Вісник Тернопільського національного технічного університету
https://doi.org/10.33108/visnyk_tntu
Scientific Journal of the Ternopil National Technical University
2025, № 4 (120) https://doi.org/10.33108/visnyk_tntu2025.04
ISSN 2522-4433. Web: ***visnyk.tntu.edu.ua***

UDC 620.1:62-226.2 CC-BY 4.0

STRUCTURAL-FRACTOGRAPHIC INDICATORS OF OPERATIONAL DAMAGE IN STEAM TURBINE ROTOR DISC STEEL

Petro Solovey[1]; Halyna Krechkovska[1,2]; Oleksandra Student[1]

[1]Karpenko Physico-Mechanical Institute of the NAS of Ukraine Lviv, Ukraine
[2]Lviv Plyitechnic National University, Lviv, Ukraine

Abstract. *The technical condition of the metal in a steam turbine rotor disk was analysed, and the causes of its failure were determined. It was shown that, despite the mechanical properties of 30KhN3M1FA steel meeting regulatory requirements under tension and impact, damage occurred in one of the rotor stages, leading to a forced shutdown of the rotor. Metallographic studies of the steel structure revealed an excessive amount of non-metallic inclusions, the high corrosive activity of which facilitated the dissolution of the matrix in their vicinity. These point defects became the sites of fatigue crack initiation. High contact stresses between the surfaces of rivets and holes in the rotor disk, and the constant increase in their relative displacement due to clearance violations during long-term operation, contributed to contact fatigue and the initiation of a network of microcracks in the vicinity of the holes. The string-like arrangement of structurally determined corrosion defects facilitated their coalescence, forming a continuous fatigue crack front. Its propagation culminated in the destruction of the bridges between the rivet holes in the rotor disc flange. Consequently, the combined effects of both corrosive inclusions and the increasing displacements in the contact zone of the elements contributed to the formation of localized crack initiation zones and intensified the growth of the main fatigue crack. Its propagation was accompanied by the formation of parallel fatigue striations at the disc fracture surface. Furthermore, the crack propagation front during localized stages of its growth was accompanied by the appearance of decorative pits on the operational fracture surface. This confirmed that non-metallic inclusions present in the steel structure facilitated crack growth not only at the initiation stage but also during the propagation stage due to the coalescence of the crack front with these defects.*

Key words: *30KhN3M1FA steel, steam turbine rotor disc, strength, ductility, impact toughness, structure, fractographic features of failure.*

Submitted 15.07.2025
Revised 11.12.2025
Published 27.01.2026

https://doi.org/10.33108/visnyk_tntu2025.04. 090

1. INTRODUCTION

The specific nature of steam turbine operation, namely high temperature and intensive static and cyclic loads combined with the influence of the technological environment, inevitably contributes to the development of damage in the constituent elements of turbine rotors (shaft, discs, blades) [1, 2]. Defects caused by mechanical and thermal treatments, which primarily occur in the surface layers of these elements, contribute to the fatigue damage of rotor elements and are therefore classified as additional factors negatively affecting their performance [3, 4, 5]. The initiation and growth of circumferential cracks in steam turbine rotor shafts, caused by the influence of torque, are also considered negative consequences of their operation [6]. In general, when investigating the causes of operational damage in steam turbine rotor elements, indicators of all types of fatigue are visualized. These include signs of low-cycle and high-cycle fatigue, thermal fatigue, and corrosion fatigue. Furthermore, under the combined effect of a high static component of cyclic stresses and a corrosively active environment, signs of stress corrosion cracking (SCC) are also found in the rotor discs [7, 8, 9, 10]. Therefore, any rotor with an operating life exceeding 20 years is inspected for the presence of these signs [11].

At the same time, in complex structures such as steam turbine rotors, there are also many locations where the surfaces of elements that transmit steam energy to the rotor shaft come into contact with one another during longtime operation. Specifically, such locations include the interaction zones between the blades' roots and the rotor discs' crests, which are joined into a single unit by through rivets [12].

As a result, conditions for fretting fatigue arise between them. Furthermore, considering the increasing relative displacements between the elements due to wear during long-time operation, prerequisites for high-load contact fatigue are created. The increased stress concentration near the rivet holes in both the disc crests and the blade roots can only contribute to the further propagation of failure across their entire working cross-section.

However, available sources scarcely provide little information on failures caused by contact fatigue under high specific loads between rotor elements. Therefore, the aim of this work is: based on a complex of metallographic, fractographic, and mechanical studies, to identify the signs of contact fatigue as the mechanism responsible for crack initiation in a steam turbine rotor disc, and to demonstrate its involvement in the premature failure of one of the rotor stages.

2. OBJECT OF ANALYSIS AND RESEARCH METHODS USED

Real fractures of a prematurely failed steam turbine rotor disc from one of the power units were analyzed. The disc was made of the heat-resistant steel 30KhN3M1FA. Despite the rotor's operating conditions conforming to the station's regulations (steam temperature and pressure were 400ºC and 10 MPa, respectively), its service life did not even reach 122×10^3 h.

To certify the 30KhN3M1FA steel for compliance with the requirements of industry regulatory documents, its chemical composition, hardness, and mechanical properties under tension and impact were determined. The content of elements in the disc steel was determined using an optical spark atomic emission spectrometer, SPECTROMAX LMF 0.5. Tensile specimens were tested on a UME-10T machine at a strain rate of $3\cdot10^{-3}$ s^{-1}. Standard cylindrical specimens with 5 mm diameter and a gauge length five times the diameter were used. The following characteristics were determined: ultimate tensile strength σ_{UTS} and yield strength σ_{YS}, relative elongation δ and reduction of area ψ. The steel's resistance to brittle fracture (impact toughness KCV) was evaluated on standard Charpy specimens (the radius of the V-notch was 0,25 mm), which were tested by impact on an IO-5003 pendulum impact tester. A scanning electron microscope, EVO-40XVP, was used to study the structural signs of damage and the fractographic features of the operational fracture surfaces of the rotor disc.

3. FINDINGS AND ANALYSIS

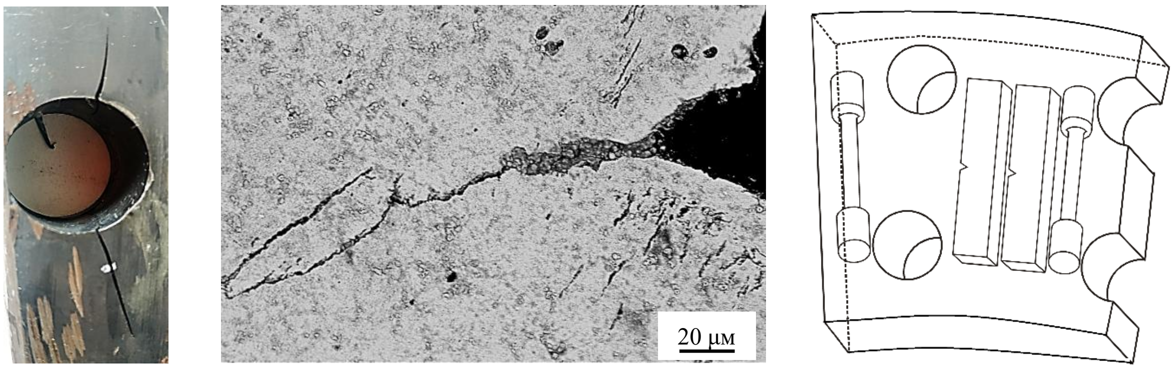
The chemical composition of the 30KhN3M1FA rotor disc and the requirements established by the technical specifications, are presented in the table. Evidently, the analyzed steel complied with the requirements of this document with respect to the content of all elements.

Table

Chemical composition of the disk metal, wt. %

C	Si	Mn	Cr	S	P	Ni	V	Mo	Cu	Fe
0,30	0,019	0,32	1,67	0,0046	0,0005	3,42	0,14	0,54	0,11	other
Regulated Content of Elements (TS 108.11.918-87)										
0,27–0,32	≤0,17	0,2–0,45	1,3–1,7	<0,015	<0,015	3,4–3,8	0,12–0,18	0,5-0,7	≤0,2	other

The fractures on the rotor disc's crest were located between adjacent rivet holes connecting the forked blade roots to the rotor disc's crest. Macroscopically, the cracks that developed in the bridges between the holes in the disk crest were oriented normally to the direction of the centrifugal forces generated during rotor operation. In the diametrical cross-section of these bridges that had not yet completely failed during operation, cracks originating from the rivet holes were detected (Fig. 1 a). At the microscopic level, these cracks were characterized by both macro- and micro-branching and a curvilinear propagation path (Fig. 1 b). Furthermore, the gap between their edges was filled with corrosion products formed as a result of the interaction of steel with the process medium during prolonged contact. All these signs indicate that the failure of the bridges between the holes occurred via a corrosion-fatigue mechanism, rather than as a result of spontaneous failure due to a single rotor overload. Taking into account the orientation of the operational fractures on the rotor disc crest, the mechanical properties of the steel were determined using specimens oriented radially relative to the rotor axis (Fig. 1 c). This was done to ensure that the macro-orientation of the specimen fractures and the operational fractures of the disk coincided. The results of the mechanical tests on these specimens showed that their σ_{UTS} and σ_{YS} values were 773 and 653 MPa respectively, δ and ψ were 22 and 71%, and KCV was 1,64 J/cm^2. All these indicators did not exceed the requirements of the industry technical specifications TS 108.11.918-87. Thus, despite the compliance of the rotor's operating conditions, the steel's chemical composition, and its mechanical characteristics with the regulatory requirements, the rotor disc still failed.

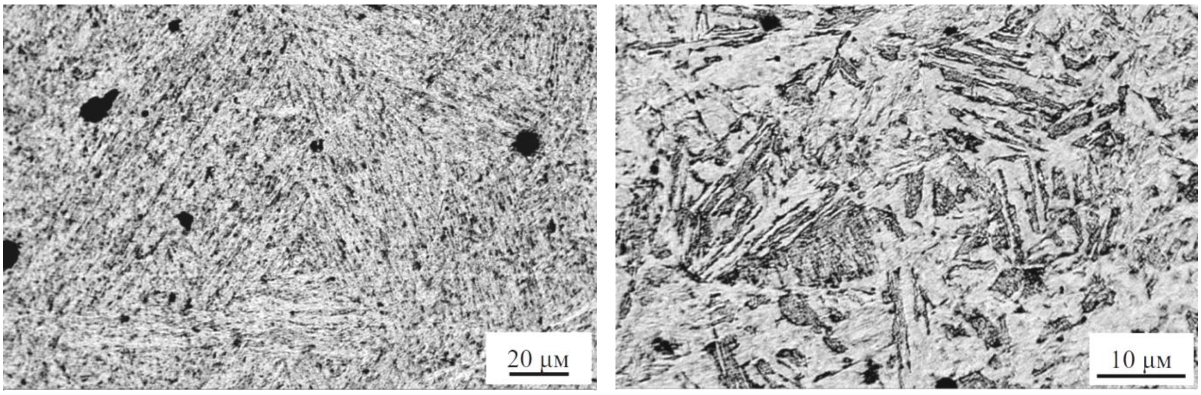


a b c

Figure 1. Macro- (a) and microscopic (b) view of cracks from a rivet hole and scheme of cutting samples (c) from the crest of a steam turbine rotor disk

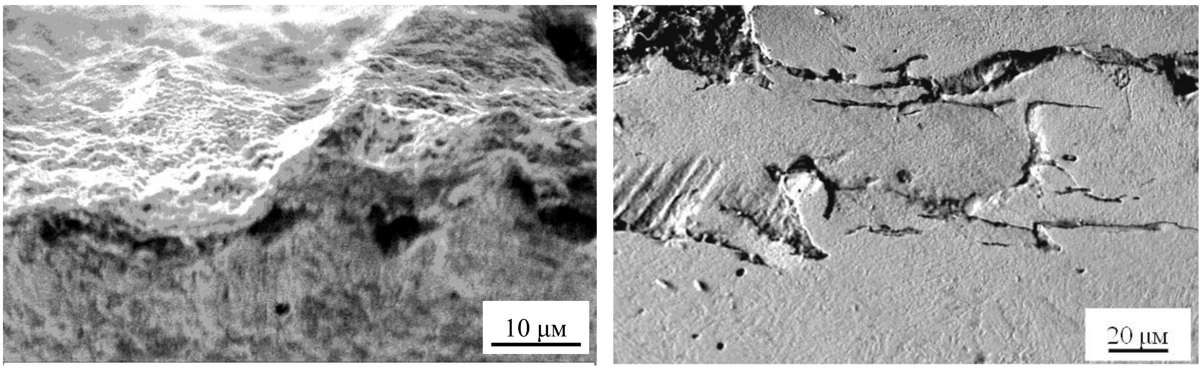
Metallographic studies of the structure of 30KhN3M1FA steel in the diametrical cross-section of the disc revealed typical morphological signs of highly tempered martensite (Fig. 2), which were more clearly identified at high magnification. The characteristic orientation of packets of practically parallel martensite laths changed during the transition from one austenite grain to another, within which they were formed. A feature of the structure was also an excessively high number of quite large (up to 15 μm) non-metallic inclusions, the high density of which was more clearly revealed at lower magnifications (Fig. 2 a). In the structure of the analyzed disc, their density was several times higher than the acceptable value for rotor disc metal (up to 2–3 particles per 1 mm^2 of polished surface area).

Since the rate of local corrosion generally increases with increasing density of non-metallic inclusions, this was considered a dangerous factor influencing the intensity of corrosive damage formation. They were classified as corrosion-active non-metallic inclusions [13], the row arrangement of which contributed to the initiation of corrosion-fatigue cracks in the bridges between the holes in the rotor disc crest. Considering the access of the process medium to the contact zones between the surfaces of the holes in the disc and the rivets, the corrosive activity of these inclusions created the preconditions for the localization of deformation processes in areas with their high density. Indeed, the corrosive pits that formed on these inclusions (due to the dissolution of the inclusions themselves or the matrix around them) acted as structural stress concentrators. They were observed even near the transitions from the surface of the rivet holes in the disk crest to the surface of its fracture in the form of unidirectional rows of corrosive defects connected by a crack parallel to the fracture and located directly below it (Fig. 3 a).



a b

Figure 2. Structure of 30KhN3M1FA steel in the diametrical cross-section of the rotor disk crest

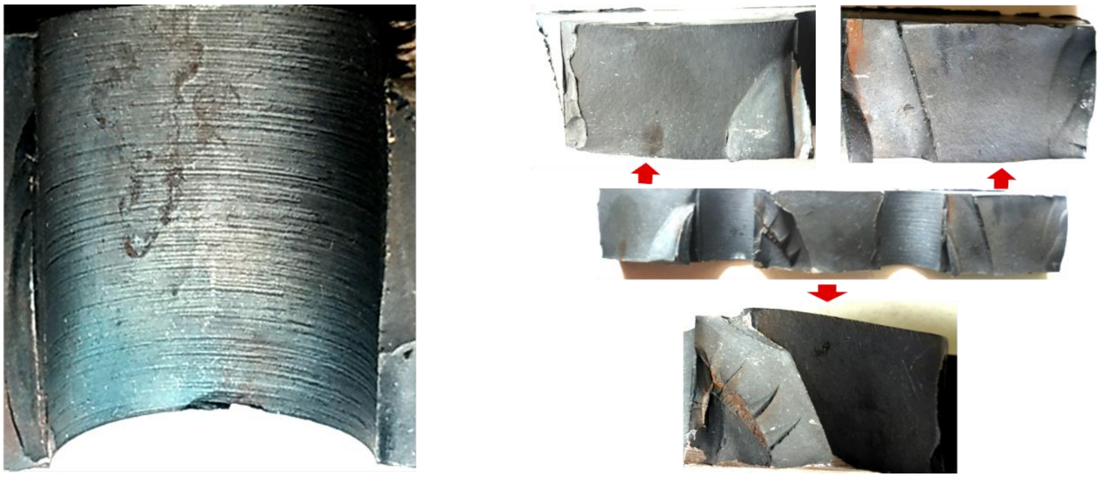


a b

Figure 3. Banded arrangement of corrosion pits of corrosive pits initiated by non-metallic inclusions on the surface of the rivet hole (in the lower part of the image), in the vicinity of its transition to the operational fracture surface (a), as well as typical contact fatigue cracks found on the diametrical polished section of the rotor disc crest under the surface of the rivet hole (b)

Such cracks are typically associated with contact fatigue. They are usually inclined relative to the contacting surfaces, and therefore, in cross-section, they appear parallel to them. The growth of contact fatigue cracks occurred through the destruction of the bridges between the closest non-metallic inclusions, which confirmed their negative role in the nucleation of damage (Fig. 3 b). Both the number of such cracks and the depth at which they were detected under the hole surface increased closer to the zone from which the disc crest failure occurred. Due to the action of high contact loads, cracks located at various distances from the hole surface in the disc crest connected via a shear mechanism, destroying the bridges between the nearest non-metallic inclusions. The transformation of one of these cracks into a main crack was accompanied by its reorientation (to one radially oriented relative to the rivet hole) and subsequent propagation under the action of cyclic tensile loads, but now as a crack oriented normally relative to the direction of the centrifugal forces acting on the disc.

During the visual inspection of the damaged elements of the disc crest, traces of contact fatigue were also found on the inner surface of the rivet holes in the damaged disc, in the form of a crack on the steam inlet side to the stage (Fig. 4). The crack is oriented along the axis of the hole (across the traces of rough machining on the hole surface). Along its growth path, corrosive pits caused by non-metallic inclusions were detected. It was these pits that determined the curvilinear propagation trajectory of the contact fatigue crack, which propagated from one pit to another. A significant portion of these inclusions, based on their elemental composition, are classified as corrosion-active non-metallic inclusions [13]. These non-metallic inclusions contributed to the active dissolution of both the inclusions themselves and the matrix phase in their vicinity when moisture entered the contact zone of the rivet surfaces and the holes in the disk crest. Taking into account the micro-displacements of the rivets relative to the hole surfaces in the disc, these local structural defects facilitated the formation of a network of fine microcracks initiated from them.



a b

Figure 4. Traces of rough machining on the inner surface of a rivet hole formed during the disc manufacturing stage, and the curved trajectory of a contact fatigue crack propagating along the axis of this hole (a, in the upper photo), as well as typical features of macro-fractures in the bridges between the closest rivet holes in the crest of the steam turbine rotor disc (b)

To limit the movement of the blade roots and the disk crest along the rivets, the rotor disk assembly technology included cold heading of the rivet ends at the exit of the holes.. However, due to non-compliance with the requirements for the cleanliness of the contact surfaces and the gaps between them, which only increased during the operation of the rotor, the circumferential movements between the rivets and the disc crest became increasingly easier, and their amplitude grew. As a result of the intensive deformation of the metal's surface layers under the surfaces of the rivet holes, the microcracks from corrosive pits on the non-metallic inclusions connected, and longitudinal contact fatigue cracks formed on the surfaces of the holes.

Macro-level analysis of the fractures in the bridges between the rivet holes showed that all failures began in the form of angular segmental cracks on the steam inlet side of the stage (Fig. 4). Their relatively smooth morphology at the initial stage typically ended in a rough final fracture with characteristic brittle tear ridges, corresponding to the overload stage upon reaching a critical state.

In addition to mechanical damage, fracture surfaces of the disk, were also covered with a dense film of high-temperature oxidation products, which hid the details of the fractures and made them practically unsuitable for fine fractographic studies at the microscopic level (Fig. 5 a). This was considered direct proof that the fractures were exposed to the high-temperature process medium for a long period, and therefore, their formation did not occur instantaneously due to overload but over a long period of the disc's service life. However, even in this state, quarter-circular marks were visible on the fractures, densely decorated with rows of circular pits (up to 5 µm in diameter), which formed due to the corrosive interaction of non-metallic inclusions with the process medium. The same pits decorated the front of the propagating fatigue crack at each subsequent stage of its growth. Based on this, it was concluded that inclusions in the steel structure (as a result of imperfections deoxidation process, incomplete homogenization of the solid solution, etc.) play a decisive role in reducing its fracture resistance.

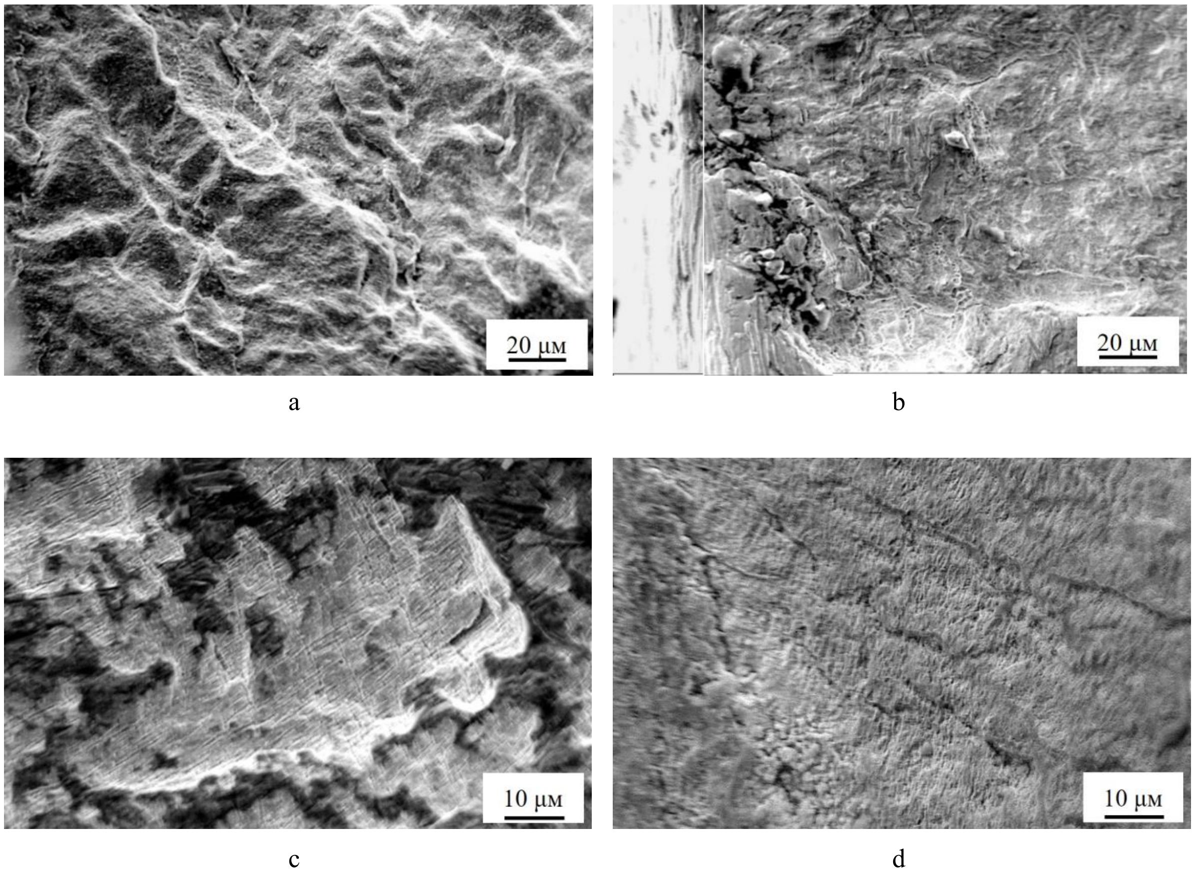


Figure 5. Typical fractograms of fractures of the bridges between the holes in the disc crest at the fracture initiation stage by the contact fatigue mechanism (a, b) and at the stage of further propagation of a fatigue crack by the fatigue striation mechanism (c, d)

To visualise the fine details of the relief of the fractures, whose depth could be even less than the thickness of the surface oxide film, it was gradually removed by chemical means in order to at least partially access the metal underneath, while preserving the fine features of the relief. According to the results [14, 15, 16], the depth of the relief with fatigue striations is measured from tens to hundreds of nanometres. Thus, in order to unambiguously prove that the destruction of the disk crest occurred not as a result of a single overload of the rotor during its operation, but as a result of its long-term cyclic loading, it was necessary to preserve the fatigue striations at the fractures.

Even partial cleaning of the fractures revealed a series of parallel cracks on the surface of the rivet disk hole, visualised by opening their edges (Fig. 5 b, parallel steps in the lower left corner of the fractogram). Secondary cracks, decorated with non-metallic inclusions, are clearly visible on the fractures of the disk crest. These cracks are traces of contact fatigue cracks, propagating from the surface of the rivet holes to their intersection with the fracture surface. These secondary cracks were not considered to be traditional branches of the crack in the direction of its propagation, which, as a rule, relax the stress at their tips and slow down their growth. However, these cracks most likely represented alternative fracture initiation pathways from the hole surface, intersecting the fracture but behind the main fracture front. In our case, this is an effective way to visualise contact fatigue cracks in the fractures of the bridges between the rivet holes.

After repeated cleaning of the fractures, it was possible to confirm that the crack initiation stage via the contact fatigue mechanism from the rivet hole surfaces in the disc crest gradually transitions to its propagation via the high-cycle fatigue mechanism. According to the results of the analysis of the fracture of the bridge between the holes in the damaged fragment of the disc crest at the stage of the angular quarter-circular crack propagation from the steam inlet side, typical signs of fatigue failure were discovered (Fig. 5 c, d). The most important of these was the presence of parallel rows of fine fatigue striations located across the festoons, extending in the main direction of fatigue crack propagation. These striations were the traces of the crack's stage-by-stage advancement during each load cycle of the disc.

The crack growth in the bridges via the high-cycle corrosion-fatigue mechanism continued until it propagated through the entire thickness of the disc crest. This indicated that favorable conditions for the growth of fatigue cracks from the inner surface of the holes in the crest existed for a considerably long period of the rotor's operation. The spacing of these striations did not exceed 0,5…0,9 µm. This made it possible to determine the crack growth rate in the analyzed bridge of the disc fragment, which reached 10^{-6} m/cycle. This corresponds to the upper part of the second region of the fatigue crack growth rate diagram for this class of steels [17]. The initiation and propagation of fatigue cracks in only a certain portion of the briges between rivet holes with the most unfavorable structural and design features (density of non-metallic inclusions, tightness of rivet fit density in the holes, and conditions for medium penetration into the element contact zone), gives grounds to state that the fatigue crack initiated and propagated in the turbine rotor disc over a fairly long period of operation, and not as a result of a single act of destruction due to overload.

After the destruction propagated via the high-cycle corrosion-fatigue mechanism through the entire thickness of the disc crest, when the quarter-circular crack weakened the working cross-section of the bridge between the holes across its entire thickness, fracture began from the adjacent hole on the steam outlet side, but now via the low-cycle fatigue mechanism. However, this stage of fracture propagation was also closely related to the structural features of the disc steel, namely the presence of an unacceptably large number of non-metallic inclusions in its structure.

4. CONCLUSIONS

Based on a detailed analysis of the damaged disc crest fractures, it was revealed that small crack initiation sites of contact fatigue initially formed on the rivet hole surfaces in the disc crest on the steam inlet side. Slight circumferential movements of the rivet surfaces relative to the holes in the crest, the access of the process medium to their contact zone, and the presence of a significant quantity of quite large non-metallic inclusions in the steel structure all contributed to the nucleation of crack in the bridges between the rivet holes via the contact fatigue mechanism.

The cracks propagate across the entire thickness of the rotor disc crest and then over a significant portion of the bridge length to the adjacent rivet hole by the mechanism of high-cycle corrosion fatigue, forming a classic fatigue relief with festoons extended along the main crack growth direction, and parallel rows of fatigue striations oriented perpendicular to them. The significantly higher stress concentration at the tips of such cracks compared to that in the rivet holes facilitated their propagation even at a low tensile stress intensity factor (far from that typical of resonance overloads). The formation of such cracks in several bridges between adjacent holes accelerated the spread of each of them until their final destruction due to the mechanism of low-cycle fatigue.

References

1. Banaszkiewcz M., Rehmus-Forc A. (2015) Stress corrosion cracking of a 60 MW steam turbine rotor // Engineering Failure Analysis, 51, pp. 55–68. https://doi.org/10.1016/j.engfailanal.2015.02.015
2. Tkachuk Yu. M., Student O. Z. (2009) Problems of thermal power engineering of Ukraine: analysis of the causes of damage to steam turbine components. Scientific notes, is. 26, pp. 329–333. http://nbuv.gov.ua/UJRN/Nn_2009_26_68/. (In Ukrainian).
3. Miller D. A., Lagoudas D. C. (2000) Influence of heat treatment on the mechanical properties and damage development in a SiC/Ti-15-3 MMC. J. of Engineering Materials and Technology, no. 1 (122), pp. 74–77. https://doi.org/10.1115/1.482768
4. Tekkaya A. E., Bouchard P.-O., Bruschi S., Tasan C. C. (2020) Damage in metal forming. CIRP Annals – Manufacturing Technology, no. 2 (69), pp. 600–623. https://doi.org/10.1016/j.cirp.2020.05.005
5. Soori M., Asmael M. (2020) Mechanical behavior of materials in metal cutting operations, a review // J. of New Technology and Materials, no. 2 (10), pp. 79–82. https://doi.org/10.12816/0058539
6. Vaziri A., Nayeb-Hashemi H. (2005) The effect of crack surface interaction on the stress intensity factor in Mode III crack growth in round shafts. Engineering Fracture Mechanics, no. 72, pp. 617–629. https://doi.org/10.1016/j.engfracmech.2004.03.014
7. Turnbull A., Zhou S. (2003) Overview Steam turbines Part 2 – Stress corrosion cracking of turbine disc steels. Corrosion. Engineering Science and Technology, 38 (3):177–191. https://doi.org/10.1179/147842203770226906
8. Matocha K., Cizek P., Kauder L., Pustejovsky P. Resistance of 10GN2MFA – a low alloy steel to stress corrosion cracking in high temperature water. Nucl Power-Control, Reliab Human Factors 2011. ISBN: 978-953-307-599-0, InTech. https://doi.org/10.5772/17280
9. Verona C. L. (2010). Stress corrosion cracking of low-pressure steam turbine blade and rotor materials. A doctoral thesis submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy. https://hdl.handle.net/2134/10165. This item is submitted to Loughborough's Institutional Repository and is available at: https://dspace.lboro.ac.uk/.
10. Luo L., Huang Y., Weng S., Xuan F.-Z. (2016) Mechanism-related modelling of pit evaluation in the CrNiMoV steel in simulated environment of low pressure nuclear steam turbine. Materials & Design, 105, pp. 240–250. https://doi.org/10.1016/j.matdes.2016.05.058
11. Weng S., Huang Y., Lin S., Xuan F.-Z. (2022) Stress corrosion crack propagation affected by microstructures for nuclear steam turbine rotor steels in the simulated environment. Journal of Materials Research and Technology, vol. 17, pp. 725–742. https://doi.org/10.1016/j.jmrt.2022.01.020
12. Solovei P., Student O., Svirska L., Kurnat I., Krechkovska S., Gural T. (2023) Establishing the causes of premature damage of steam turbine rotor blades of TPP. Scientific Journal of the Ternopil National Technical University, no. 2 (110), pp. 46–56. https://doi.org/10.33108/visnyk_tntu2023.02
13. Krechkovska H. V., Solovei P. R., Student O. Z. (2025) Effect of non-metallic inclusions in steel structure on the premature failure of the steam turbine rotor disk. Materials Science, 61 (1), pp. 74–80. https://doi.org/10.1007/s11003-025-00962-3
14. McEvily A. J., Matsunaga H. (2010) On fatigue striations, Mechanical Engineering Transaction B, 17 (1), pp. 75–82.
15. Cai H. (1997). The mechanisms of fatigue crack growth in 1018 steel, PhD Dissertation, University of Connecticut AA19807524
16. Ruchert C. O. F. T., Filho A. A. M., Filho W. W. B., Spinelli D., Tarpani J. R. (2011) Load ratio estimation through striation height and spacing analysis of an aerospace Al alloy 7475-T7351. Journal of Materials Engineering and Performance, 20 (3):382–389. https://doi.org/10.1007/s11665-010-9687-0
17. Maruschak P., Vorobel R., Student O., Ivasenko I., Krechkovska H., Berehulyak O., Mandziy T., Svirska L., Prentkovskis O. 2021Estimation of fatigue crack growth rate in heat-resistant steel by processing of digital images of fracture surfaces. Metals, 11, 1776. https://doi.org/10.3390/met11111776

УДК 620.1:62-226.2

СТРУКТУРНО-ФРАКТОРГАФІЧНІ ПОКАЗНИКИ ЕКСПЛУАТАЦІЙНОЇ ПОШКОДЖЕНОСТІ СТАЛІ ДИСКА РОТОРА ПАРОВОЇ ТУРБІНИ

Петро Соловей[1]; Галина Кречковська[1,2]; Олександра Студент[1]

[1]Фізико-механічний інститут імені Г. В. Карпенка Національної академії наук України, Львів, Україна
[2]Національний університет «Львівська політехніка», Львів, Україна

Резюме. *Проаналізовано технічний стан металу диска ротора парової турбіни та встановлено причини його руйнування. Показано, що незважаючи на відповідність механічних властивостей сталі 30ХН3М1ФА за розтягу та удару регламентним вимогам в одному зі ступенів ротора виникли пошкодження, що спричинили вимушену зупинку ротора. Металографічними дослідженнями структури сталі виявили надмірну кількість неметалевих включень, висока корозійна активність яких сприяла розчиненню матриці в їх околі. Ці точкові дефекти ставали осередками зародження втомлених тріщин. Високі контактні напруження між поверхнями заклепок і отворів у диску й постійно наростання їх переміщення одне щодо одного через порушення зазорів між ними в процесі тривалої експлуатації, сприяли контактній втомі та зародженню мережі мікротріщин в околі отворів. А стрічкове розташування структурно зумовлених корозійних дефектів сприяло формуванню суцільного фронту втомної тріщини внаслідок їх злиття. Поширення тріщини завершилося руйнуванням перетинок між отворами для заклепок у гребені диска ротора. Отже, сукупний вплив корозійно-активних включень і зростаючих переміщень у зоні контакту елементів сприяли формуванню зон локального зародження тріщин та інтенсифікували ріст магістральної втомної тріщини. Її поширення супроводжувалося утворенням на зламі диска паралельних втомних борозенок. Крім того, фронт поширення тріщини на локальних етапах її зростання супроводжувався наявністю декору з виразок на експлуатаційному зламі. Це підтверджувало, що існуючі у структурі сталі неметалеві включення полегшували ріст тріщини на етапах і зародження, і поширення завдяки об'єднанню фронту тріщини з цими дефектами.*

Ключові слова: *сталь 30ХН3М1ФА, диск ротора парової турбіни, міцність, пластичність, ударна в’язкість, структура, фрактографічні ознаки руйнування.*