing construction and the threaded rod which links the pipeline to the suspension guide.

In this case study, the failure of the rod occurred in the contact zone between the inferior board of the spring guide and the nut that locks the threaded rod to the board of the spring.

For the failure analysis, the fracture surface of the threaded rod was investigated using the following laboratory techniques: optical microscopy, scanning electron microscopy/ energy dispersive X – ray spectrometry(EDS) and mechanical tries (Brinell hardness) .

2. Experimental

After all available data have been collected, a laboratory investigation is often needed to fully analize the physical evidence and to identify the failure mechanism.

This laboratory investigation has been performed in the Nuclear Materials and Corrosion department from Institute for Nuclear Research, Pitesti. The steps performed in the laboratory to solve the problem have been: visual examination; mechanical tries (Brinell hardness); metallographic examination; fractographic examination.

The visual examination of the failed part, as well as a non-destructive examination of the failure, with extensive photographic documentation, precedes any mechanical testing or any metallurgical examination and remains the cornerstone of any failure examination. The photographic records are useful as subsequent reference or comparison.

Metallographic examination includes the macroscopic examination of the surface of the selected specimen and microscopic examination.
Careful macroscopic examination is extremely important but may be insufficient to properly evaluate fracture modes; therefore, it must to be followed by a microscopic examination of the material as well as a transverse and longitudinal cross section examination.

For microscopic analysis a metallographic microscope OLYMPUS GX 71 type which permits magnifications in the range of x 12.5 - x 2000 has been used. Because sometimes the abnormalities of the possible fractures may complicate microscopic examination, micro fractographic examination of failed components is often a necessity.

Fractographic examination includes analysis of damaged surfaces, secondary cracks, origin of fracture, and direction of the crack growth. For this analysis a TESCAN VEGA II LMU electron microscope operating up to 30 kV has been used. This device is equipped with 3 detectors: a secondary electron (SE) detector, a back-scattered electron (BSE) detector and an energy dispersive X – ray spectrometer (EDS).

3. Results and discussions

The first data obtained from the NPP mentioned that the rod belonged to a elastic guidance system that kept hold up the pipelines from the raw water cooling system (RCW). The threaded rod was made of OLC 25, in accordance with STAS 880-88. From the analysis of the project loads, it resulted that the bifilar elastic support was subjected to a force of 2662 daN, respectively 1031 daN on the branch. From the calculation of the static tensions a load of 585 daN / cm^2 has been obtained for both rods, which means 292 daN / cm^2 for a rod indicating a very high design reserve of about 400%. This means that the load to which a threaded rod is subjected under normal conditions had the value below the limit established by the project [2].

3.1. Visual examination

In order to determine the cause of the failure, in the begining, the fracture surface was photographed and visually examined. After the visual examination the following aspects were observed:

- The rod had one end screwed into the lower board of the sprind guide, while the other end was welded;
- The rod had an imprint due to the friction with the guide plate and was bent near the welded end
- The thread of the rod is corroded, presenting rust (Figure 1a).
- The thread of the rod was corroded, showing traces of red color (rust) which in some places were quite thick.

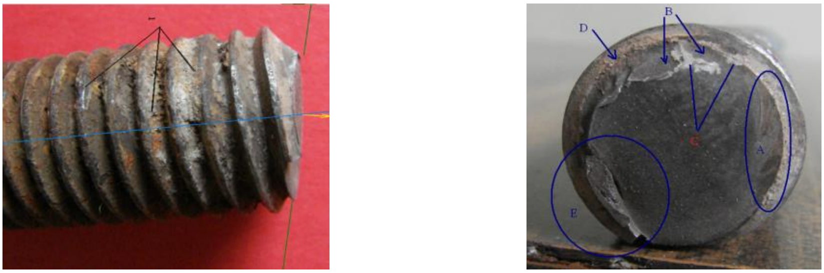


Figure 1. The threaded rod (a) and the fracture surface (b)

Analysing the fracture surface (figure 1b), the following were observed:

- a crack due to torsion (the zone A), caused by inadequate or excessive screwing.
- surfaces with different orientation to the fracture surface (the zone B).
- light grey colour surfaces (the zone C).
- region with reddish coloration, suggesting the presence of corrosion products that entered into breaking zone (the zone D).
- final breaking region (the zone E), with torn material.

Aside from the above mentioned regions, the fracture surface was smooth, indicating a fragile break, possibly through fatigue mechanism.

Because on the fracture surface reddish zones (rust) were observed, it was concluded that they were formed before the break. Moreover, it was observed a crack produced by torsion (in the zone A), due to an inappropriate or excessive threading, as well as a crack at the bottom of the thread (zone D).

3.2. Metallographic analysis

The metallographic analysis followed the fracture surface analysis. Thus, from the threaded part of the rod a sample was cut which was longitudinally sectioned. Through optical microscopy have been revealed a crack at the bottom of the thread (Figure 2). A larger detail shows that the crack is very long and sharp at the tip, which means a high concentration of tensions at tip.

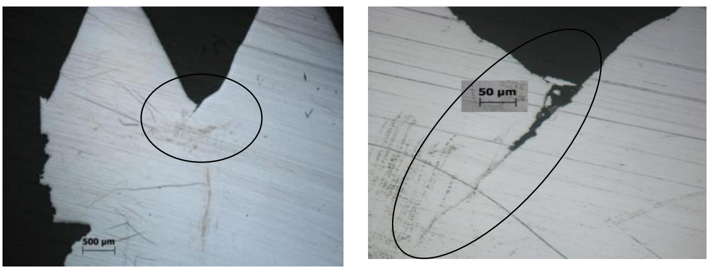


Figure 2. a) Crack inside of the thread (x100) b) detail (x200)

3.3. Chemical composition identification

The chemical composition of the threaded rod have been determined by X-ray fluorescence (XRF), using the spectrometer "ARL ADVANT'X Series" (Table 1).

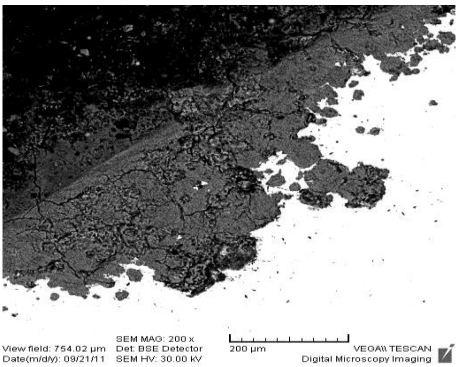
Table 1. Chemical composition of the threaded rod

	XRF results	OLC 25, STAS 880-88,
Element	**[mass%]**	**[mass %]**
C	0.3	0.22-0.29
Mn	0.79	0.10-0.70
Si	0.40	0.17-0.37
Cr	0.90	max.0.30
Ni	0.21	max.0.30
Cu	0.22	max.0.30
P	0.02	max.0.04
S	0	0.02-0.040
Fe	96.68	rest

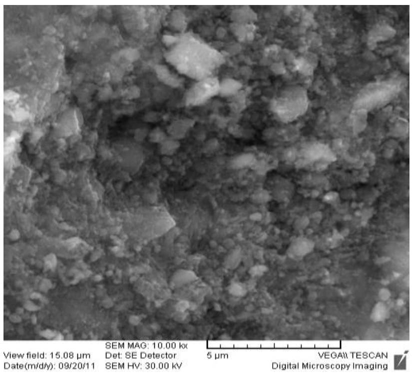
3.4. Fractographic examination

The technique used in this investigation was the scattered electron microscopy (SEM), using the secondary electron (SE) and the backscattered electron (BSE) detectors of the VEGA II LMU electron microscope. First of all, the area with torsion marks and reddish zones (rust) was scanned.

Furthermore, the corrosion products found at the bottom of the thread (the zone D) were analyzed and the thickness of the products indicated a long time for developing. At higher magnification (Figure 3b) the crystalline structure of the oxides can be observed (generally magnetite and hematite, based on their shape).



a)



b)

Figure 3. Corrosion products inside of the thread; a) BSE image b) detail (x10000 magnification)

The zone C from figure 1 (light grey colored), was marked as the crack initiation. Generally, in fractography, different colored regions indicate a difference in atomic number, more precisely the presence of impurities. In the Figure 4, the zones considered to be impurities are highlighted with red arrows. In order to identify the chemical elements, the impurities were analyzed through the EDS technique.

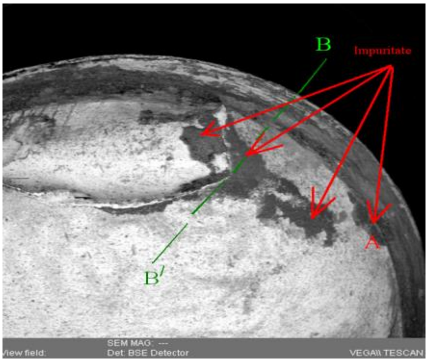


Figure 4. BSE image of the fracture surface

In Figure 5, it can be observed that in the impurities region (indicated above by red arrows) the fracture surface changes the orientation plane, which led to the conclusion that in this region the fatigue fracture nucleated.

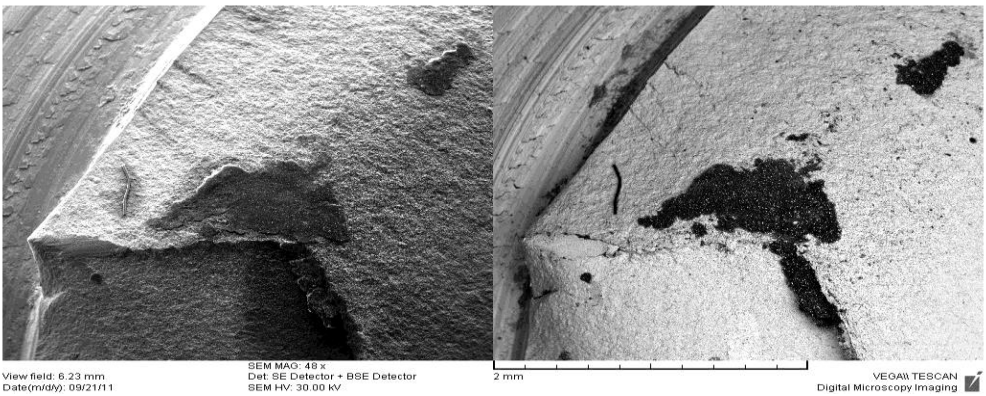


Figure 5. SE image of the surfaces with different orientation than fracture plane (region B)

For a more detailed analysis of the impurity from which the fatigue nucleated, a cut was made through the impurity, the examined section being presented in the Figure 6. Around the impurity it was observed the cracked material which means that the fatigue crack propagated progressively after nucleation.

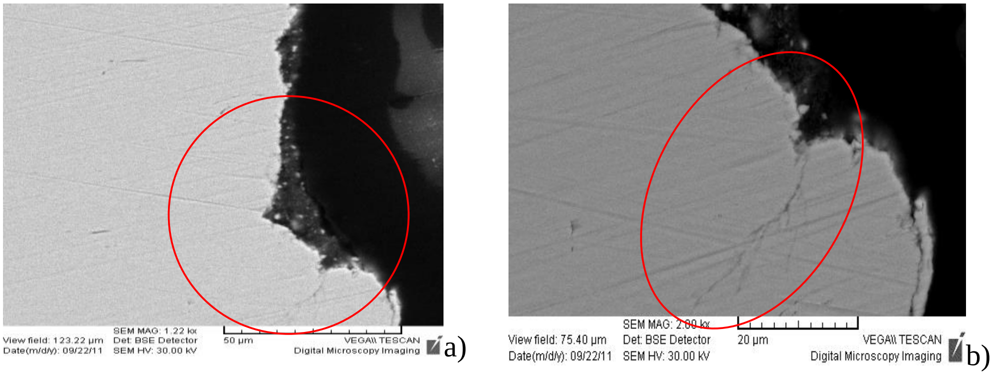


Figure 6. a) BSE image of the section through impurity b) detail

The development of the crack was explained by the concentration of tensions at the bottom of the thread during screwing process. Also, the cracks could be caused by a chemical composition not conforming to the standards (XRF analysis) or by a hardening of the material (Brinell hardness test demonstrated that comparatively with the standard hardness (180 HB), the measured hardness was greater (195 HB).

3.5 EDS Analysis

EDS analysis identified the presence of impurities in the fracture surface. The Figure 7 presents the images obtained with secondary electrons and the elemental map.

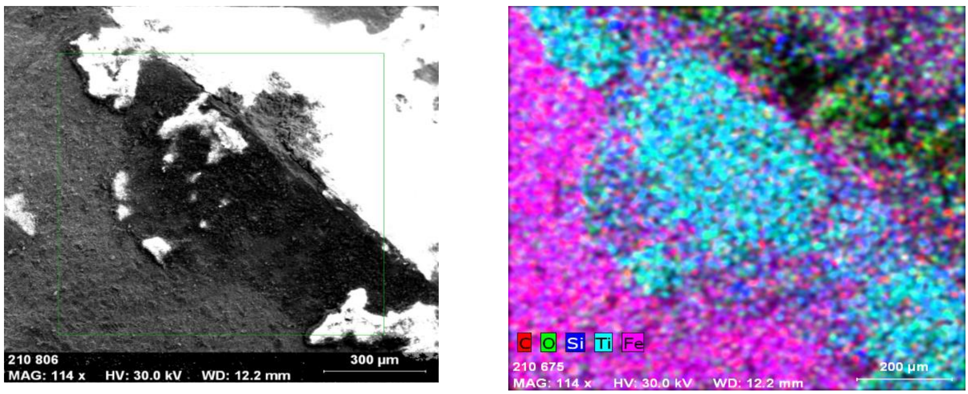


Figure 7. SE image with elemental compounds (C, O, Si, Ti) of the impurity

After elemental cartography, titanium was identified in the impurity (normally, titanium is not a part of a carbon steel), combined with carbon and with silicon particles. The concentration of titanium and carbon has been observed only in the region of the impurity, comparatively with the rest of the alloy, which is preponderantly iron . Thus, we concluded that the impurity appeared during the fabrication process, titanium carbide and sand being included in the material during manufacturing.

4. Conclusions

The failure of the threaded rod was caused by improper mounting of the rod in the spring guide system which led to contact and friction with the upper board, and to the rigidity in the system. Thus, a complex distribution of tensions emerged, rather than the vertical distribution as designed for the spring guide system.

In this context, excessive screwing of the nuts has lead, since installation, to the appearance of multiple tension concentrators (torsion cracks, axial cracks of the rod and cracks at the bottom of the thread).

However, improper screwing of the rod may not be the only cause; it was complemented by the hardenness and the chemical composition non conformant with the technical specifications for the material and by the presence of the titanium carbide hard impurity, right in the threaded region, which favored the appearance of the crack..

5. Recomandation

Prior to mounting the threaded rod, it is recommended that the material used is verified to be conform to the technical specifications (composition, hardness, etc.) and with the project specifications.

During the mounting of the rod, it is recommended that operations such as screwing, welding and mounting be done without damaging the components (forceful insertion , bending the components, excessive tightening).

During inspection and maintenance operations, it is recommended that attention should be given to friction between rods and the openings in the upper and lower board.

R E F E R E N C E S

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