THE INFLUENCE OF A SURFACE QUALITY ON MEASURING MECHANICAL PROPERTIES WITH A CYLINDRICAL INDENTER

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Abstract

The aim of the work is to develop a new method for yield strength determination of chosen corrosion resistant steels using the micro-indentation measurements. The main advantage of such method is a demand for minimal amount of analyzed material. In the frame of the experiment, the elastic-plastic behavior of special corrosion-resistant - ferritic, martensitic and austenitic - steels was investigated. These steel types are partly suitable for nuclear energetics and also for other fields with high demands on steel quality.

The experiment is focused on discovering and defining of such surface quality which would be optimal for maximal yield strength evaluation accuracy determined by micro-indentation measurements, and along with on finding the strengthening trend of the steel types investigated. As the main tool for the evaluation, of the elastic-plastic response, the methodology based on the instrumented penetration test by means of 0.7 mm indenter diameter was chosen. The basic principle of the experiment was comparing evaluated yield strength with help of micro-indenter and those determined by classical tensile test.

This paper also deals with FEM simulation of indentation by a flat-ended cylindrical punch into elastic-plastic material with assumed rough contact surfaces. This work shows one of the ways how to include the influence of rough surface into numerical calculation without requiring all asperities of contacting rough surfaces modelled by the finite elements in detail. The influence of the rough surface in combination with the elastic-plastic materials behavior on the shape of the loading curve is subject of this study.

Keywords: Mechanical properties, indentation method, tensile test, elastic-plastic behavior, finite element method simulation

1. INTRODUCTION

The subject of this contribution is a possible assessment of mechanical properties by the indentation methods using corrosion-resistant materials used in the nuclear industry. The assessment is more thoroughly described for 015Ch17M2B steel (see **Table 1**). Primarily, it is about these steels:

14CH17N2 is martensitic corrosion-resistant steel which can, in a suitable mode of heat processing, deliver combinations of excellent mechanical properties and resistance against the intercrystalline corrosion in the primary circuit environment.

08CH18N10T is austenitic corrosion-resistant steel stabilized by titanium. The chemical composition of the steel and its stabilization by titanium ensures good weldability of the steel and also excellent corrosion-resistance not only in the primary circuit environment. On the other hand, its chemical composition with a relatively high content of carbon, together with titanium alloying, has a negative impact on the micropurity of the steel. These limit parameters (the requirements for high corrosion-resistance, high value of the yield point and the micropurity of the steel) place high demands on keeping the working procedure [1].

015Ch17M2B is ferritic corrosion-resistant steel. One of the biggest problems, associated with processing of the steel, is the tendency to a brittle fracture and a limited range of temperatures and time periods during which it is possible to mold the steel.

Steel is used mainly for manufacturing rotor pole-pieces, electromagnet capsules and drive armatures (VVER 1000). In all of these cases, it is used because of its specific magnetic properties and the good corrosion-resistance.

Table 1 Chemical composition [wt.%]

Element	volume [wt.%]
C	max. 0.015
Si	max. 0.80
Mn	max. 0.80
P	max. 0.035
S	max. 0.025
Cr	16.00 – 18.00
Ni	max. 0.60
Cu	max. 0.30
Co	max. 0.05
Ti	max. 0.20
N	max. 0.015
Mo	1.50 - 2.50
Nb	0.20 – 0.30

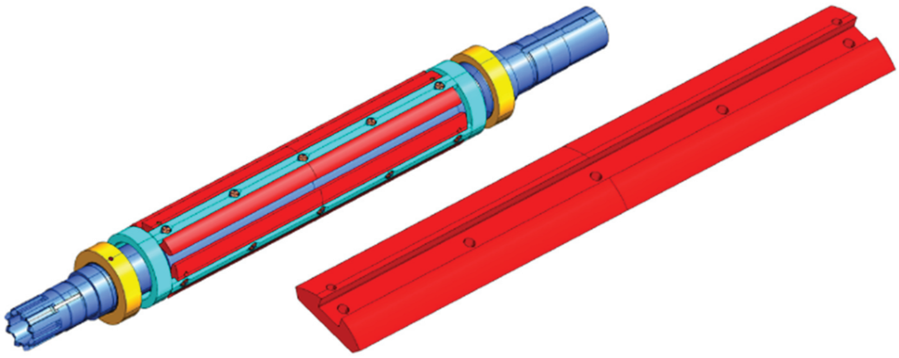

Figure 1 a) Schema of the rotor of the electromotor
b) the pole piece

2. EXPERIMENTAL PROCEDURE AND RESUTS

2.1. The real experiment description

The measuring of the yield point with the help of the indentation method was performed on all supplied materials. The measured surface was under Ra = 0.5 µm and subsequently around Ra = 5 µm. The measuring of the yield point was performed randomly in both cross and longitudinal sections.

The measuring was performed by a cylindrical 0.7 mm-diameter indenter (WC material). The output data was recalculated according to the Hencky hypothesis [2]. A macro created in Microsoft Excel was used to assess the yield point. The results for each of the steels are shown in **Table 2**. The methodology is further described in [3].

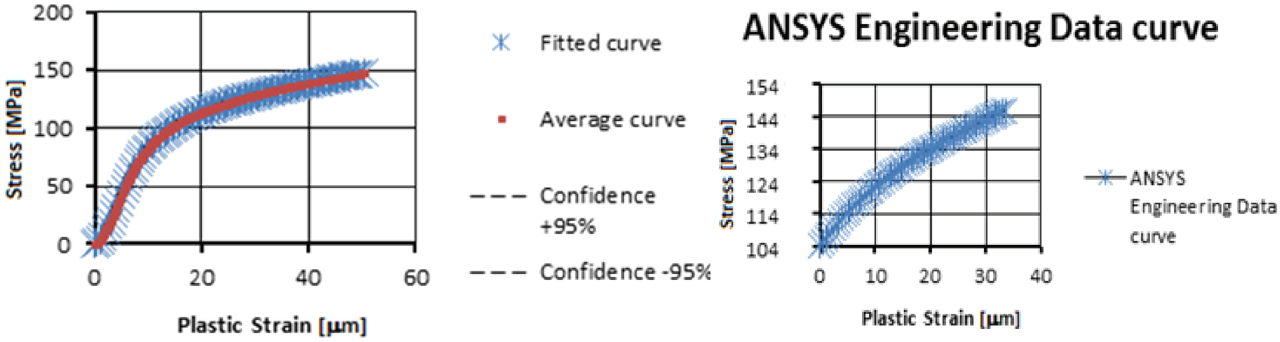

Figure 2 The assessment of the yield point with the help of the macro in Microsoft Excel

Table 2 Indentation Method - indentation shear yield strength vs. tensile yield strength

14Ch17N2			
measuring	Indentation yield point Rs [MPa] Ra (0.5 µm)	Indentation yield point Rs [MPa] Ra (5 µm)	$Rp_{0.2}$
1	900	700	902
2	920	765	898
3	886	728	908
4	880	780	900
5	892	720	906
08Ch18N10T			
measuring	Indentation yield point Rs [MPa] Ra (0.5 µm)	Indentation yield point Rs [MPa] Ra (5 µm)	$Rp_{0.2}$
1	243	200	243
2	222	190	258
3	252	205	247
4	248	200	248
5	252	198	252
015Ch17M2B			
measuring	Indentation yield point Rs [MPa] Ra (0.5 µm)	Indentation yield point Rs [MPa] Ra (5 µm)	$Rp_{0.2}$
1	350	160	299
2	352	180	300
3	345	155	306
4	338	186	286
5	342	165	292

Results

Based on the performed measurings and the result comparison, it is possible to state that the tested method is suitable for the yield point assessment of the researched steels. Precision restrictions of the measurings depend on the surface quality, where the results show growing differences with growing roughnes Ra.

2.2. FEM model

The model represents indentation by a flat-ended cylindrical indenter into elastic-plastic body with rough surface. Model was prepared for solver Abaqus 6.14. Elastic-plastic body consists of 2918 CAX second order elements (QUAD 8-nodes and TRIA 6-nodes). The smallest element has an edge length 0.02mm. The width of the body B = 7mm and the height of the body H = 7mm (**Figure 3**). The indenter is modeled using analytical rigid surface elements. Radius of the indenter R = 0.7mm (**Figure 3**). The softened contact FEM, indentation test represents **Figure 4**. The edge of the indenter has radius R = 1µm. Zero displacement boundary condition was prescribed in y direction at the lower part of the sample (AB) and also in x direction at the axis of symmetry (AD). Each node of the analytical rigid surface is tied by the rigid body bond with the reference node of the analytical rigid surface. Forced displacement boundary conditions uy = 20 µm were prescribed at the reference node of the analytical rigid surface. Sliding contact (surface to surface) between the indenter and the body was used, with the value of friction coefficient f = 0.2. By default, a "hard" contact pressure-overclosure relationship is used for contact definition in Abaqus. When the surfaces are in contact, any contact pressure can be transmitted between them. Separated surfaces come into contact when the clearance between them reduces to zero. The "softened" contact pressure-overclosure relationships might be used to model a soft, thin layer on one or both surfaces. In Abaqus they are also sometimes useful for numerical reasons because they can make it easier to resolve the contact condition. The rough surface is modelled using exponentially defined softened contact relationship (**Figure 5**) with parameters:

$$p_0 = \frac{F_0}{A_0} \quad \text{for} \quad c_0 = 0 \tag{1}$$

$$c_0 = -0.45\mu m \quad \text{for} \quad p_0 = 0 \tag{2}$$

where p_0 is contact pressure corresponding to the complete contact, F_0 is a contact force which can be obtained from the indentation test (**Figure 4**) and c_0 is the height of the rough surface undulations. Parameters p_0 and c_0 can be also calculated using FEM. The shape of the rough surface can be approximated using triangular wave function as is indicated in [4].

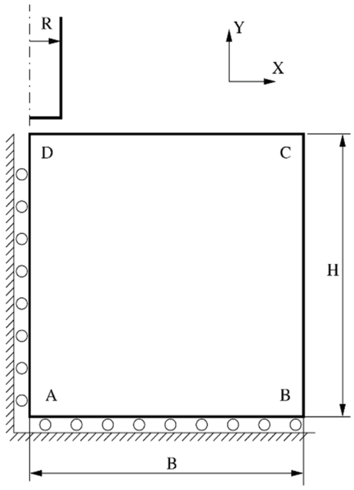

Figure 3 Scheme of axisymmetric FEM model

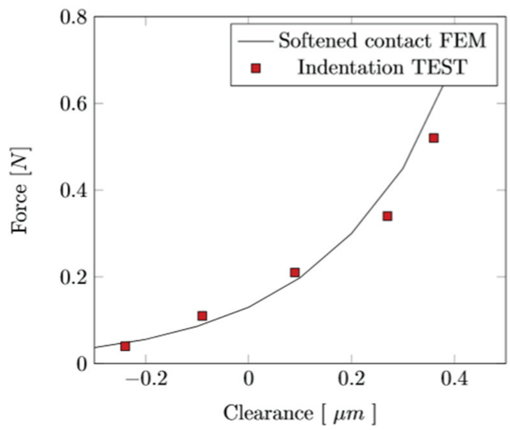

Figure 4 Softened contact FEM, Indentation test

Material

The material of the body used Johnson-Cook model defined as follows:

$$\sigma = E \cdot \varepsilon \quad \text{for} \quad \sigma < \sigma Y \tag{3}$$

$$\sigma = A + B \cdot \varepsilon^n \quad \text{for} \quad \sigma > \sigma Y \tag{4}$$

where σY is the yield strength. This model was assigned as an analytical input with the constants: Poisson's ratio μ=0.3, elastic modulus E = 210000 MPa, A = 345.4 MPa, B = 197 MPa and *n* = 0.4. The solver Abaqus calculated the individual values from the equations above. Parameters A, B and *n* can be used as variables of an external iteration process, where the sum of deviations between the tested loading curve and response of the FEM simulation is minimized.

Results and discussion

There were calculated three loading curves of indentation by a flat-ended cylindrical punch (**Figure 5**). Thin line exhibits the analytical solution of elastic loading. The dashed line shows the response of an elastic-plastic indentation with a perfectly smooth contact surfaces and the thick line shows the response of an elastic-plastic indentation with a rough surface. An analytical curve was calculated as follow:

$$F = 2 \cdot R \cdot E^* \cdot h \quad \text{where} \quad E^* = \frac{E}{(1-\mu^2)} \tag{5}$$

The perfectly smooth contact was calculated numerically with a "hard contact" surface relationship and rough surfaces contact was also calculated numerically with a "softened contact" surface relationship.

From the (**Figure 5**) is obvious an effect of rough surface. Theoretically the rigid flat punch indentation for elastic loading where the reduced stresses $\sigma < \sigma Y$ exhibits the same slope as an analytical solution:

$$\frac{dF}{dh} = 2 \cdot a \cdot E^* \tag{6}$$

as it is in the case of perfectly smooth surfaces [5]. Loading curve with assumed rough surface and with an elastic-plastic behavior cannot have the same slope as an analytical solution as is shown in the (**Figure 5**). Reduce stress Von Mises for h = 0.7e^{-2} mm and for case of rough surfaces contact (**Figure 6**).

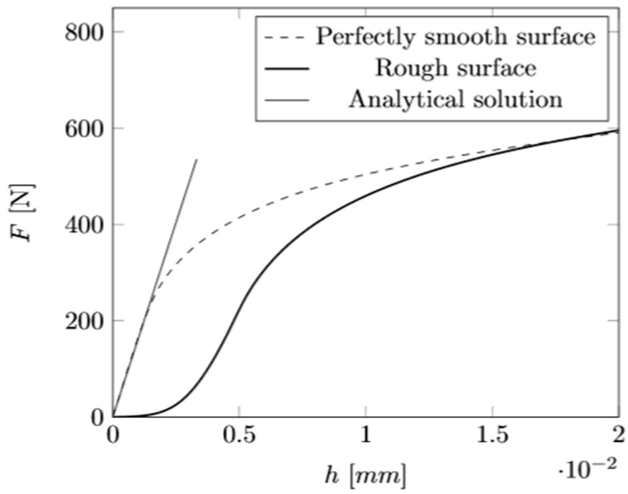

Figure 5 Loading curve

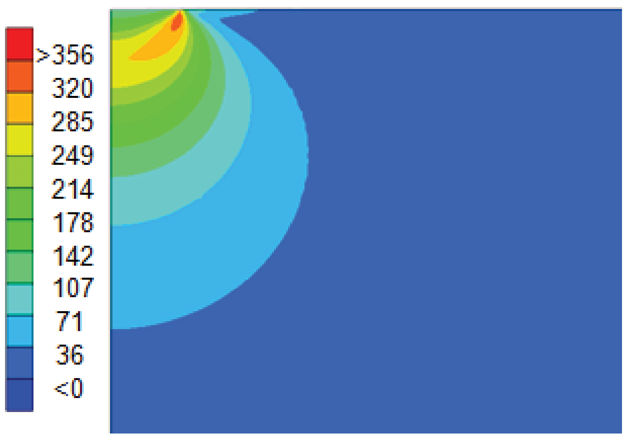

Figure 6 Reduced stress Von Mises [MPa]

3. CONCLUSION

The result of the experiment shown the fundamental influenced of the surface quality on the measured values of the yield point, when the micro-indenter method is used. It was proved on the yield point values measured on the surface with the roughness Ra (0.5 µm) and Ra (5 µm). The biggest influence of the surface quality on the point was observed on the ferritic stainless steel.

Currently, this paper shows one of ways how to include the rough surface into finite element calculations. From the results of numerical calculation is seen that the loading curve with assumed rough surface and with an elastic-plastic behavior cannot have the same slope as an analytical solution. It is also indicated the possibility of estimation Johnson-Cook material model parameters A, B and n from indentation loading curve in combination with the finite element calculation. The procedure of their estimation will be subject of the next study.

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