SMALL PUNCH TEST APPLICATION TO FRACTURE TOUGHNESS DETERMINATION IN THE UPPER SHELF REGION

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Aims of This Work:

- Verification of methods used for fracture mechanics parameters determination with the use on mini-samples in the ductile region
- Comparison of fracture toughness results obtained from conventional tests and from small punch tests at room temperature
- Comparison of additional results obtained from tensile tests and small punch tests (comparison of ultimate tensile strength and maximal force obtained by SPT)

Problem Solution

- Evaluation of mechanical properties (e.g. fracture toughness) obtained from conventional tests for 2 materials in different states
- Performance of small punch tests on these 2 materials in different states and their evaluation with the use of published methods
- Assessment of the applicability of the used methodics and its limits

Experimental Material – 2 Steels

➢**Experimental low carbon steel (**designated as *steel 1)*

3 different states:

Annealed at: 440°C

500°C

620°C

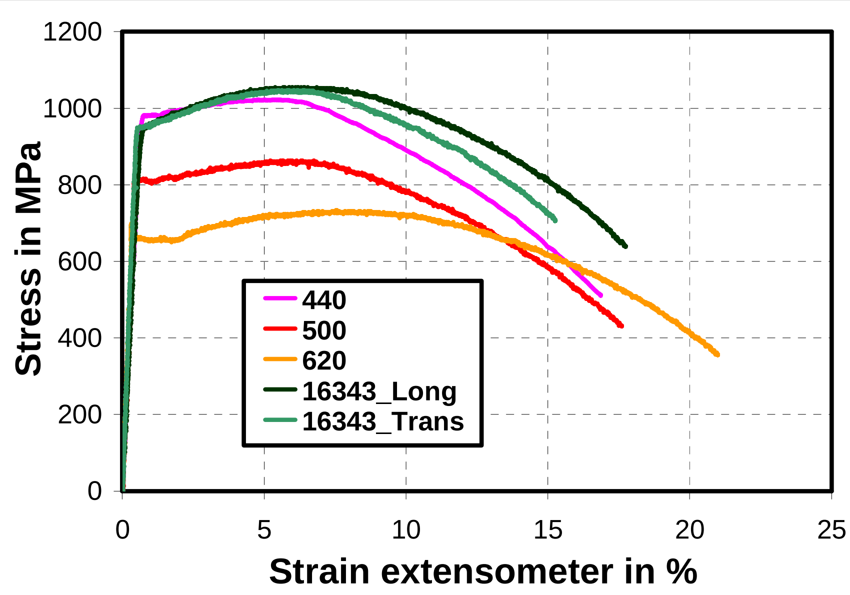
➢**16 343 (according to ČSN) (EN: 34CrNiMo6)**

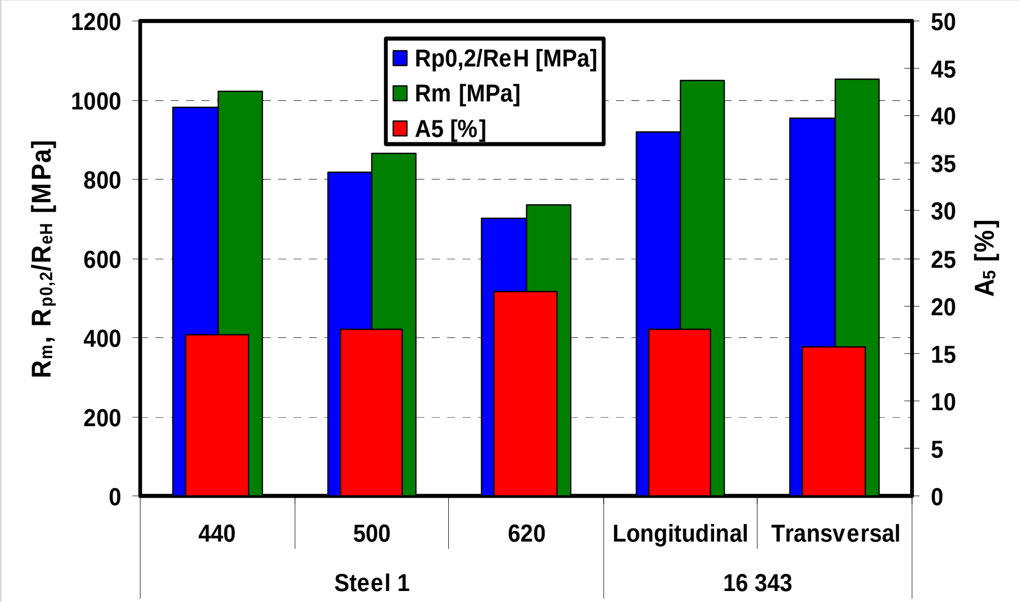
tested in 2 directions - longitudinal and transversal direction of rolled bar semi-product

Material exhibited upper shelf behavior in delivered condition

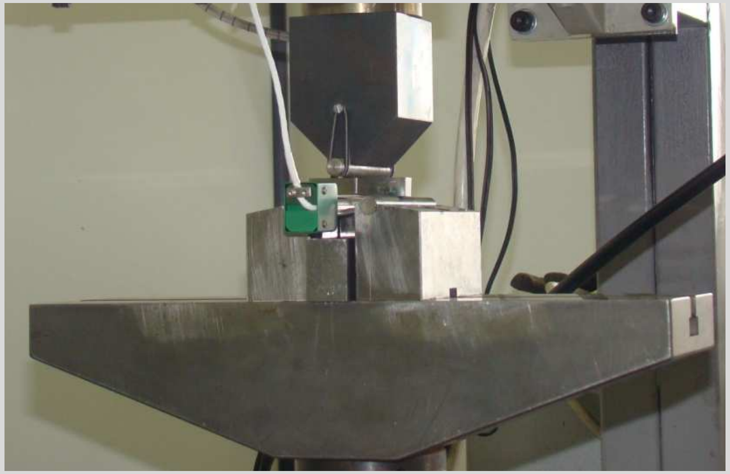
Basic mechanical properties obtained from tensile test

Material	State	Test Temp. ℃	$R_{p0,2}/R_{eH}$ [MPa]	R_m [MPa]	A_5 [%]	Z [%]
Steel 1	440	20	981,1	1022,1	16,9	70,9
	500	20	816,0	863,3	17,5	71,2
	620	20	699,9	734,0	21,4	74,1
16 343	Longitudinal	20	921,3	1050,4	17,5	63,4
	Transversal	20	952,6	1053,3	15,7	60,0



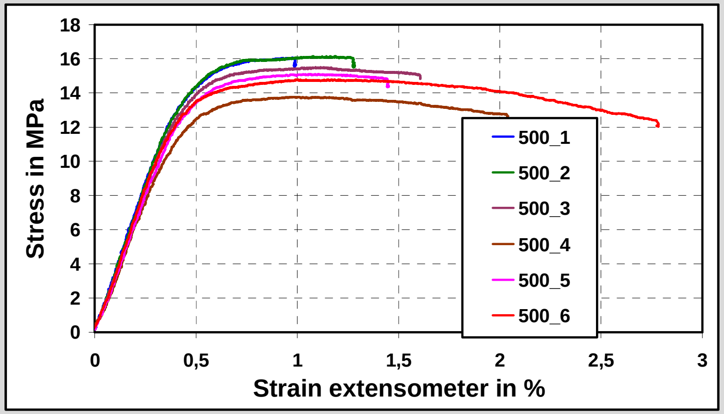


Fracture Toughness Tests



- Three point bend specimen
- Specimens were fatigue pre-cracked with the final stress intensity factor of about 20 $MPa.m^{1/2}$ and then side grooved
- Tests were executed at ambient temperature
- Crack lengths were measured by digital image processing
- Evaluation according to ASTM E 1820
- Determination of J-R curves for all materials investigated

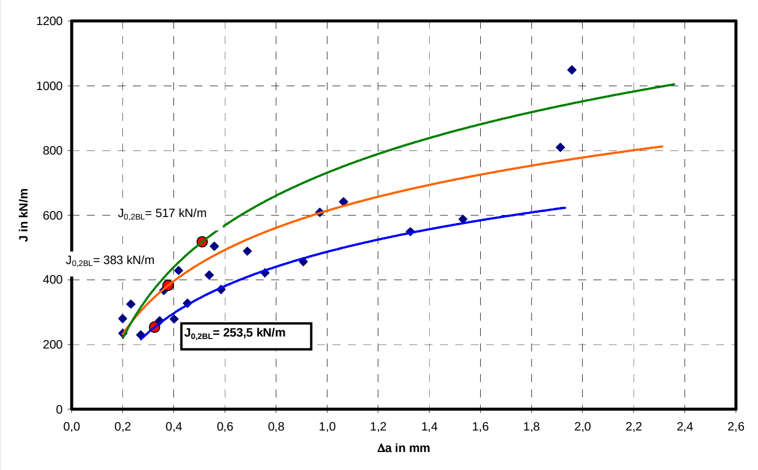
Example of fracture toughness tests records – steel 1 annealed at 500°C



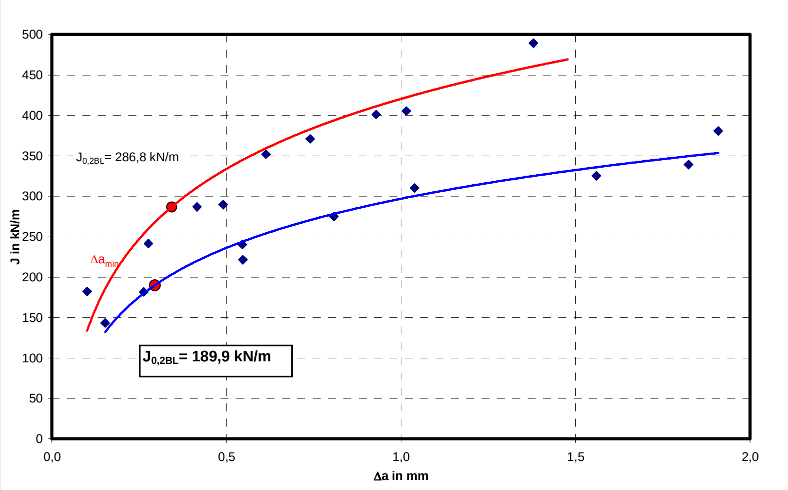
Fracture Toughness Tests-Results

	State	Test Temp. ℃	$J_{0,2BL}$ kN/m
Steel 1	440	20	253,5
	500	20	383,0
	620	20	517,0
16343	Longitudinal	20	286,8
	Transversal	20	189,9

Evaluation according to ASTM E 1820

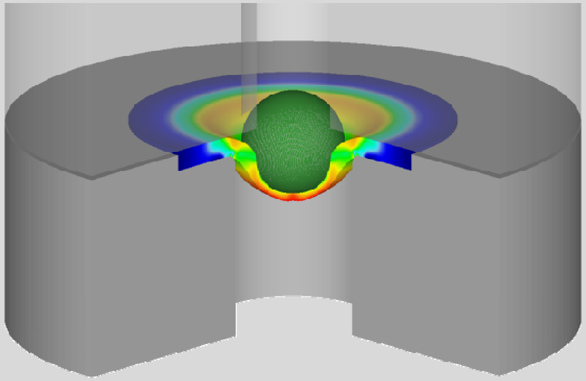


J-R curve – steel 1 – annealed at 440, 500, 620°C



J-R curve – 16 343 – both directions

SPT – Principle and Conditions

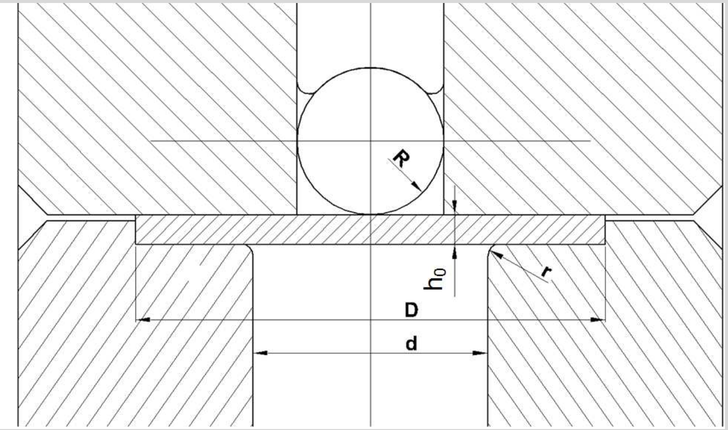


Principle: penetration of hard ball through the tests sample while the force and ball displacement is measured.

Polished specimens with the 8 mm diameter and the thickness of 0.5 mm were used

Preparation of Samples:

- made from stick, diameter 8 mm
- then cut on 1 mm thickness
- polished with final grain 1200
- final thickness 0.5 mm ±0.003mm



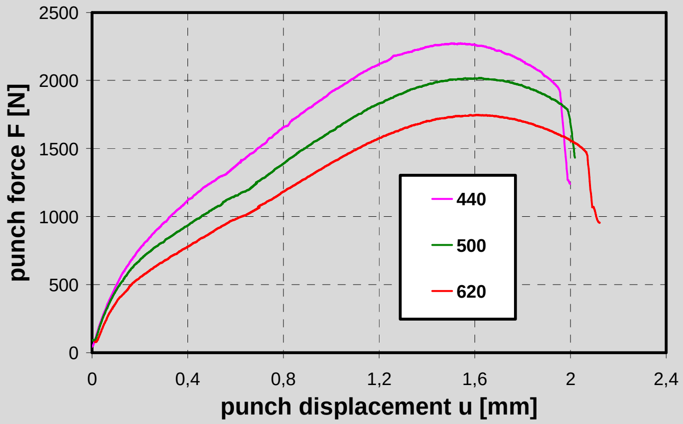
Conditions of Test:

- tests were performed at room temperature
- speed of tests was 0.5 mm/min

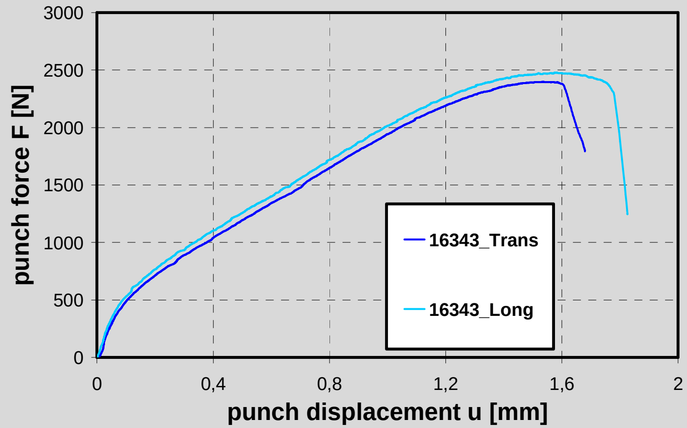
h_0	D	R	r	d
0,5	8,0	1,25	0,5	4,0

SPT Evaluation

Steel 1



16 343 steel



Each state was measured on 5 samples.

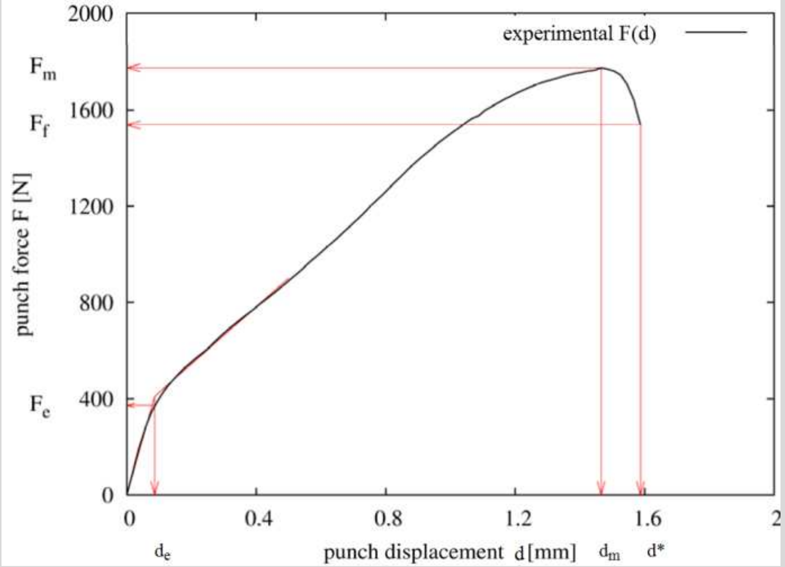
The following values were determined on the basis of the graphs:

F_m [N] – maximum load recorded during SP test

F_e [N] – yielding load (load characterizing the transition from linearity to the stage associated with the spread of the yield zone through the specimen thickness)

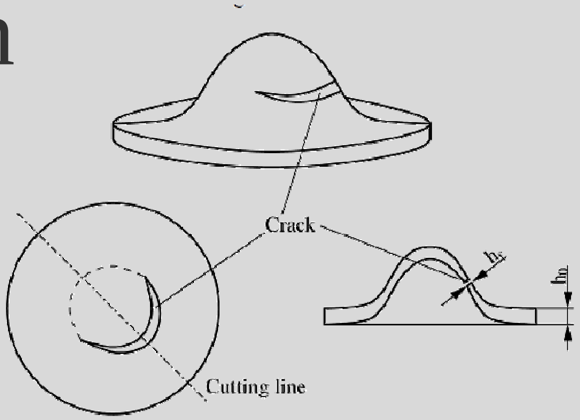
d_m [mm] – displacement corresponding to maximum load F_m

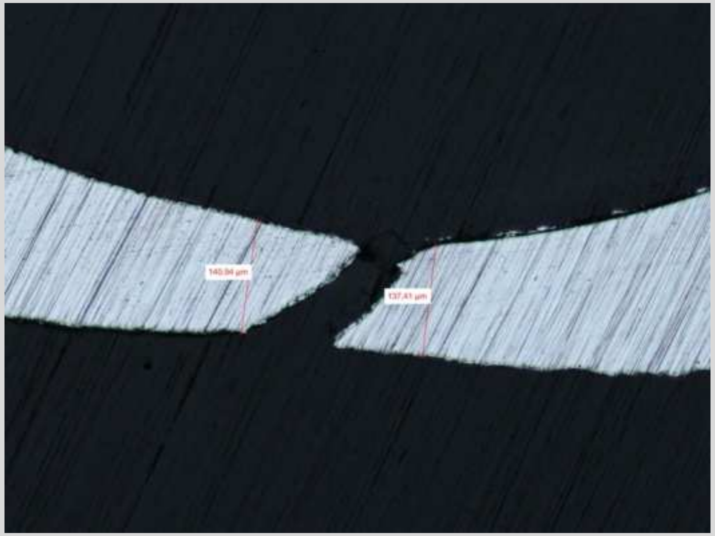
*d** [mm] – displacement corresponding to samples fracture



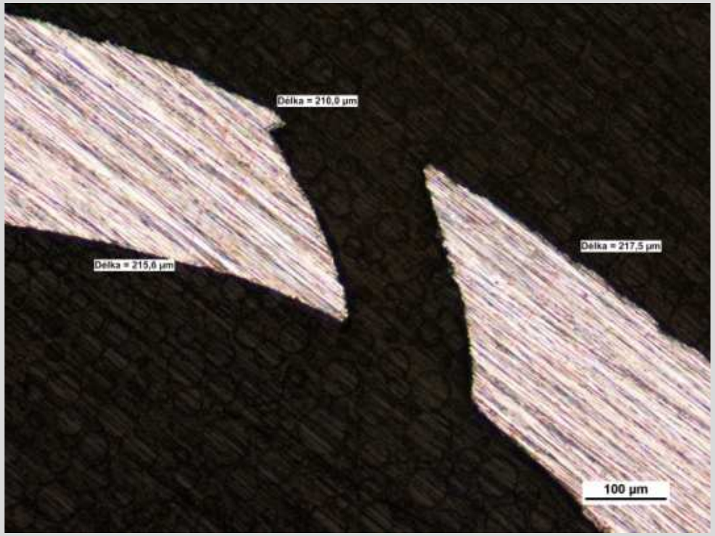
SPT Evaluation

- In order to determinate the fracture toughness, it is important to measure the thickness (h_f) of the specimen in the crack region after the tests
- This measurement is done on samples that are cut in the middle of crack, perpendicularly to the crack.





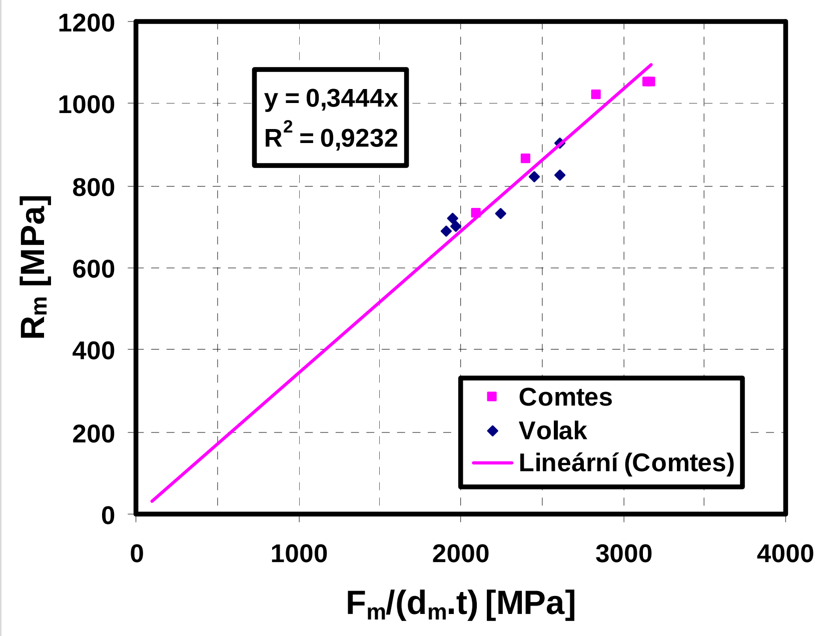
Steel 1 – annealed at 500°C



16 343 – longitudinal

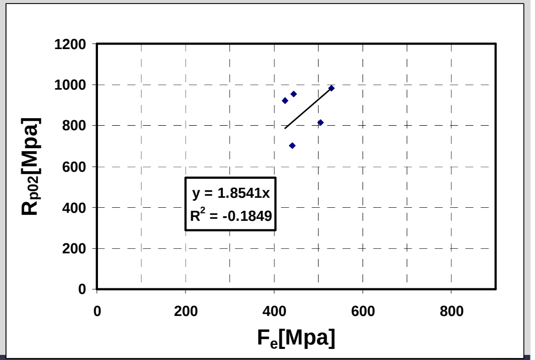
SPTs Evaluation-Tensile Properties

Material	State	R_m	F_m	d_m	$F_m/(d_m.t)$
		[MPa]	N	mm	MPa
Steel 1	440	1022,1	2282,5	1,61	2841,0
	500	863,3	1999,6	1,66	2402,0
	620	734,0	1763,2	1,68	2095,6
16 343	Longitudinal	1050,4	2477,5	1,57	3150,0
	Transversal	1053,3	2398,3	1,51	3174,7



- The curves obtained from SPTs and from tensile tests were evaluated
- Ultimate tensile strength and normalized yielding force from SPT were compared
- Clearly linear trend was found
- Good agreement is found also with the published data from Volak

Yielding load F_e was evaluated too but there was no linear trend in this case



VOLÁK, J.: Provedení miniaturizovaných zkoušek tečení, Bakalářská práce, ZČU, FST, 2006

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SPTs evaluation- fracture toughness

- There are published various procedures for fracture toughness evolution (based i.e. on SP fracture energy or maximum force)
- In the case of upper shelf behaviour there is widely used the following relation

$$J_{IC}=k.\varepsilon_f-J_0$$

k, J_0 – empirical determinate constants
ε_f – effective fracture strain

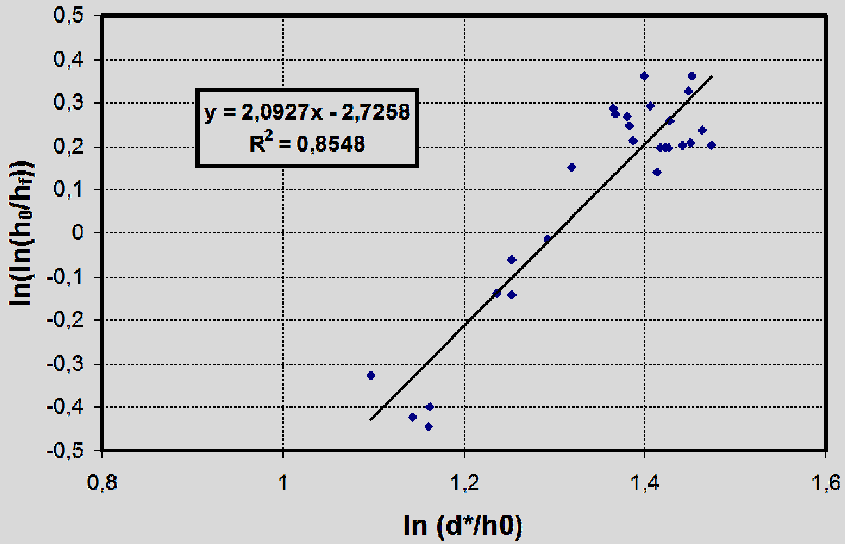
- There are 2 possibilities how to determinate fracture strain:

$$\varepsilon_f = \ln(h_0/h_f) = \beta.(d^*/h_0)^x$$

β=0.111
x=1.69

Metallographic investigation

Test record with the use of d^*



Material	State	Metallography			Graph		
		h_f	ε_f	SPT-J_{IC}	d*	ε_f	SPT-J_{IC}
		mm	---	kN/m	mm	---	kN/m
Steel 1	440	0,137	1,293	396,5	1,989	1,145	347,9
	500	0,147	1,221	373,0	2,080	1,235	377,5
	620	0,135	1,309	401,8	2,149	1,304	400,4
16343	Long.	0,205	0,893	264,7	1,779	0,948	283,0
	Trans.	0,255	0,673	191,8	1,579	0,775	225,7

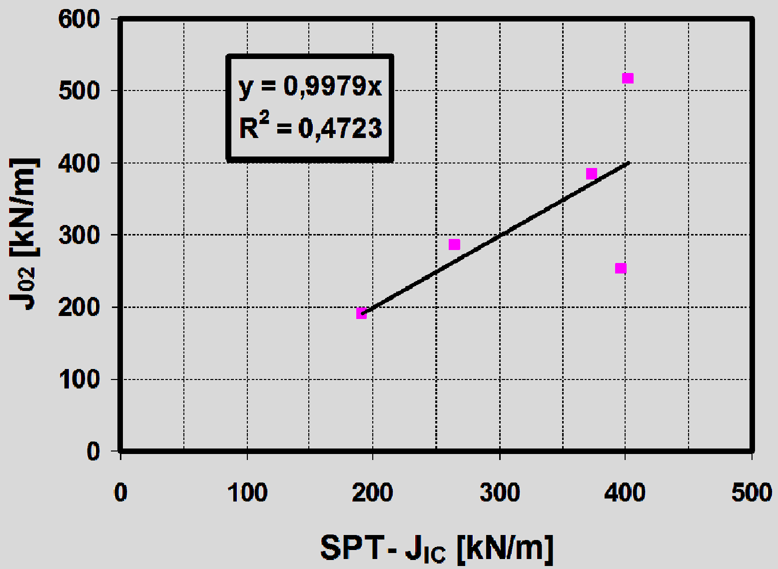
Results of fracture toughness evaluation

Material	State	Test Temp.	SPT-J_{IC}	$J_{0,2BL}$
		°C	kN/m	kN/m
Steel 1	440	20	396,5	253,5
	500	20	373,0	383,0
	620	20	401,8	517,0
16343	Longitudinal	20	264,7	286,8
	Transversal	20	191,8	189,9

$$J_{IC}=k.\varepsilon_f-J_0$$

$k = 330$

$J_0 = 30$



- The results of fracture toughness evaluated from SPT with the constant obtained here are compared with fracture toughness data evaluated from standard tests.
- SPT evaluation was using measured sample thickness in the point of the crack initiation
- The obtained results exhibit disagreement of SPT based fracture toughness and standard tests for steel 1. It is because of the thickness h_f, which was almost the same for all 3 states of steel 1.
- Very good agreement between SPT results and results of standard fracture toughness tests for steel 16 343 was found.

Conclusions

- Within presented work SPTs were performed for two materials in different states.
- Clearly linear trend can be seen between ultimate tensile strength and normalized yielding force from SPT. When this trend was confronted with published results, excellent agreement was found. It confirmed applicability of determined parameters for further determination of tensile strength from SPT
- Good agreement was found between fracture strain determination from direct measurement of sample thickness and from SPT record.
- The obtained results exhibit disagreement of SPT based fracture toughness and standard tests for steel 1. This is due to the fact that the fracture strain for all samples of steel 1 was almost the same.
- In the case of steel 1 it is not useful to use this approach to determinate fracture toughness
- Very good agreement between SPT results and results of standard fracture toughness tests for steel 16 343 was found. Anisotropy between longitudinal and transversal direction was well detected by SPT for this material.

Thank you for your attention

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