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Rapid Determination of Changes in Material Properties of Water Turbines Blades

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The changes in the material properties of water turbine blades are characterized an undesirable process, which could lead to the end of usable life or to the emergency conditions of this turbine. For this reason, it is important to determine of any material quality changes and continuously monitor them. Considering that, these essential parameters are showing the ability of material to resist the operational stress. It is necessary to choose rapid methods of the material testing which are without preparation of the samples (it is inadmissible to the functional blades) able to immediately monitor the state of the materials by non-destructive methods. Due to mechanical stress and operational wear, the losses and damage occur in the water turbine blades, as the result, it leads to the deformation changes.
This article is focused on the methodology of determination mechanical properties of corrosion-resistant steel, which is used on a large scale for the production of hydraulic elements and especially blades of water turbines.

Keywords: Stainless steel CA6NM, ABI tests, Indentation curve, Stress and deformation states, Mechanical properties

1 Introduction

Based on hardness measurements, it is possible to get an idea of how the material will behave during the machining or mechanical loading under cyclic loading. It involves pushing a harder body-indentation with a defined geometry into the surface of the test material. From this test, it can be assumed that it will be only a small volume under the surface, which will be only partially affected by this test. Therefore, this method can be classified as non-destructive testing. Hardness tests are fundamental tests of mechanical properties that can divide into the materials for hard and soft by according to the response of its microstructures to the known load. This method is fast and simple because it does not need to produce a sample separately. Along with being a simple test, it is always necessary to consider other aspects that could affect the quality and accuracy of the measurement. These are external and internal influences that include the characteristics of not just the material being tested, but also the environmental aspects in which the tests take place [1, 2, 3, 4].

In the case of design for a rapid check, which will serve to identify changes in mechanical properties, a rapid method of instrumental indentation is proposed in this paper [5]. Whereas it will be a continuous check of changes in the mechanical properties of the water turbine blades, it will be significant to identify its critical locations that would represent the greatest load, thus the greatest wear of the material. The test sites should show the material response of the water turbine blades to the combined load. In the aquatic environment corrosion, cavitation and abrasive wear are mainly, as well as the mechanical loading of the blades. In some cases, it may also be a vibrational load. A right choice of the control point that should be continuously monitored at the same time would not affect the operation of the turbine, it is also crucial for measuring accuracy.

In practice, the ways for improving quality of turbine materials are most looking for, which is a good prerequisite for increasing the efficiency of turbines. From material properties, hardness can be taken as one of the basic characteristics due to the ongoing process in the material. The indentor passes through areas of elastic, elastic - plastic and plastic deformation in a small volume of material. Based on its response and acquired values, other properties can be derived that extend the knowledge of the material. These include strength, stiffness coefficient modulus and others. Hardness methods use indentors of spherical or conical geometry that are loaded with relatively large forces (from hundreds to thousands of Newtons). Only the Vickers and Knoop methods use a small load (in tens of Newtons), where a regular three-sided pyramid is used as an indentor. All these methods are based on the optical analysis of the indentation and its application is limited to the visible dimensions of using optical microscopy. As a presented result of the new method "instrumented indentation" is the possibility to obtain material properties depending on the load on the penetration of the indentor into the material. The graphical processing of the obtained data is characteristic indentation curve, the load - the indentation depth, see in Fig. 1.

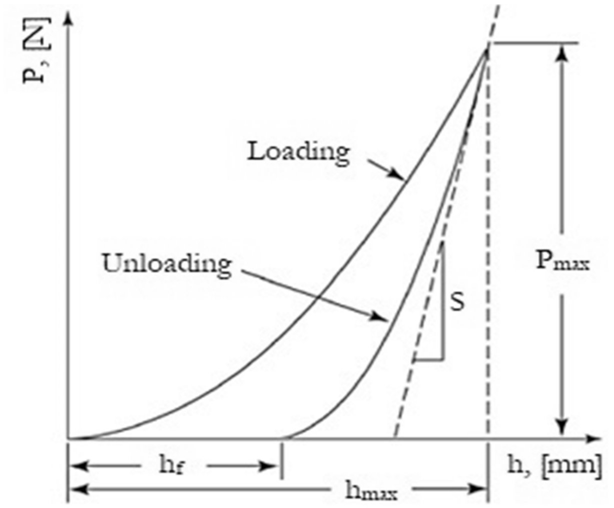

Fig. 1 *The schem of the indentation curve*

The first phase of the indentation cycle is a controlled load during which the indentor with a defined speed and force penetrates into the surface. The second phase of the cycle can be labeled as relieving, as the downward force is reduced to zero. Frequently, during loading and unloading delay occurs on the applied load where the material is subjected to a maximum load force, which may also correspond to the flow process [6, 7].

2 Materials and methods

An elastic modulus, fracture toughness, phase transformation and work of creation an indentation could be obtained by using the described method [6, 7]. Based on the reaction of the surfaces to external forces, the materials can be divided into three groups according to the characteristic shapes of the indentation curves. Depending on the nature of the deformation are classified on the elastic, plastic and elastic-plastic.

In the following experiment, it will be materials where elastic and plastic deformations will occur during the insertion of the indentation body on the same materials with different technological history.

Stainless steel was used for the experiment which is designed to produce the water turbine blades. The manufacturer decides whether the blades will be casted or used in the rolled sheet to be welded. So, what will be the difference in the starting material properties, if the material is used in the form of a casting or a semi finished product after plastic deformation, from rolled sheets. The experiment should demonstrate whether a fast indentation test is sufficient to determine the difference in alloy steel with the same microstructure and distinguishes the material characteristics that will declare the difference in the production of technical objects (TO), in the case of water turbine blades. The chemical composition of the steel corresponds to the elements shown in Table 1.

Tab.1 *Chemical composition of CA6NM Stainless Steel from spectral measurements*

Casting	Fe(%)	Cr(%)	Ni(%)	Mo(%)	Ca(%)	Cu(%)	S(%)	V(%)	Mn(%)	C(%)
	80.54	13.67	3.722	0.585	-	0.023	0.0092	0.023	0.746	0.029
	Si(%)	Ti(%)	P(%)	Al(%)	As(%)	B(%)	Co(%)	N(%)	Nb(%)	W(%)
	0.512	0.001	0.011	0.014	0.0057	0.001	0.015	0.026	0.026	0.0061
Sheet	Fe(%)	Cr(%)	Ni(%)	Mo(%)	Ca(%)	Cu(%)	S(%)	V(%)	Mn(%)	C(%)
	81.33	12.87	3.776	0.548	-	0.146	0.0053	0.042	0.652	0.017
	Si(%)	Ti(%)	P(%)	Al(%)	As(%)	B(%)	Co(%)	N(%)	Nb(%)	W(%)
	0.377	0.001	0.022	0.01	0.0094	0.001	0.044	0.055	0.0052	0.082

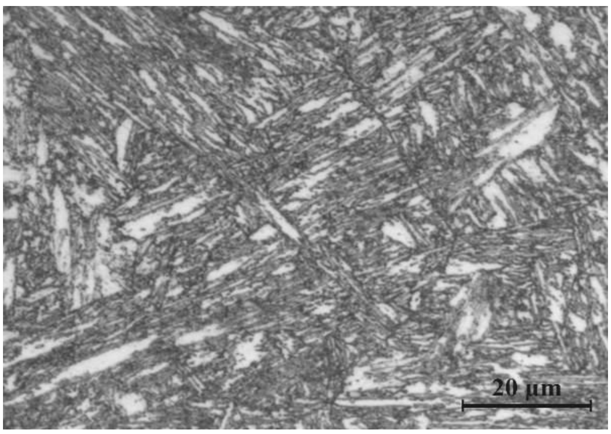

Fig. 2 *Microstructure of CA6NM Stainless Steel (Casting), magnification 1000x*

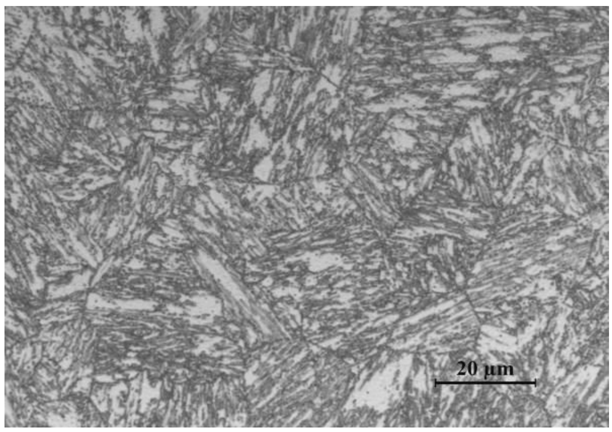

Fig. 3 *Microstructure of CA6NM Stainless Steel (Sheet), magnification 1000x*

The microstructure of these steels is made up of mud martensite containing residual austenite with different sizes of martensitic needles. The reason can be explained in connection with heat treatment, in the formation of the original austenitic structure, see Fig. 2 and Fig. 3. In both types of microstructure, the character of austenitic grain was similar.

3 Results and discussion

The present microstructure is typical with partial heterogeneity in the grain size. The performed heat treatment corresponded to the declared requirements of the manufacturing company. From the point of view of micro-cleaning, it can be stated that this stainless steel is generally marked by the occurrence of fine undesirable phases, which was also evident in the investigated material. In our case, these were carbonitrides and unbalanced silicates. In castings additionally occurred foundry defects such as staples and bubbles, see Fig. 4 and Fig. 5. The sheets shown in Fig. 3 demonstrated a lower degree of contamination than castings. The samples (square cross section) of the same volume and edge length of 12 mm were made from the above materials. The described materials were subjected to a rapid instrumental test, where on the basis of the measured values see Table 2, the following material properties were identified in Table 3.

Tab. 2 *Measuring values*

Material	P_{max} [N]	h[mm]	HBW 5/750	W_t [mJ]	W_e [mJ]
Casting (Run_0)	7 443	0.216	223	903.7	143.5
Sheet (Run_1)	7 457	0.184	264	780.3	125.1

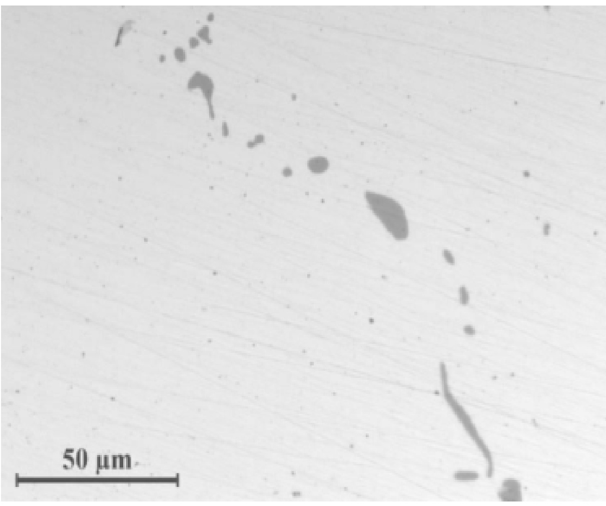

Fig. 4 *Micro-purity of CA6NM Stainless Steel (Casting)*

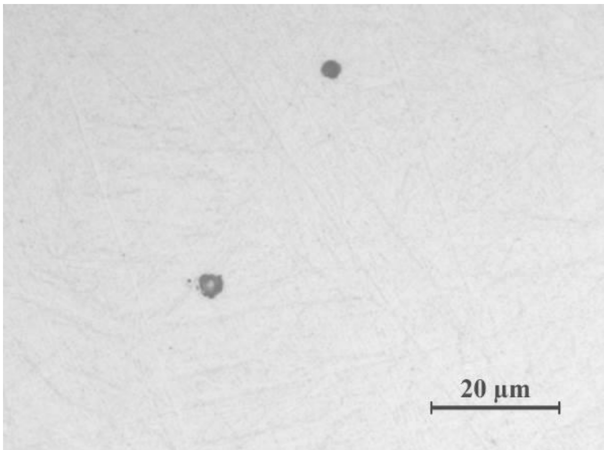

Fig. 5 *Silicates in CA6NM Stainless Steel (Sheet)*

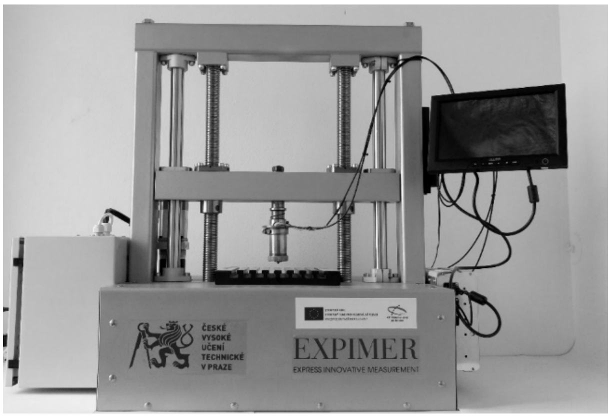

Fig. 6 *Experimental indentation equipment*

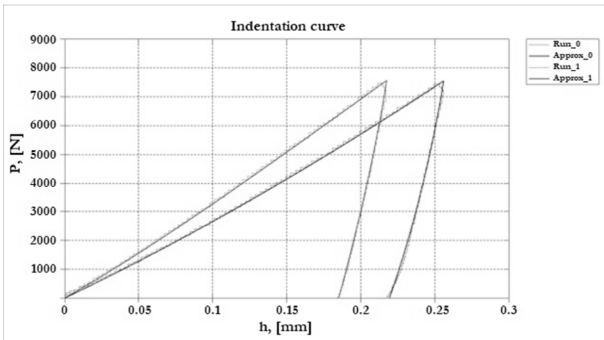

Fig. 7 *Measured indentation curves*

The hardness was calculated by the formula (1) and the following formula (2) was used to determine the tensile strength (R_m). Formulas (3) and (4) were used to determine the yield strength ($R_{p0.2}$). Modulus of Elasticity was evaluated from unload part of indentation curve according standart ISO 14577 and ASTM WK381 [8, 9, 10, 11].

$$HBW = \frac{P}{\pi \cdot D \cdot h}, \tag{1}$$

$$R_m = c \cdot HBW, \tag{2}$$

$$R_{p0,2} = c \cdot HM = \frac{c \cdot P}{\pi \cdot a^2}, \quad (3)$$

$$a = \sqrt{(D \cdot h) - h^2}, \quad (4)$$

Where:
HBW…Brinell hardness,
P…Load, [N],
D…Diameter of indenter [mm],
h…Indentation depth [mm],
c…Coefficient of hesitate [-],
HM…Meyer hardness,
a…Contact radius, [mm].

The dependencies of the indentation depth and applied load, which were recorded in the ABI study, see Fig. 6, were represented on the Fig. 7. The curve "load - indentation depth" describes the characteristic behavior of the material during elastic, elastic-plastic and plastic deformations. They show how the material behaves in the research process, which consists of three parts: as load, holding at maximum force and unloading. The growing part of the curve describes the process of loading. This process has an elastic and elastic-plastic section. Then, after holding at maximum force for 10 s, the unloading process begins. The waning part of the curve describes the process of unloading. The point where the curve intersects with the x-axis will correspond to the plastic indentation depth (h_p). The difference of the plastic depth with the depth of maximum load (h_{max}) corresponds to the elastic depth (h_s).

Tab. 3 *Evaluated mechanical properties*

Material	E_{IT} [MPa]	$R_{p0,2}$ [MPa]	R_m [MPa]
Casting (Run_0)	216 785	546	622
Sheet (Run_1)	230 030	546	737

Based on the microscopic examination of the structure, it can be stated that the formed sheets showed a lower degree of contamination than the castings. This evaluation was performed on produced samples of the same volume with an edge length of 12 mm.

Graphic dependences of load - indentation depth were obtained from both measurements (Fig.7). The character of the graphic dependence from the measured values proved to be identical for both materials only with differences in the indentation depth.

The hardness of the cast materials was lower (HBW 5/750 223), compared to the formed materials (HBW 5/750 264), the strength of the casting (R_m - 622 MPa) was also lower than that of the formed sheet (R_m - 737 MPa).

4 Conclusions

In conclusion, it can be stated that this instrumented test is not only fast, but also sufficiently accurate, which was confirmed on the materials. Although the investigated materials differed relatively little structurally, the material properties showed a large difference. Based on the experiment, it can be stated that this fast indentation method can be used to distinguish materials with the same chemical composition, similar microstructure, but produced by different technologies. If these differences can be detected by this test, it is assumed that any change in material properties during operation will be detected relatively quickly by this new method. For water turbine blades, this would mean the possibility of continuous monitoring of degradation processes on site without special preparation and production of standardized and laboratory-tested samples.

The strength characteristics were additionally checked on standardized test bars using a tensile testing machine, which were compared with each other. The results presented in this article were verified as correct by further experiments.

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