APPLICATION OF MICROBENDING TEST ON AUSTEMPERED IRON

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Abstract

This paper describes the use of a microbending test for determination of mechanical properties of austempered ductile and grey iron (ADI/AGI) and austempered vermicular-graphite iron (AVGI). Possibilities and benefits of microbending test compared to conventional testing methods are highlighted.

Keywords: microbending test, mechanical properties, austempered iron

1. INTRODUCTION

A microbending test in comparison with standard bending test uses significantly smaller sample with variable dimensions. It allows to specify stress limits for the material at a specific site - standard test method relates more to the specimen than to a specific casting and is time-consuming and also expensive (see standardized specimens). In this case, the microbending test was used for determination of mechanical properties of austempered irons within the dissertation “Non-destructive structuroscopy of austempered irons”. This dissertation aims to develop NDT control procedures for 100 % inspection of austempered castings. This production is very demanding and requires a fast and reliable control to minimize losses from poor production. The result of the non-destructive measurement is a physical quantityThe value of the physical quantity is related to mechanical quantities. During the introduction of non-destructive inspection methods is therefore necessary to determine accurately the stress limits of the material in a controlled place to get the conversion relation to the measured physical quantity. This pretty much allows the microbending test. [2], [5], [8]

2. THE PRINCIPLE

For the microbending test is used a special measuring device. A sample (commonly with the rectangular cross section) is placed at a pair of solid plates which distribute the pressure and prevent breaking into the supports. The punch transfers a load by the force *P* [N] which is initiated eg. by a tensile tester. In the basic kit the force is generated manually - turning the screw with a fine trapezoidal thread in the four-legged caliper. Strain gauges placed on the punch are scanning the load strain gauges placed on the metal plate just under the bending pin are scanning the deflection. The distance of supports can be 25 to 40 mm and the maximum dimensions of the samples b*h are limited by stress ratio $\sigma_{red.} \cong \sigma_{oh}$ and by the maximum load (cca 6.5 kN). Dimensions of the whole device are just 60×60×180mm - see **Fig 1** [6].

Parameters that can be determined from a graphic record of the test are:

- bending strength Rm_o
- yield strength in bending R_{Po}, possibly limit of proportionality R_{Eo} in case of ductile irons
- quotient of non-linear and linear deflection y_p (plastic deflection)

$$R_{mo} = \frac{M_{o\max}}{W_o} = \frac{3}{2} \cdot \frac{P_{mo} \cdot l}{b \cdot h^2} \left[MPa\right] \qquad (1)$$

$$y_p = \frac{p}{y-p}\,[-] \qquad (2)$$

Where is:	M_{omax}	*maximum bending moment*
	W_o	*section modulus in bending*
	P_{mo}	*ultimate strength*
	l	*distance of the supports*
	b,h	*sectional dimensions of the sample*
	p	*linear (elastic) deflection*
	y	*maximum bending*

Quantities of R_{po} and y_p are not generally defined. For this case R_{po} is defined as the stress corresponding to the point in a graph where is a maximum curvature (see **Fig. 2**). It is not possible to evaluate this state in case of common gray irons. Value of y_p is similar to the ductility A_x (tensile test). Value of R_{Eo} corresponds mainly to the elastic deformation. It does not depend on the size of the sample. Data from the test can be further processed, such as derivation to obtain real physical limit state under the load [6] [7].

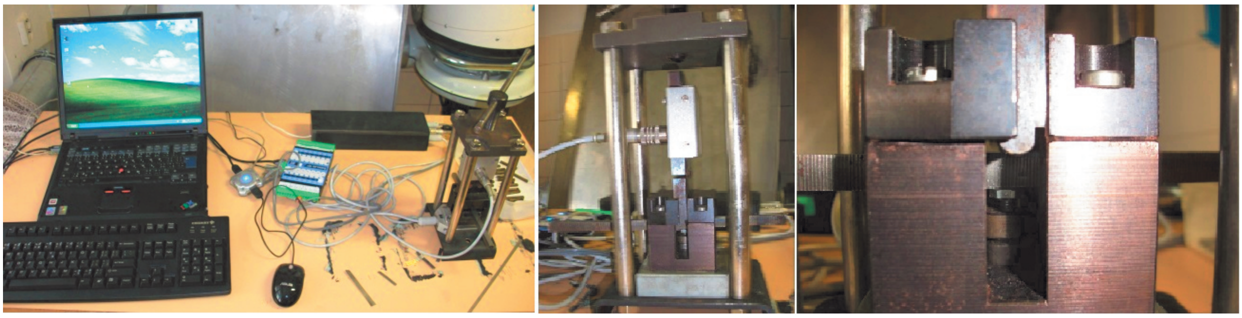

Fig.1 The microbending test device

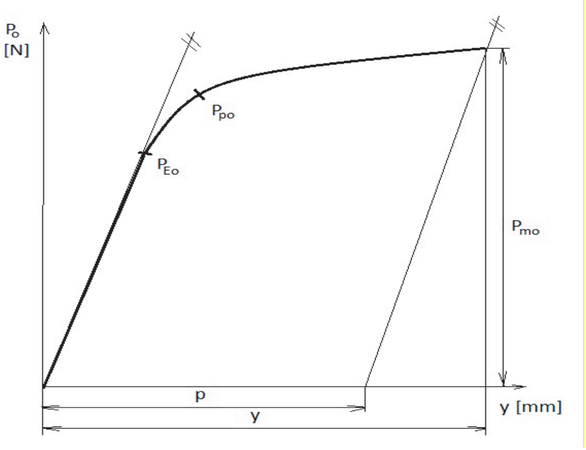

Fig.2 The graphic record of microbending test [6]

Table 1 Relation between *Rm* and *yp* of basic irons - median values, standard deviations *S* is drawn from dozens of measurements [6]

Rm=0,51Rmo	Rmo [MPa]	S	yp [-]	S
Ferritic-pearlitic ductile iron(GJS)	1140	100	6.6	1.5
Ferritic vermicular iron (GJV/CGI)	820	41	1.46	0.21
Gray iron (GJL)	438	54	0.51	0.16
Ferritic-pearlitic malleable iron	627	50	0.9	0.06

3. EXPERIMENT

3.1 Materials and samples

Sets of reference samples of cast irons with lamellar (C 3.15; Si 2.24; Mn 0.19; P 0.02; S 0.016; Cu 0.02; Ni 0,01), vermicular (C 3.62; Mn 0.18; Si 3.5; S 0.015; P 0.024; Cu 0.21; Mg 0.014; Mo 0.35; Cr 0.04) and nodular graphite (C 3.3; Si 2.45; Mn 0.25; Mg 0.046; Cu 0.04; P 0.02; S 0.015) were created there. Type of the material as well as HT can be read from the identification of the sample according to the ***Key****. There have been used 37 samples with variable HT and dimensions 5x5x30-40 mm (rectangular). These samples were dissected using EDM - so as to ensure dimensional accuracy and the original condition, without affecting by the heat or by deformation.

3.2 Terms and procedure of the measurement

The measurement was performed using microbending device (MOP), which is connected via an electronic outputs and A/D converter with notebook (see **Fig. 1**), where is installed the MOP 3.0 software. This software stores measured data into the DBF format, which can be opened using Open Office Calc or MS Excel. The values are:

"DATUM"	DATE, indicates the current measurement date
"ČAS"	TIME, indicates the current measurement times (GMT+1)
"N"	serial number of the record (1,2,3,…n)
"IN1"	INPUT 1, coordinate **x** = force [V]
"IN2"	INPUT 2, coordinate **y** = deflexion [V]

Software was created within [7] as the first functional version, thus, lacks small user-friendly details, but this does not affect the conduct and outcome of the measurement. The software stores only single file for current date, individual measurements can be distinguished according to the TIME channel (real time GMT+1), according to the initial step of the record (begins always at 1) and according to the description, which can be assigned to each sample before the start of the measurement. The measurement does not start automatically. It´s necessary to preset the time period during which the data should be recorded from sensors (eg. 30 s, 60 s…) and the measurement is then initiated with the Start button. It is therefore necessary to select and omit the blind data during the data processing. Individual values of force and deflection are given in volts [V], they need to be converted to Newtons [N] and milimetres [mm] with use of calibration curves (see **Fig.3**). The strength was calibrated at the universal tensile strenght tester LabTest II. Loading up to 6500 N - corresponds to a maximum of 10V at MOP. Initial value x=0.222V corresponds to zero load. The deflection was calibrated using Johansson's blocks.

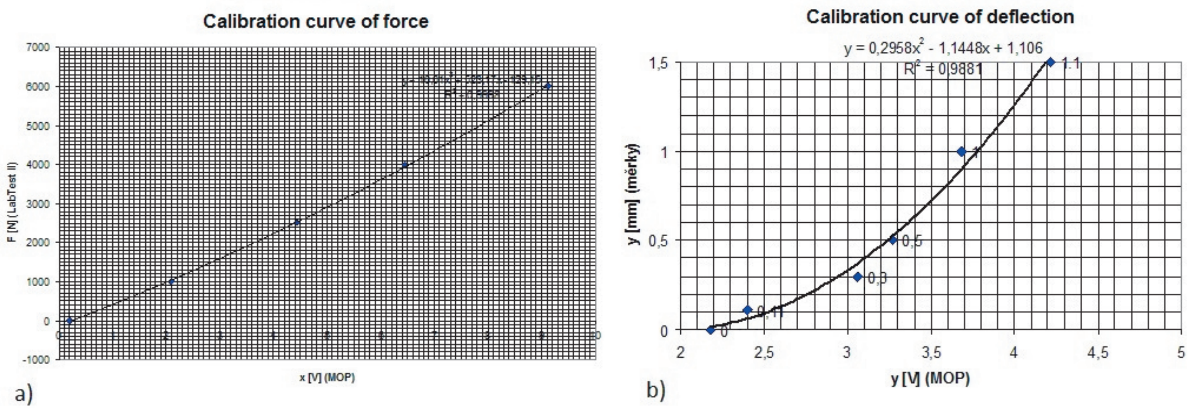

Fig. 3 Calibration curves of the microbending test; a) force calibration, b) bending calibration

Table 2 Results of microbending tests on ADI/AGI/AVGI samples

Sample	P_{mo}	y	R_{mo}	R_m	P_{po}	R_{po}	P_{Eo}	R_{Eo}	p	y_p
	[N]	[mm]	[MPa]	[MPa]	[N]	[MPa]	[N]	[MPa]	[mm]	[-]
ZS LLG	1506.07	0.281	449.14	229.06	1410	420.49	1250	372.78	0.10	0.528
3L2 240	2122.15	0.178	622.92	317.69	2070	607.62	1980	581.20	0.04	0.289
3L1 240	2139.07	0.248	634.11	323.40	2040	604.74	1760	521.74	0.05	0.222
3L6 240	2287.15	0.353	683.42	348.55	1960	585.67	1160	346.62	0.13	0.548
9L2 240	1761.12	0.239	529.40	269.10	1500	450.91	1030	309.63	0.05	0.264
9L1 240	2055.96	0.261	610.67	311.44	1820	544.92	1450	434.14	0.06	0.285
9L6 240	1872.85	0.271	558.52	284.85	1790	533.81	1560	465.23	0.07	0.348
3L2 310	2153.41	0.283	643.46	328.16	1950	582.68	1490	445.23	0.07	0.353
3L1 310	2074.74	0.273	616.28	314.30	1840	546.55	1500	445.56	0.05	0.224
9L2 310	2134.51	0.296	650.82	331.92	1880	564.01	1450	435.01	0.09	0.451
9L1 310	2265.42	0.329	658.34	335.75	2050	595.74	1650	479.49	0.08	0.343
ZS LVG	2587.05	0.759	765.38	390.34	1950	576.90	1400	414.19	0.70	11.803
3C2 240	3391.86	0.146	1013.52	516.90	2150	642.44	1500	448.21	0.05	0.571
3C1 240	4497.21	0.362	1327.89	677.22	4400	1299.19	4100	1210.61	0.08	0.302
3C6 240	4845.16	0.369	1444.93	736.91	4600	1371.82	3860	1151.13	0.07	0.230
9C2 240	3347.75	0.175	998.37	509.17	3140	936.42	2802	835.62	0.04	0.260
9C1 240	4480.45	0.286	132.,60	676.06	3500	1035.52	3200	946.76	0.05	0.227
3C1 310	5673.14	0.637	1698.60	866.29	4250	1272.50	2850	853.32	0.21	0.484
3C2 400	1981.75	0.309	593.36	302.61	1600	479.06	1260	377.26	0.14	0.850
3C1 400	4186.72	0.742	1238.64	631.70	3320	982.22	2400	710.04	0.42	1.331
3C6 400	4013.19	0.747	1194.42	609.15	3180	942.69	2280	675.89	0.49	1.865
9C2 400	4156.05	0.404	1236.94	630.83	2350	699.41	2480	738.10	0.16	0.683
9C1 400	4614.10	0.651	1354.57	690.83	3400	997.95	2100	616.38	0.25	0.607
9C6 400	4568.25	0.702	1354.18	690.63	3300	982.13	2590	770.82	0.42	1.443
ZS LKG	3250.74	1.980	965.55	492.43	2190	650.49	1850	549.50	1.10	1.250
3K2 240	3648.34	0.166	1081.59	551.61	3450	1022.79	3000	889.38	0.03	0.230
3K1 240	2486.34	0.130	738.59	376.68	2250	668.38	2000	594.12	0.02	0.203
3K6 240	6763.55	0.554	2066.06	1053.69	5350	1634.26	3300	1008.05	0,20	0.566
9K2 240	1098.04	0.163	325.51	166.01	1088	322.53	1042	308.89	0.04	0.335
3K1 310	6006.35	1.980	965.55	492.43	2190	650.49	1850	549.50	1.10	1.250
3K2 400	5832.10	1.459	1794.83	915.36	3850	1150.47	2900	866.59	1.04	2.483
3K6 400	4416.80	1.072	1317.19	671.76	3500	1043.78	3000	894.66	0.75	2.326
9K2 400	6313.35	0.876	1835.79	936.25	2300	688.64	2200	658.70	0.62	2.419
9K6 400	6763.55	1.294	2001.00	1020.56	4500	1331.39	3600	1065.11	0.93	2.553

3.3 Results and discussion

The results are summarized in **Table 2**, the measured values of voltage have been converted to values of force and deflection.

See the graphic records of selected samples in **Fig. 4** (as cast state and heat-treated) - records correspond to the expected (theoretical) dependencies for these materials, as well as the calculated values of basic mechanical properties match the expected values for given type of iron and HT conditions. Results of the microbending test can be considered as relevant.

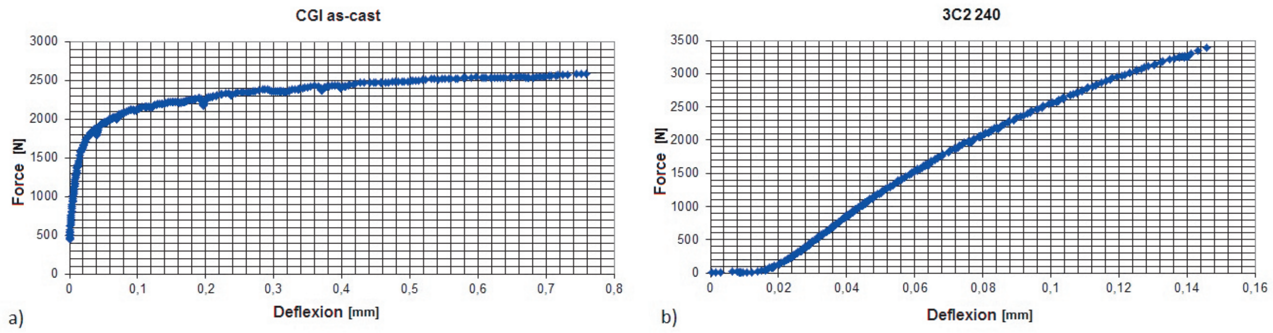

Fig. 4 Graphic records of measurements a) GJV (CGI) in as-cast state, b) austempered AVGI_3C2_455_240*

* **Key - labeling of samples:** 3=30min or 9=90 min austenizing; L = lamellar graphite, C = vermicular graphite, K = nodular graphite; 240, 310, 400 = austempering temperature; 2, 1=10, 6=60 min dwell (eg. 3C2 310 = 30 min austenizing, 310°C austempering/2 min dwell, C = vermicular/compacted graphite).

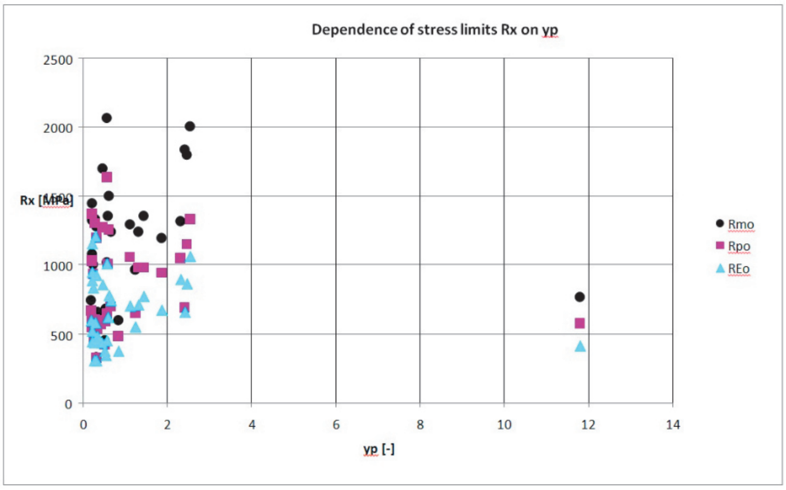

Fig. 5 Dependence of stress limits R_{mo}, R_{po}, R_{Eo} on y_p of all irons

The graph in **Fig. 5** shows that the correlation between limits of stresses (Rx) and the plastic deflexion (yp) is not monotonous. For each type of iron (due to the shape of graphite) the monotonic dependences are different. However, the relation of R_{mo} and R_{po} and R_{Eo} (see **Fig. 6**) is monotonous for all irons together, even with a relatively wide spread especially at higher values. The worst use of matrix properties provides 9K2 400 (short isothermal dwell - its structure contains martensite). In contrast, irons which are most suitable for fatigue loading - with the highest values of R_{Eo} - strength Rmo have often only about 1400-1500 MPa (eg. 3C6 240). Higher values of R_{mo} do not lead to the increase of R_{Eo}, but only the R_{po}.

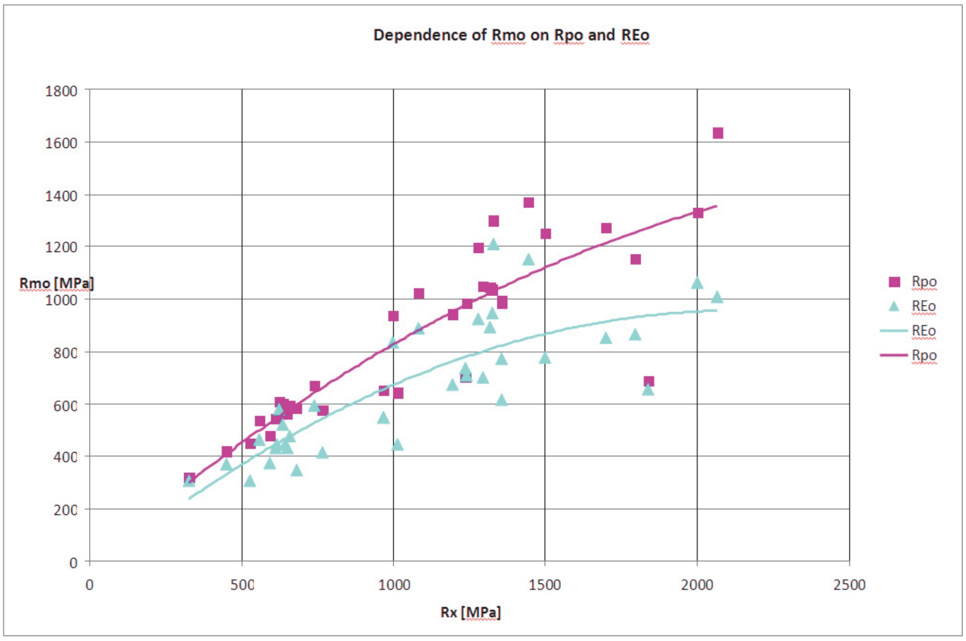

Fig.7 The dependence of the R_{mo} on stress limits of all investigated irons

CONCLUSION

Microbending test is very convenient method for the detection of mainly local mechanical properties. The method of determination of the limit states takes into account the real, not contractual properties (as eg. $R_{p0,2}$ or $Rp_{0,005}$ in case of tensile test). The huge advantage is a detailed electronic record of the test which allows mathematical processing using available software (Open Office Calc, MS Excel, Matlab). Due to the size of the device and its mobile nature is possible to use it almost everywhere. It´s not necessary to limit the use of the microbending test to the area of irons. It is intended to use this method for other materials such as composites, iron aluminides or natural samples within the development of the field of bionics.

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