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APLIKÁCIA SKÚŠKY TYPU SMALL PUNCH TEST PRI HODNOTENÍ DEGRADÁCIE VLASTNOSTÍ MATERIÁLOV TLAKOVEJ NÁDOBY REAKTORA

A SMALL PUNCH TEST METHOD APPLICATION FOR THE EVALUATION OF REACTOR PRESSURE VESSEL MATERIAL PROPERTIES DEGRADATION

Príspevok popisuje stanovovanie základných mechanických vlastností materiálov tlakovej nádoby reaktora (TNR) pomocou skúšky typu „small punch test“. Najväčšou výhodou skúšok tohto typu sú malé rozmery vzoriek, a teda nízka spotreba často originálneho skúšobného materiálu.

Použitím skúšky small punch test môžeme stanoviť nasledovné hodnoty základných mechanických vlastností:

- medza klzu a medza pevnosti v ťahu,
- prechodová teplota vrubovej húževnatosti,
- lomová húževnatosť.

Táto metódika skúšania je súčasťou Nového programu overovacích vzoriek, koordinovaného VÚJE Trnava, a. s. Program sa zaoberá hodnotením vlastností materiálov TNR jadrovej elektrárne staršieho typu V-1 v Jaslovských Bohuniciach. V príspevku je popísaná metódika vyhodnocovania výsledkov, metalografická príprava malých vzoriek, a aj porovnanie výsledkov skúšky small punch test s výsledkami štandardných skúšok mechanických vlastností.

In this paper we describe a new non-standard method for estimation of the reactor pressure vessel (RPV) materials mechanical properties by a small punch (SP) test. The great advantage of the SP test method is a low volume of test samples.

Using this method it is possible to obtain the following data of basic mechanical properties:

- the yield stress and ultimate tensile strength,
- ductile-brittle transition temperature,
- the fracture toughness value.

This method has been involved in the VÚJE project “New Surveillance Specimen Program for Jaslovské Bohunice V-1 nuclear power plant (NPP)” (NSSP). This paper describes the basic information about a testing procedure, metallographic preparation of test samples and comparison between results from standard tests and this new testing method.

1. Introduction

Presently, there has been a number of investigations on the evaluation of mechanical properties of various alloys using the small punch test method [1-3, 6].

Small punch testing methods are very popular now due to the:

- low consumption of the original testing material,
- relatively simple evaluation,
- possibility of using universal and cheap testing machines,
- uniformity of specimen for the several type of testing procedures.

However, the details of the method employed by individual research teams have differed somewhat from one to the other according to:

- specimen size and shape,

- punching tool (ball or rod),
- configuration of testing holder,
- number of specimen for one type of material, etc.

Most of research teams used this method for mechanical properties of metallic materials evaluation, but relatively few investigations have dealt with irradiated specimen [6].

Various standard tests are available for the determination of mechanical properties such as tensile strength, ductile-brittle transition temperature and fracture toughness, which are required for the structural integrity assessment of NPP components. In order to study irradiation damage, small samples are required because there are limitations on a sample size in irradiated material testing evaluation. SP samples have a great advantage in reducing the radioactivity of the irradiated materials for their small volume.

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The SP procedure has also advantage for the determination of material properties, which are highly dependent on the local microstructure (e.g. heat affected zone).

2. Basic information on a small punch test method

2.1 Outline of the test

Figure 1 shows the set up for the small punch test. The principle of our testing procedure is penetration of the disk sample by hemispheric rod [5]. Disk shaped sample has 8 mm in diameter and 0.5 mm in thickness (Figure 2). The specimen holder consists of a lower and upper die and holder body. Using this specimen holder, the specimens are prevented from cupping upward during punching and therefore, the plastic deformation is concentrated in the region below the punch rod. Using a relatively simple system with recorders of the load and deflection values, we can obtain the following data of basic mechanical properties:

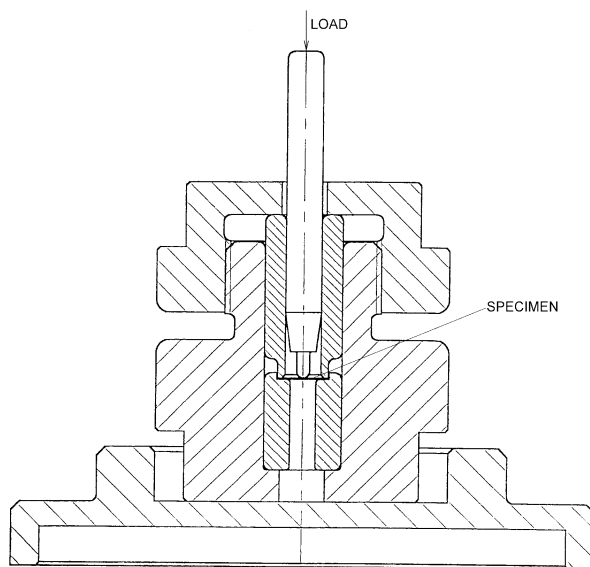


Fig. 1. The set up for the SP test procedure

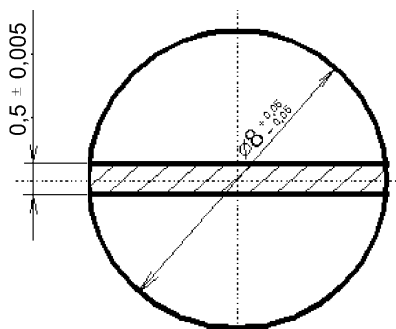


Fig. 2. The SP sample dimensions

- The yield stress and ultimate tensile strength at room temperature, which are correlated well with the parameters P_y and P_{max} , respectively. P_y and P_{max} are the loads corresponding to the yield and maximum strength of testing material.
- Ductile-brittle transition temperature (DBTT) measured by a Charpy test can be predicted from the results of temperature dependence of small punch energy (SP energy) determined from the area under the load - deflection curve.
- Fracture toughness J_{IC} can be evaluated using equivalent fracture strain $\bar{\epsilon}_{gf}$.

2.2 Apparatus

The testing is performed on a universal test machine INOVA TSM 10, equipped with load recorder, crosshead speed recorder, and data recorder for registration of load-deflection curves. Special fixture is used for the fixing of specimen and realization of SP test. For the low-temperature test, special temperature chamber cooled with liquid nitrogen vapor or liquid nitrogen is used[8].

2.3 Evaluation method of the base mechanical properties

2.3.1 Tensile properties

A typical load-deflection curve is shown in the figure 3. The loading force P at initial localized plastic strain is P_y and load maximum, P_{max} , can be related to the yield strength and the ultimate tensile strength, respectively. The empirical linear relationships can be expressed by equation:

$$\sigma_{y, \max} = kP_{y, \max} + q \quad (1)$$

where k , q are constants obtained from comparing small punch results and results from the standard tensile test on the reference material.

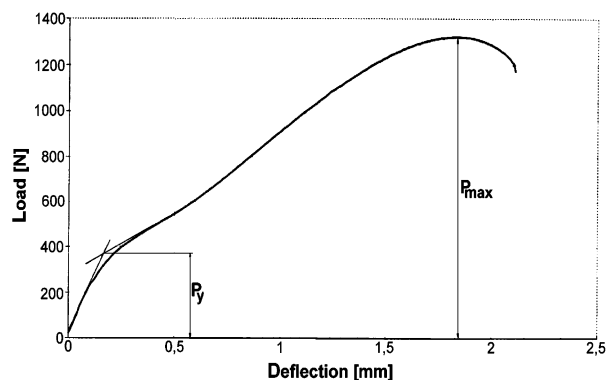


Fig. 3. Typical load-deflection SP curve for 15Ch2MFA material

2.3.2 SP Energy and SP ductile-brittle transition temperature (SPDBTT)

SP energy is estimated from the area under the load-deflection curve up to the fracture load or maximum deflection. Numerical integration method is used for the estimation. SPDBTT is defined by temperature at the energy level

$$SPDBTT = (SP_{max} + SP_{min})/2 \quad (2)$$

where SP_{max} and SP_{min} are energies at the upper and lower shelves, respectively. SP energy was analytically related with the ductile-brittle transition behavior by several authors. SPDBTT is approximately linear correlated with DBTT measured by a Charpy test using formula:

$$TT_{SP} = \alpha \cdot DBTT \quad (3)$$

where α is correlation coefficient [6].

2.3.3 Fracture toughness

According to Mao et al. [3] δ^*/t_0 is related to the equivalent fracture strain $\bar{\epsilon}_{gf}$ by equation:

$$\bar{\epsilon}_{gf} = \ln(t_0/t^*) = \beta (\delta^*/t_0)^2 \quad (4)$$

where t^* is the minimum thickness at the fracture portion and t_0 is initial thickness of specimen, β is a constant, and δ^* is the maximum deflection at fracture. J_{IC} can be estimated by a correlation between $\bar{\epsilon}_{gf}$ and J_{IC} obtained for testing material.

3. Application of the small punch test for NSSP

3.1 Materials

The experimental materials were base material, weld metal and heat affected zone of the RPV 15Ch2MFA steel. From this type of material we prepared samples, which have been irradiated in power reactor in Jaslovské Bohunice V-2 NPP unit 3 [4, 9].

3.2 Sample preparation

The testing results are extremely depended on the quality of specimen preparation. Samples are polished by one of the following methods:

- manually polish on the polishing papers for final thickness,
- grinding on the horizontal machine and then manually polish on the papers.

We have tested a new effective polishing method of the SP sample preparation, using the metallographic polishing machine on the special abrasive disks, which is illustrated on the figure 4. Three special holders are used for the fixation of four samples in each holder.



Fig. 4. Metallographic polishing machine with special holders

3.3 Testing conditions

Yield strength and ultimate tensile strength are evaluated by ambient temperature. The fixing torque is less than 5 Nm. Crosshead speed was 2 mm/min. For the evaluation of the ductile-brittle temperature, we used special cooling chamber. Testing was performed in the range temperatures from 77 K to ambient temperature. Temperature precision is controlled by system of the three thermocouples. Crosshead speed was higher (3 mm/min) than for tensile testing to achieve the constant temperature during the single test. For the evaluation of the fracture toughness value, we used cross section measurement of the sample after the penetration. Fracture thickness portion and initial thickness of specimen were measured by image analyzer procedures.

3.4 Correlations and examples of the initial state RPV materials results for NSSP

Correlations of SP parameters with the tensile properties for the base material and weld metal are described in Ref. [6]. Both SP and standard tests were done at room temperature. P_y and P_{max} correlate well with yield strength and ultimate tensile strength, respectively.

Table 1 summarizes the results from SP test for tensile properties estimation.

SP results for estimation of the tensile properties for the 15Ch2MFA steel

Table 1

Material	P_{max} [N]	P_y [N]	R_m [MPa]	R_e [MPa]	R_m^* [MPa]	R_e^* [MPa]
base material	1274	316	657	512	641	525
weld metal	1298	318	602	479	589	467
HAZ	1328	330	685	540	-	-

* average results from standard tests

Example of the temperature dependence of SP energy for the base metal RPV is shown on the figure 5. In this case, SPDBTT is defined as the temperature corresponding to the middle energy between the energy at the intersection of the two fitting curves and energy at 50 K.

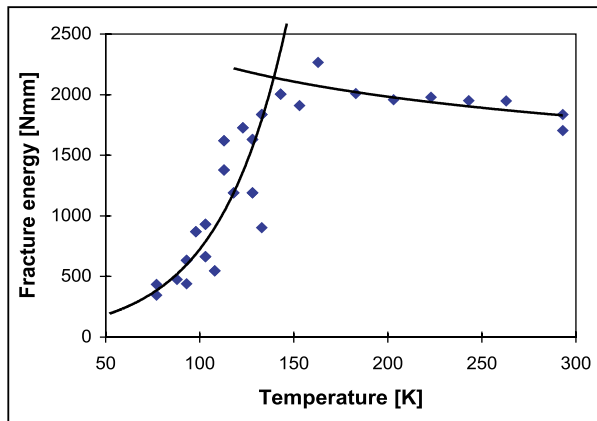


Fig. 5. Temperature dependence of the SP energy for 15Ch2MFA

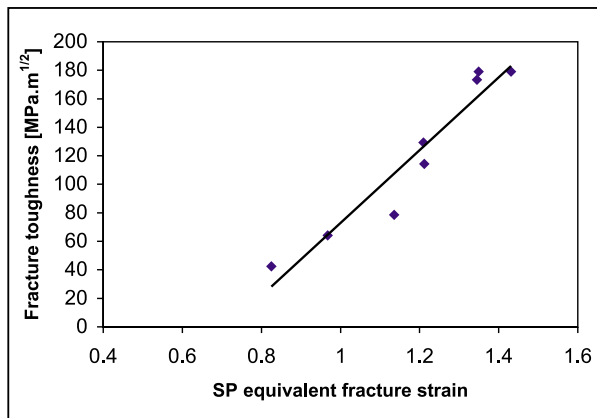


Fig. 6. Correlation between J_{IC} and \bar{E}_{gf} for the weld metal RPV

Transition temperatures from standard Charpy-V tests and small punch tests are summarized in the table 2.

5. References

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Transition temperatures for materials from NSSP

Table 2

Material	Charpy-V test			SP test
	TT_{KCV50} [°C]	TT_{PHL} [°C]	$TT_{\Delta B}$ [°C]	TT_{SP} [°C]
BM	-43	-16	-	-15.2
WM	-15.4	-12.9	1.2	-15.5
HAZ	-	-	-	-35.2

Value of \bar{E}_{gf} was calculated using equations from chapter 2.3 using both formulas. For the weld metal RPV, J_{IC} obtained from standard test versus \bar{E}_{gf} calculated from these equations is plotted in figure 6. This curve will be used for evaluation of the J_{IC} shift after irradiation in the NSSP [3]. Table 3 summarized fracture toughness values measured on ambient temperatures by standard test on the COD samples and by small punch test.

Fracture toughness values measured on ambient temperatures for NSSP materials

Table 3

Material	$J_{IC \text{ standard COD}}$ [MPa.m ^{-1/2}]	$J_{IC \text{ SPT}}$ [MPa.m ^{-1/2}]
BM	-	369
WM	179	163
HAZ	-	306

4. Conclusions

From the experiments follow these main conclusions:

- SP test methods are suitable for basic mechanical parameters like tensile properties, evaluation of DBTT or fracture toughness.
- The great advantage of SP test methods is a low consumption of experimental material and possibility to use this method for irradiation experiments in power reactors.
- Geometry of specimen is convenient for properties evaluation of the heat-affected zone.

Main goal for the future is to standardize SP method for industrial applications.

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RIEŠENIE KRÍZOVÝCH SITUÁCIÍ 2002

Fakulta špeciálneho inžinierstva Žilinskej univerzity v spolupráci s Ministerstvom hospodárstva Slovenskej republiky organizuje v dňoch 22. a 23. mája 2002 *VII. medzinárodnú vedeckú konferenciu Riešenie krízových situácií v špecifickom prostredí*

Konferencia sa bude rokovať na plenárnom zasadnutí a v štyroch sekciami:

- Sekcia č. 1: Krízové riadenie a krízové plánovanie
- Sekcia č. 2: Požiarna ochrana a záchranné služby
- Sekcia č. 3: Bezpečnostný manažment - ochrana osôb a majetku
- Sekcia č. 4: Ľudský činiteľ v krízovom riadení

Konferencia sa uskutoční v priestoroch Žilinskej univerzity.

Všetkých záujemcov srdečne pozývame.

CRISES SITUATIONS SOLUTION 2002

The Faculty of Special Engineering of the University of Žilina in cooperation with the Ministry of Economy of the Slovak Republic is organizing from 22 to 23 May, 2002 the *Seventh International Scientific Conference devoted to Crises situations solution in specific environment.*

The conference will proceed in plenary session and in these four sections:

- Section No. 1: Crisis management, crisis planning
- Section No. 2: Fire prevention and safeguarding services
- Section No. 3: Security management - people and property protection
- Section No. 4: Human factor in crisis management

The conference will be held at the University of Žilina.

All interested are cordially invited.

Sekretariát konferencie:

Fakulta špeciálneho inžinierstva Žilinskej univerzity v Žiline

Secretary of the conference:

The Faculty of Special Engineering of University of Žilina, Slovakia,

Ing. Ladislav Novák, PhD.

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