APPLICATIONS OF SMALL PUNCH TEST

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Abstract

Small punch test is an advantageous method for evaluation of mechanical properties of components especially in cases, where it is technically difficult or even impossible to obtain enough bulk material for standard tests. Therefore, the method is very well applicable in power industry, for example in residual lifetime assessment of critical parts of components and structures after long-term operation. The testing material is sampled by using special sampling device that ensures no component damage and the amount of material being sampled is so small that no component repair is necessary after sampling. Small punch testing is viable not only for evaluation of mechanical properties, but also microstructural and chemical analyses can be performed from the obtained sample and complex actual material characteristic of component can be assessed. MATERIAL AND METALLURGICAL RESEARCH, Ltd., has more than 20 years of experience with small punch testing in industrial applications and several examples of its application for analysis of material properties and residual lifetime assessment are presented in this paper.

Keywords: Small punch test, actual material properties, residual lifetime

1. INTRODUCTION

Small punch test (SPT) is a useful method for evaluation of actual material properties of components in power industry. A big advantage of this method is that material can be sampled from studied component directly on site without negative influence on its function and also without any repair. This method can be also used in cases when it is necessary to obtain test specimen from very narrow layers of material, for example from decarburized layers, segregations, coatings, etc. Another typical example of utilization of SPT method is evaluation of material characteristics of specific areas of weld joints or deposit layers.

Mechanical properties, especially yield stress and transition temperature (FATT), are degraded during long-term operation at elevated temperature, as well as microstructure in which cavitation damage can develop during creep exposure. An approach based on specimen sampling from critical parts of components in periodic intervals (including first sampling from virgin state of newly produced component) with complex material analysis allows to determine material degradation for each period and subsequently to assess the residual lifetime of a component. MATERIAL AND METALLURGICAL RESEARCH, Ltd., has been performing long-time monitoring of components in power industry for about 20 years [1]. It is an owner and also a producer of specialiazed scoop sampling machine and offers long-term monitoring of operated components behaviour within Europe. This paper summarizes some key results, emphasizes an importance of SPT in this field and shows new results of small punch testing of different materials.

This article summarizes evaluation of ductile-brittle transition temperature of cover plate of the channel of a heat exchanger (in three different states and locations) by two different approaches using SPT. In the second part of the article author takes a closer look at assessment of actual material properties of secondary reforming reactor evaluated with help of SPT after incineration nozzle fault.

2. EVALUATION OF TRANSITION TEMPERATURE AFTER DIFFERENT HEAT TREATMENT

The evaluated sample was a cover plate of the channel of a heat exchanger. It is the first heat exchanger downstream the hydrotreatment reactor, cooling down the reactor effluent by heating up the reactor feed. Reactor effluent is in the tube side. The exchanger is from 1968. The plate was made of 1%Cr-0.5Mo low alloyed steel and was cladded on internal, process side with austenitic stainless steel. The total plate thickness was 215 mm with 3 mm cladding. Operating pressure was 60 bar and operating temperature 370-400 °C.

The goal was to repair the cover plate without negative influence on material properties and especially on raising the transition temperature. The transition temperature of small punch tests (T_{SP}) of heat exchanger plate was evaluated on delivered sample in three different conditions of heat treatment:

- 1 – in as-delivered state,
- 2 – after simulated post weld heat treatment (PWHT) at 680 °C/1.5h/cooling in furnace,
- 3 – after quenching and tempering (920 °C/1h/oil + 710 °C/2h/air).

Dimensions of blocks used for heat treatment were around 40 x 70 x 180 mm. T_{SP} was evaluated in 3 different locations of the heat exchanger cover plate in each heat treatment condition by 2 mm punch, because of the large thickness of material. These locations were defined as **C** (under the cladding), **M** (in mid-thickness) and **S** (approximately 4 mm under the outer surface).

Two different methods can be used for evaluation of T_{SP}:

- the **two-curve method** (**Figure 1**), which is based on finding the highest and the lowest energy of the test by exponential fit of the lower and upper shelf of the dataset. T_{SP} is then calculated as the mean value of the highest and the lowest energy
- the **hyperbolic tangent (tanh) fit method** (see **Figure 2**), which is based on normalizing the test energy E_n according to Equation (1):

$$E_n = E/F_m \quad (1)$$

Where:

E – test energy (mJ)

F_m – maximum force achieved during small punch test (N)

The relation between the normalized energy E_n and temperature is then calculated by using the least square method and T_{sp} is defined as the inflection point of the Equation (2).

$$E_n(T) = A + B \cdot tanh\left[\frac{T-T_{sp}}{C}\right] = \frac{E_{US}-E_{LS}}{2} + \frac{E_{US}-E_{LS}}{2} \cdot tanh\left[\frac{T-T_{sp}}{C}\right] \quad (2)$$

Where:

$E_n(T)$ – normalized test energy at temperature T (mJ/N)

E_{US} – upper shelf energy (mJ/N)

E_{LS} – lower shelf energy (mJ/N)

T – thermodynamic temperature (K)

T_{SP} – transition temperature of small punch test (K)

A, B, C – constants

Both methods are explained in detail in [2,3].

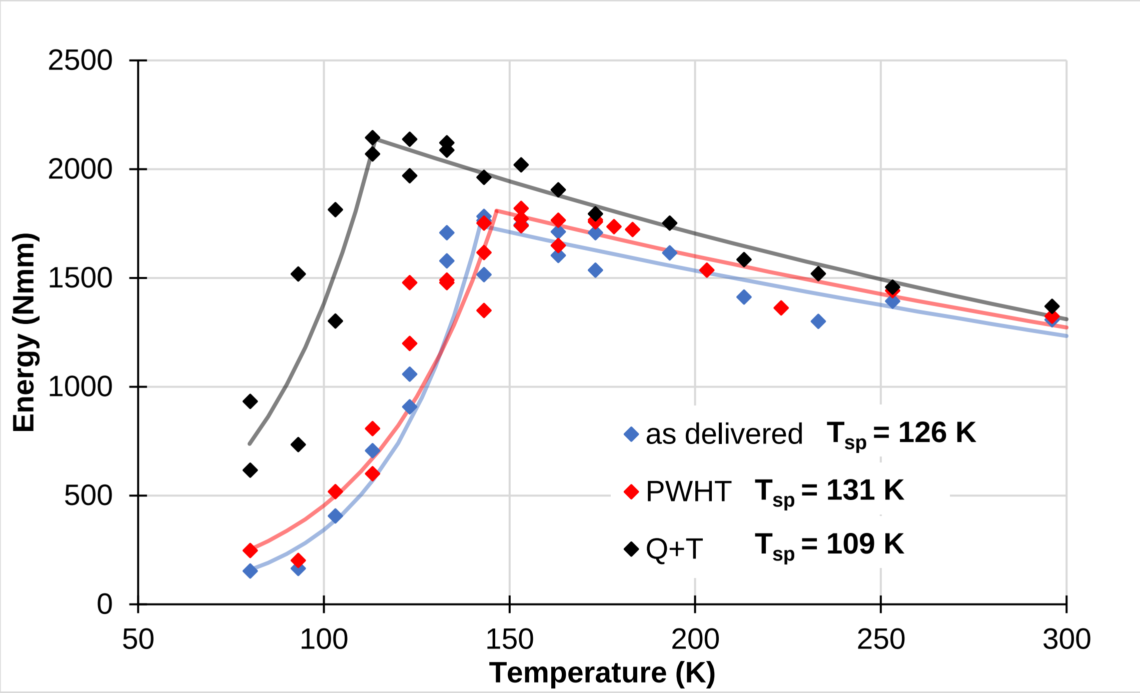

Figure 1 Influence of heat treatment on T_{SP} of sample S (under surface) evaluated by the two-curve method

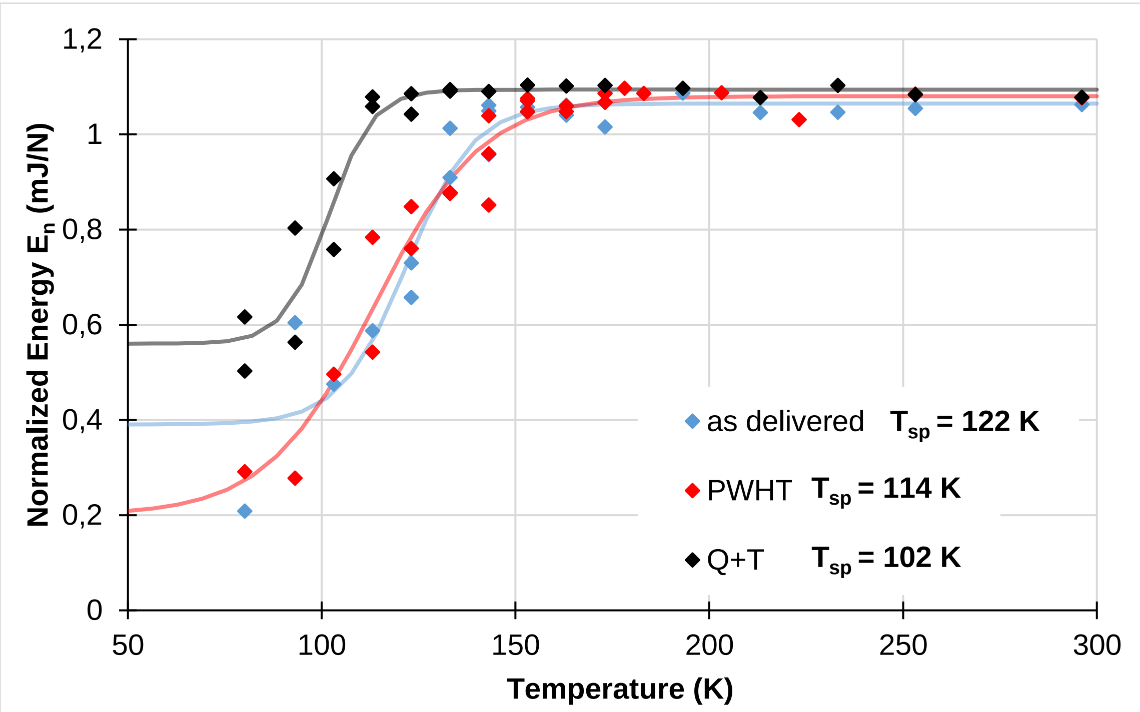

Figure 2 Influence of heat treatment on T_{SP} of sample S (under surface) evaluated by tanh fit method

Table 1 shows comparison of T_{SP} evaluated in all locations by both methods. Regardless the evaluation method, the T_{SP} in each location is lower after quenching and tempering than in as-delivered state, meaning the material is more ductile after quenching and tempering. However, depending on evaluation method, the T_{SP} increased or decreased slightly in samples after simulated PWHT. When using the two-curve method the T_{SP} after simulated PWHT is lower under the cladding (location C), but higher in mid-thickness (location M) and under the surface (location S) compared to as-delivered state. On the other hand, when using the tanh fit, the values of T_{SP} after PWHT are lower in all locations compared to as-delivered state. The effect of simulated PWHT on changing the T_{SP} is therefore minor compared to quenching and tempering which proved to lower the T_{SP} in every case.

Table 1 Comparison of T_{sp} by evaluation method used

Sample	Location of sample	T_{SP} – two-curve method (K)	T_{SP} – tanh fit method (K)
1 (as delivered)	C – under the cladding	131	116
	M – mid-thickness	123	121
	S – under the surface	126	122
2 (simulated PWHT)	C	119	113
	M	135	115
	S	131	114
3 (quenched + tempered)	C	109	98
	M	121	111
	S	109	102

There is only small difference between transition temperature of surface and mid-thickness in all states investigated, sampling from surface represents mechanical properties of part well.

3. ASSESSMENT OF ACTUAL MATERIAL PROPERTIES OF SECONDARY REFORMING REACTOR

The assessment of actual material properties was carried out in the shell of the secondary reforming reactor operated in Slovakia. Design temperature of the reforming was exceeded during operation due to incineration nozzle fault. Walls of reactor were made of Gr. 11 steel according to ASTM A 336. Chemical composition of examined steel determined by x-ray fluorescence and combustion analysis is stated in **Table 2** and compared with the chemical composition of Gr. 11 steel. After on-site examination of the whole reactor, it was decided to scoop small samples from places with the highest measured temperature (outside – sample 1, inside – sample 2) and in the reference place not affected by heat (sample 3) and to perform complex material analyses in order to evaluate residual lifetime and the extent of damage suffered. The reactor was sampled by special scooping machine, which allows almost non-destructive extraction of samples, **Figure 3**. The chemical composition, hardness and microstructure were evaluated from these samples.

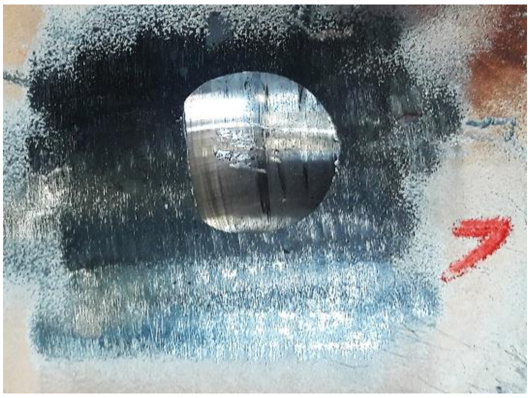

Figure 3 Reactor wall after sampling of Sample 1

Table 2 Chemical composition of reactor wall (wt. %)

Element	C	Mn	Si	P	S	Cu	Ni	Cr	Mo
Reactor wall	0.12	0.51	0.50	0.010	0.004	0.15	0.083	1.18	0.48
Gr. 11	0.10 0.20	0.30 0.60	0.50 1.00	Max. 0.025	Max. 0.025	-	-	1.00 1.50	0.45 0.65

Five small disc specimens 8 mm in diameter and 0.5 mm thick [1,3,4] were made by EDM (electrical discharge machining) from each place of interest to evaluate yield stress $R_{p0.2}$ and tensile strength R_m. The results of mechanical properties and hardness testing are stated in **Table 3**, the microstructure of samples 1 and 2 is documented in **Figure 4**.

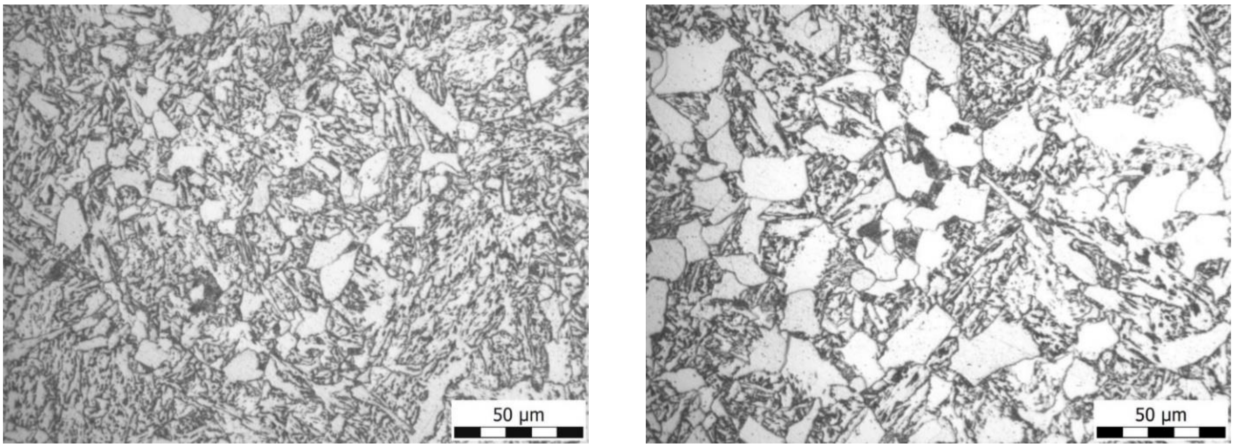

Figure 4 Sample 1 (left), sample 2 (right) detail of microstructure

Table 3 Mechanical properties of reactor wall evaluated by SPT

Sample	Specimen	$R_{p0.2}$ (MPa)	R_m (MPa)	Hardness HV10
1 (outer side of reactor)	1	383	564	193, 200, 189
	2	409	571	
	3	390	556	
	4	394	564	
	5	475	630	
2 (inner side of reactor)	1	450	616	191, 189, 188
	2	469	629	
	3	469	608	
	4	436	605	
	5	449	644	
3 (not affected place)	1	463	608	190, 187, 190
	2	473	616	
	3	455	642	
	4	477	627	
	5	470	615	
Gr. 11	-	min. 310	515-690	-

Correlations developed and exploited in MATERIAL AND METALLURGICAL RESEARCH [2] were used to calculate $R_{p0.2}$ and R_m of the reactor material. Values of $R_{p0.2}$ and R_m correspond very well to the standardized properties of Gr. 11 steel and thus show no signs of material damage, as well as hardness values that show good correlation to R_m values and low scatter of individual results.

Microstructure was evaluated after etching in 4% Nital and all three samples showed identical mixture of bainite, ferrite with precipitate and small amount of pearlite in form of small islands. No coarse carbides, decarburization or signs of creep damage (e.g., cavitation) were detected in any of three samples.

Results of abovementioned analyses thus confirmed that the incineration nozzle fault had practically no impact on material properties of the reactor wall as no signs of degradation of material properties and/or microstructural changes or creep damage due to high temperature exposition were found.

4. CONCLUSION

This paper explores two different uses of SPT on operated components. The evaluation of T_{SP} transition temperature in the first case confirmed that when using the same punch diameter (2 mm), the evaluated T_{SP} transition temperatures show the same trend regardless the evaluation method used. The second presented case showed use of SPT as a tool for evaluation of actual material properties on secondary reforming reactor, this evaluation helped to prove that the material was not damaged whatsoever, which meant significant time and economic savings.

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