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turbine blades,
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ANALYSIS OF THE WIRE ELECTRICAL DISCHARGE MACHINABILITY OF ROOTS OF STEAM TURBINE BLADES

This paper presents method for the unconventional machining of the blades of steam turbines. Blade material as steel X12Cr13 was chosen into the investigation. Blade failures in gas turbine engines often lead to loss of all downstream stages and can have a dramatic effect on the availability of the turbine engines.. Conventional machining of the roots of steam turbine blades causes high temperature and rapid wear of tool which makes machining expensive WEDM is currently regarded among the most popular non-conventional machining. WEDM allows treatment of hard, brittle materials and composite, irrespective of their structure (thin-wall components) and mechanical properties. Submitted work is an analysis of potential impact on the received thickness of heat affected zone by appropriate heat treatment of material prior to WEDM. Such action is intended to eliminate or reduce the initiating impact of any microcracks on the formation of surface defects on the turbine blades roots during operation. The aim of the article is to replace the traditional methods of machining the blades roots by WEDM and thus the elimination of problems such as the need to monitor the tool wear. The presented experimental study was carried out on a modern wire EDM Sodick AQ327L. Investigated were the effects of WEDM of X12Cr13 steel as the Heat Affected Zone, the micro-fractures and surface roughness parameters.

1. INTRODUCTION

WEDM is a technology which shows considerable advantages in terms of response time and cycle. WEDM is now among the most popular non-conventional treatments. The electrical discharge machining allows processing hard, brittle and composite materials, irrespective of their structure and mechanical properties. Turbine working at a speed of approximately 12 000 revolutions per minute has a tremendous centrifugal force on the blade. Blades are only one part of about 3000 parts of a steam turbine - but also one of the most important when it comes to its proper work [7]. The task of the turbine blades is direction and compression for example of air. Blades are mounted to the core one by one and all together form a circle [3]. WEDM can be used in the manufacture of roots through which blades are attached to the turbine (Fig. 1). Blade roots are made in various ways such as dragging (punching), milling, grinding, using universal and specific tools. In these conventional methods of treatment there are many problems. One of the problems is the

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damage such a tool during the production of a series of blades. Then the exchange of tools is time consuming and expensive. In addition, if repairs

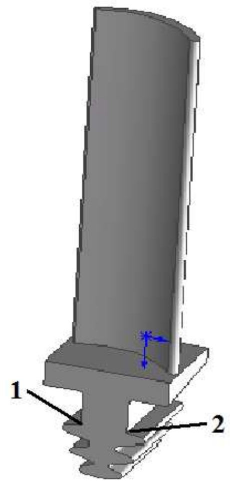

Fig. 1. A multi-trapezoidal-type blade root.1) is typically found cracks, 2) recorded only traces of corrosion

involve the exchange of the blades on a few garlands of the turbine, requires the use of multiple cutting tools. Control lifetime is irrelevant when WEDM but it is very important for for tools used previously. WEDM also provides tolerance of several micrometers. One reason of large savings in time is the high level of precision instruments in his lifetime. Rare changes of tool also save time, which had to be spent to check the dimensions of the newly installed tools to ensure compliance with the required tolerance – even maybe several times, because each turbine consists of almost thousand blades. To date mentioned milling tool cutting operations at 17. Application of WEDM in manufacturing steam turbine blades helps to reduce the tolerances with which blade roots were designed so far. This provides resistance emerging in the work of the turbine high stress that can lead active or corrosive damage as a result of fatigue cracks of blade roots (Fig. 2). Interruption or damage to the electrode wire is automatically repaired within a few to several seconds. New electrode immediately cut with the same accuracy.

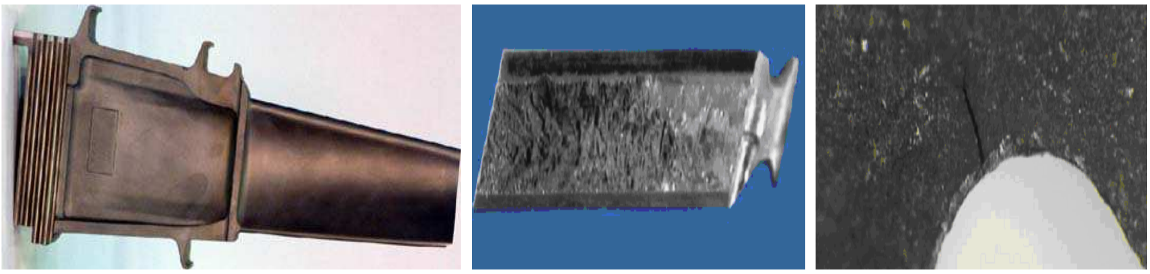

Fig. 2. Multi-trapezoidal-type turbine blade Most common failure

2. WEDM STEEL X12Cr13

Annealed X12Cr13 steel structure is: ferrite and carbides. After quenching the structure is the ferrite and martensite and after tempering structure is ferrite and tempering structures (perlite). During the WEDM particles of workpiece material melt and vaporize as a result of the impact of high temperature. After treatment, on the surface occurs a thin layer of remelted material with composition and structure different from the original material. Amended HAZ layer located on the outer layer of material, which appeared due to recrystallization after the impact of high temperatures generated during machining. Stresses occur on the surface area after WEDM. Introduced in this way stresses with high forces encountered during the work could lead to damage the turbine blades as a result of to the propagation of fatigue cracks. State of the electrical discharge machined steel surface depends on many parameters such as the number of passes, voltage and intensity of the working current, applied dielectric and electrode material.

3. RESEARCH METHODOLOGY

The analysis concerns the implementation of the multi-trapezoidal-type blade root. It has a very high strength and excellent vibration damping properties. Such roots are used in long blades, which operate at high power, primarily in gas turbine blade. Its implementation is relatively expensive, requiring, for machining roots male-type applying expensive special shaped cutter or a broach. Such root is characterized by a small width of the chevron, and therefore it is convenient for high-density blades in the palisade. This paper studied HAZ thickness, surface roughness and the presence of surface defects in the form of microcracks and the surface chemical composition. Analysis of the impact of selected parameters on the effects of WEDM machining steel X12Cr13 enable selection of settings for cutting with proper performance, while maintaining the smallest thickness of HAZ.

4. WORKSTATION

The construction of wire electrical discharge machine AQ327L (Fig. 3.), construction of the workstation in large part consists of ceramic. Implemented ceramics is characterized

Fig. 3. Workstation with wire electrical discharge machine Sodick AQ327L

by at least twice lower the coefficient of thermal expansion than traditional materials and higher resistance to corrosion. Ceramic body ensures a high thermal stability during processing. Modern 64 - bit control based on the Windows NT operating system, along with built-in q^3vic software, enable a wide area of applications AQ 327L [6].

5. DISCUSSION AND RESULTS

Composition of test material: steel X12Cr13 shown in Table 1. In this study machining was conducted using as a tool brass wire CuZn37 with diameter Φ = 0.25 mm. Brass wire electrode is a summary of zinc, low-melting point (420° C) and high-pressure of sublimation of copper (1080° C).

Table 1. Chemical composition of stainless steel X12Cr13

EN	**AISI USA**	**C**	**Si**	**Mn**	**P**	**S**	**Cr**	**Ni**	**Fe**	**Hardening Temp.:**	**Tempering Temp.:**
X12Cr13	410	<0.08-0.15	<1.0	<1.5	<0.04	<0.015	11.50-13.50	<0.75	reszta	950 - 1000ºC	640 - 780ºC

CuZn37 wire, allowed to significantly increase productivity through better flushing (compared to copper electrodes). During the cutting Zinc undergoes sublimation and ensures the high stability of the process due to minimizing the number of particles emitted into the slot.

Table 2. The value of the most important settings WEDM in the seven stages of cutting

Passes nr	**ON**	**OFF**	**SV**	**WP**	**WT**	**WS**
1	012	013	0,4	045	160	130
2	013	013	0,2	055	160	130
3	002	011	0,53	140	180	130
4	001	014	0,42	240	180	130
5	015	014	0,16	240	180	130
6	000	001	0,12	240	180	130
7	100	000	000	240	180	130

Cutting parameter values were chosen on the basis of preliminary tests of steel materials. Setting values for the various stages of cutting is given in Table 2

5.1. SURFACE ROUGHNESS

Roughness measurements were carried out on profilografometr RANK Taylor Hobson's model TALYFORM SERIES 120L. On the surface of the root measured were many parameters for example roughness Ra = 0.1961 um (Table 3). Measured surface roughness of the root after WEDM is acceptably low. Roughness measurement does not give full information about the state of the surface after WEDM. It is essential to accurate (microscopic) examination of the surface.

Table 3. WEDM'ed surface roughness of multi-trapezoidal-type blade root

Ra	0.1961µm	Rku	3.419	RIq	9.91µm
Rq	0.2498µm	Rz	1.6905µm	R3y	1.5541µm
Rp	0.8087µm	Rz1max	2.1408µm	R3z	1.3611µm
Rp1max	1.0926µm	Rz(DIN)	1.6905µm	RS	7.88µm
Rv	0.8817µm	RSm	34.03µm	RIn	19.2000mm
Rv1max	1.0749µm	Rc	0.8961µm	Rdz	9.00 °
Rt	2.1675µm	Rz(JIS)	1.3960µm	Rda	7.08 °

5.2. THICKNESS OF HAZ

Samples for microscopic examination were performed on cross-section. Observations were conducted at magnifications range from 100x to 1000x, in unetched state and after etching reagent Mi30Fe by PN-61/H-04503 standards. Metallographic microscope Neophot 32 coupled with a digital camera Spot Insight CCD were employed. The paper presents photographic documentation of characteristic structures. On an area of roughly cut surface there are many impurities, discontinuities, and craters of different diameters and depths. These all surface imperfections can become centres of stress in terms of increased workload. The next move while WEDM is to modify the outer layer and reduce the resulting stresses. Also change stresses nature in neutral. The thickness of thermally modified zone varies depending on the energy which is supplied to the slot during WEDM. The greatest value is obtained after rough cutting. The following passages are cutting peaks of surface roughness and there is much less energy delivered to the gap. Measured thickness of the HAZ decreases after successive passages. High temperature during the WEDM in the steel X12Cr13 melts martensite. More time or heat is needed to melt occurred ferrite [2]. In unetched sample found to contain a small amount of non-metallic inclusions mainly in the

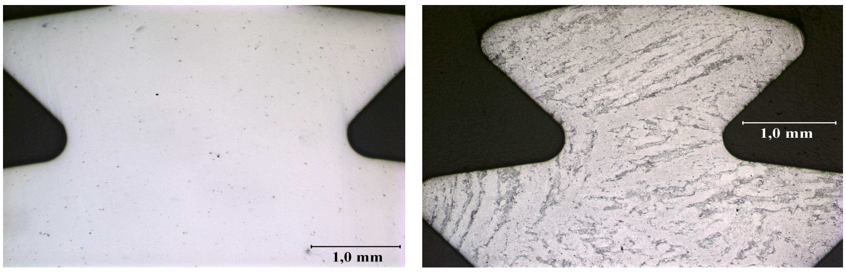

Fig. 4. Outer surfaces of the test item. The material of nonmetallic inclusions visible principally in the form of sulphides and oxides of spaced spot. Unetched state. Light microscopy

form of sulphides and oxides arranged spot on the external surface of the test element (Fig. 4). Also, after etching, there was no HAZ layer thickness greater than 1 µm due to WEDM. It should be noted that the HAZ are mainly recrystallized metal layer and erosion products of the electrode wire. [4,5].

5.3. MICROCRACKS

One effect of WEDM martensite steel X12Cr13 are cracks on surface after treatment. Further examination of the surface showed that these cracks are most visible after being cut roughly (1 pass) then may have a depth of about 2-4 µm. The cause of these cracks are stress existing in the material being processed. Material is compounded by the strong warming during the WEDM and sudden cooling by the dielectric in the slot between electrodes administered under high pressure. The course coincides with the micro-grain boundaries. Testing different varieties of steel workpieces X12Cr13 show that it is possible a significant reduction in the number of microcracks at grain boundaries applying a suitable heat treatment. Another recuts allow reducing the depth of micro-cracks or even eliminate them completely. In addition, this grade of steel is usually tempered to a temperature of about 1100 ° C. Mainly steel tempering process must be carried out at temperatures greater than 200 ° C [1]. Visible after etching heterogeneous structure of ferrite with a strong segregation (band) of chromium carbides is strongly undesirable. Structure shows no resistance to corrosion and can cause a substantial reduction in strength properties (Fig. 5). On the external surfaces of machined samples after etching were no microcracks or significant changes in the structure caused by electrical discharge machining.

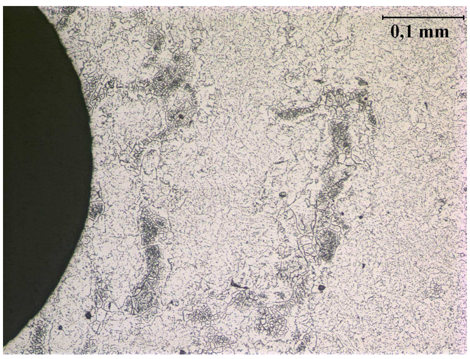

Fig. 5. Cross-section. Heterogeneous ferritic structure with a strong segregation (band) chromium carbides

5.4. CHEMICAL COMPOSITION OF SURFACE AFTER WEDM

Using the X-ray micro-analyzer was possible to estimate and compare the composition of the material recrystallized and original (Fig. 6.). Presence of copper and zinc from the material of the wire electrode was found in the crater.

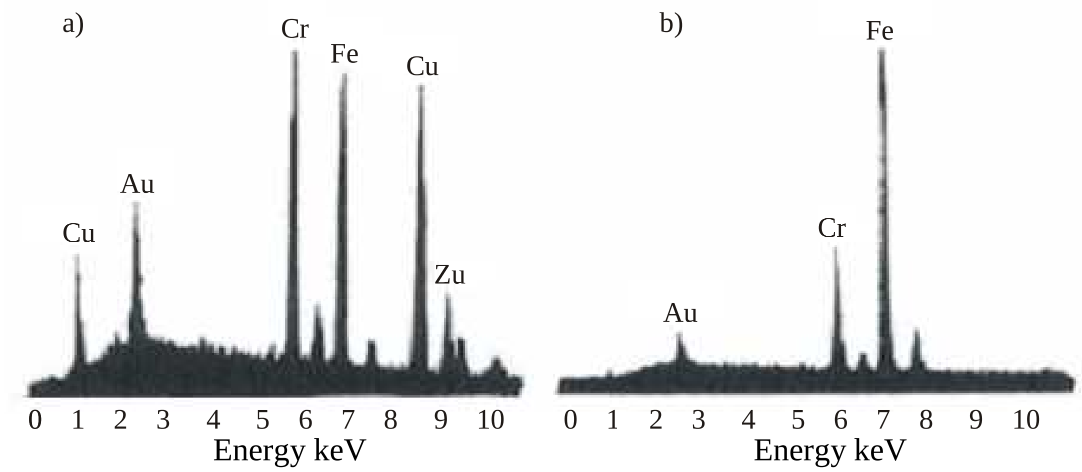

Fig. 6. a) Analysis of X-ray chemical composition in crater b) Analysis of the composition of surface around the craters

Also interesting turned out to be higher chromium content in the craters than in the original material. Chrome has the form of spherical alpha phase precipitation. This phase does not occur in steel X12Cr13. The emergence of this phase was due to an impact of WEDM. Phase alpha Fe - Cr has a higher chromium content than the gamma phase of Fe-Cr.

6. SUMMARY AND CONCLUSIONS

WEDM is an interesting alternative to traditional methods of working blade roots of steam turbines. For many types and sizes of roots may be used one machine and one and the same electrode. Problems such as a thick layer of HAZ, tensile stress and the microcracks can be reduced and even eliminated through proper selection of machining parameters and the number of passes. Conducted analysis and research points to the following conclusions:

- Micro cracks visible on the machined surfaces are deepest after rough cutting. Size decreases due to the implementation of micro-consecutive transitions
- Micro cracks usually formed at grain boundaries and spread along the grain boundaries
- Cracks are filled with recrystallized material after rapid melting and evaporation. High pressure of dielectric, which is administered, pushes the products of erosion in the cracks during the rough cut.
- The study of thermally changed layer consists of two different phases of martensite and ferrite. And its thickness varies between 5 µm on the first pass and about 1 µm after the seventh pass.
- Increased number of chromium inside the crater is a spherical phase Fe-Cr sigma is caused by the impact of WEDM. By contrast, the gamma phase of Fe-Cr occurs naturally in the steel X12Cr13 characterized by lower content of chromium.

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