Recenzované vědecké články

Factors Influencing the Outcome of the Time Independent Small Punch Tests

Faktory ovlivňující výsledky časově nezávislých penetračních testů

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The underlying purpose of this paper is to evaluate the effects of thickness of the disc test specimens 8 mm in diameter, stiffness of the testing machine, punch tip diameter (2 and 2.5 mm), chamfer radius of the receiving hole and orientation of the disc test specimens on the parameters of load – displacement curves used for determination of YS, UTS and DBTT from the results of SP tests. The results obtained should contribute to the revision of CWA 15627 "Small Punch Test method for Metallic Materials" and for the transformation of this document to EU standard.

Key words: *Small Punch (SP) test; load–displacement curve; stiffness of the testing machine; punch tip diameter; orientation of disc test specimen*

Účelem tohoto článku je zhodnotit vliv tloušťky zkušebních vzorků tvaru disku o průměru 8 mm, tuhosti zkušebního stroje, průměru hemisférického razníku, poloměru zaoblení otvoru spodní opěrné matrice a orientace zkušebních vzorků na parametry křivek zatížení – posunutí používané pro stanovení meze kluzu, meze pevnosti a tranzitní teploty z výsledků penetračních testů. Získané výsledky by měly přispět k revizi dokumentu CWA 15627 „Small Punch Test Method for Metallic Materials" a pro transformaci tohoto dokumentu na normu EU.

Klíčová slova: *penetrační zkouška; křivka zatížení – posunutí; tuhost zkušebního stroje; průměr hemisférického razníku; orientace zkušebního vzorku tvaru disku*

The need for evaluating the actual mechanical properties of structural components by means of a direct testing method has led to the development of innovative techniques based on miniaturized specimens. Among these, a technique called the Small Punch (SP) test has emerged as a promising candidate [1 – 4]. It is a mechanical testing method used at the present time to obtain tensile, fracture and creep data from very small quantities of experimental material. In 2007, the CWA 15627 "Small Punch Test Method for Metallic Materials" [5] was issued by CEN (European Committee for Standardization). Major benefits of this method are [6]:

1. It can be applied as a virtually non-destructive tool to monitor in service components in structural plants.
2. It enables determination of the tensile, fracture and creep characteristics of materials at critical locations of the components.
3. The test itself is rather simple to perform and inexpensive.
4. It gives the possibility to study locations such as interfaces, coatings, welded joints (BM, HAZ, WM) and exotic materials e.g. anisotropic, single crystals.

The use of this method was accelerated by the development of sampling devices for obtaining and retrieving a sample of material for analysis in a virtually non-destructive manner, not requiring post sampling repair [7].

The objective of the time independent SP test is to produce a load-displacement (punch displacement, crosshead displacement) record and/or load-specimen deflection record (Fig. 1), which contains information about the elastic-plastic deformation and strength properties of the material [5].

ISSN 0018-8069

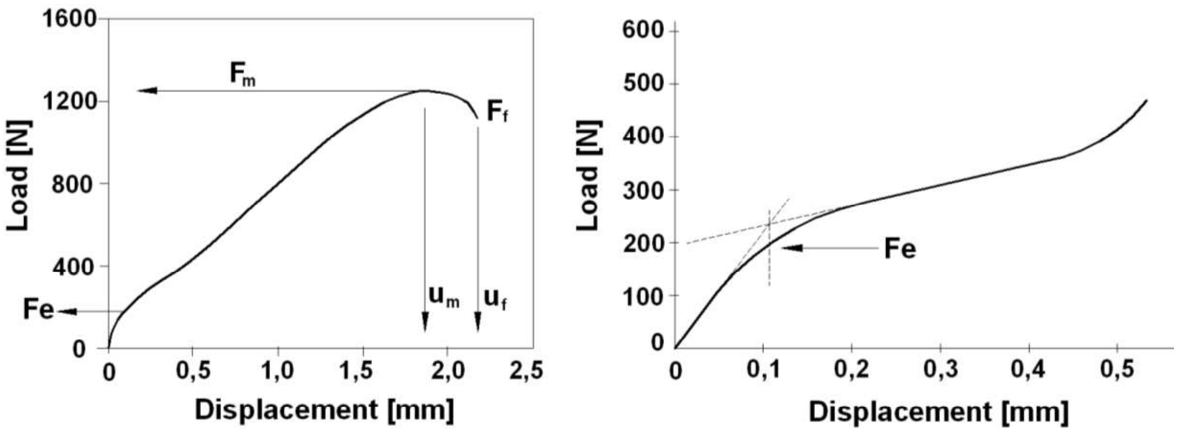

Fig. 1 Load – displacement curve recorded during a time independent Small Punch (SP) test
Obr. 1 Křivka zatížení – posunutí snímaná v průběhu časově nezávislého penetračního testu

The curve can be divided into several parts [2, 8]. The initial linear region corresponds to elastic deformation and micro-yield under the penetrator; this is followed by a deviation from linearity associated with the spread of the yield zone through the specimen thickness. The subsequent inflection point is associated with the transition from bending to membrane stretching. The following parameters are determined from the load-displacement curve during the time independent SP tests [5]:

F_m [N] - maximum load recorded during SP test,
F_e [N] - load characterising the transition from linearity to the stage associated with the spread of a yield zone through the specimen thickness. It is determined according to the Code by the two tangents method (Fig. 2),
u_m [mm] - displacement corresponding to the maximum load F_m,
u_f [mm] - displacement corresponding to 20% load drop,
E^{SP} [J] - SP fracture energy obtained from the area under the curve up to the displacement u_f

The shape of the load – displacement curve can be affected by [19]:

1. thickness of the disc test specimen,
2. testing material,
3. stiffness of the testing machine,
4. testing rig (punch tip diameter, dimensions and shape of the chamfer edge, receiving die diameter (Fig.2),
5. method used for detecting the test specimen displacement,
6. test temperature,
7. orientation of test disc specimen.

The load – displacement curves obtained can be utilised to derive empirical correlations between SP and standardised test results [9 – 13] or they can be analysed in terms of elastic-plastic finite element methods [14 – 18]. The present paper describes the effect of above mentioned factors on the SP related parameters used for determination of YS, UTS and DBTT from the results of SP tests.

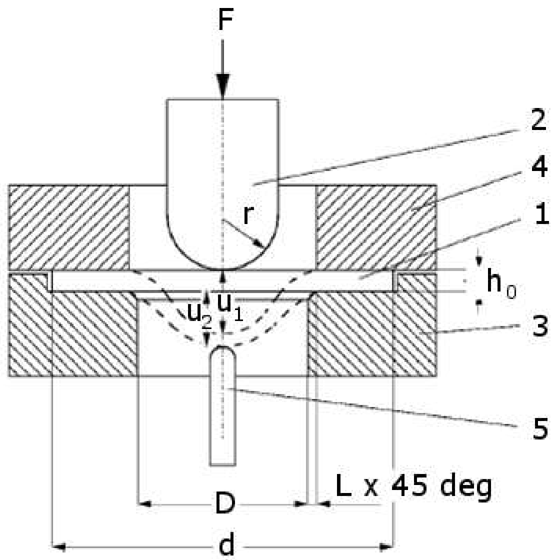

Fig. 2 Geometry of the SP test installation: 1 – specimen, 2 – punch, 3 – receiving die, 4 – clamping die, 5 – deflection measurement rod
Obr. 2 Geometrie zařízení pro penetrační testy: 1 – vzorek. 2- razník, 3 – spodní opěrná matrice, 4 – horní přítlačná matrice, snímač posunutí

Factors affecting the shape of load – displacement curve

Effect of disc specimen thickness

Fig. 3 shows the effect of disc specimen thickness on the dependence of load F_e, on yield strength, determined according to the Code [5]. The effect of the disc specimen thickness can be eliminated by normalising F_e as $\frac{F_e}{h_0^2}$, where h_0 is the initial thickness of the disc (Fig. 4) [6]. Fig. 5 shows the effect of disc specimen thickness on dependence of load F_m on tensile strength. The effect of disc specimen thickness can be eliminated in this case by normalising F_m as $\frac{F_m}{u_m \cdot h_0}$ (Fig. 6). However the empirical correlations for determination of tensile strength mostly show significantly lower scatter band in comparison with correlations for yield strength determination [6]. For this reason the empirical correlation for determination yield strength from the results of SP tests should be expressed as a dependence of yield strength on $F_e/(h_0)^2$ and the empirical correlation for estimation of material tensile strength from the results of SP tests should be expressed as a dependence of tensile strength on $\frac{F_m}{u_m \cdot h_0}$.

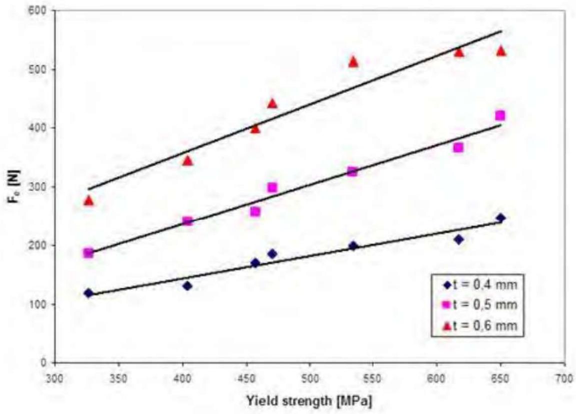

Fig. 3 Effect of the disc specimen thickness on the empirical correlation F_e vs. yield strength (14MoV6-3 low alloy steel in as received state)
Obr. 3 Vliv tloušťky disku na empirickou korelace *Fe* versus mez kluzu (nízkolegovaná ocel 14MoV6-3 v dodaném stavu)

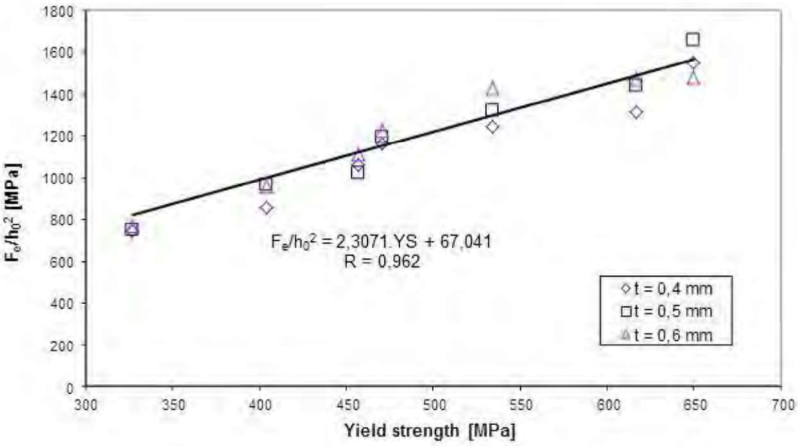

Fig. 4 Dependence of $\frac{F_e}{h_0^2}$ vs. yield strength independent on disc thickness

Obr. 4 Závislost $\frac{F_e}{h_0^2}$ versus mez kluzu nezávislá na tloušťce disku

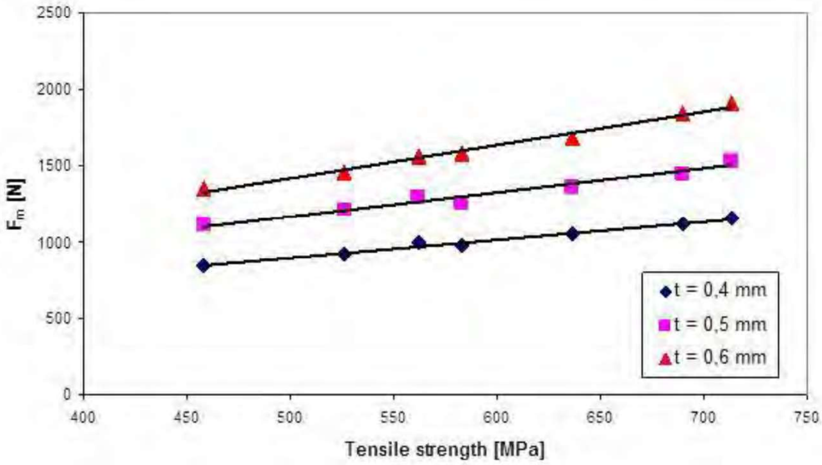

Fig. 5 Effect of the disc specimen thickness on the empirical correlation F_m vs. tensile strength. (14MoV6-3 low alloy steel in as received state)
Obr. 5 Vliv tloušťky vzorku na empirickou korelaci F_m versus pevnost v tahu (nízkolegovaná ocel 14MoV6-3 v dodaném stavu)

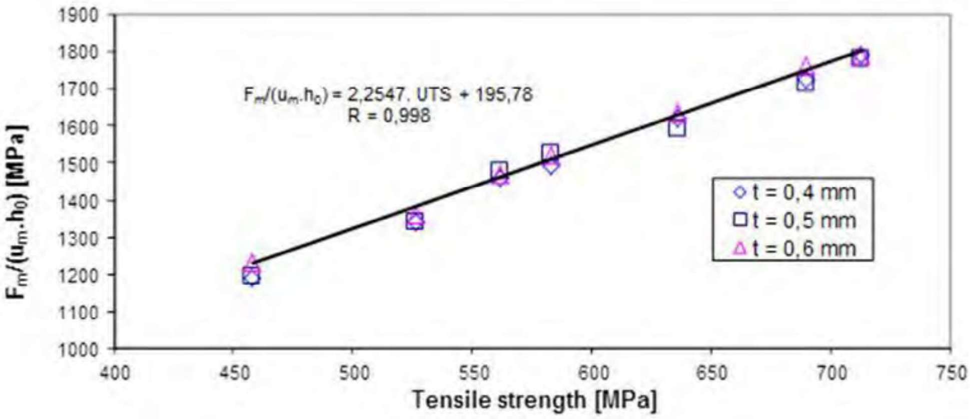

Fig. 6 Dependence of $\dfrac{F_m}{u_m \cdot h_0}$ vs. tensile strength independent on disc thickness

Obr. 6 Závislost $\dfrac{F_m}{u_m \cdot h_0}$ versus pevnost v tahu nezávislá na tloušťce disku

Effect of the stiffness of the testing machine

The effect of the stiffness of the loading system on the determination of tensile characteristics from the results of SP tests was demonstrated in [20]. Fig. 7 shows the differences in stiffness of the servo-mechanical testing machine Lab Test 5.10 ST (capacity of 5 kN) before and after repair (bearing replacement) [19].

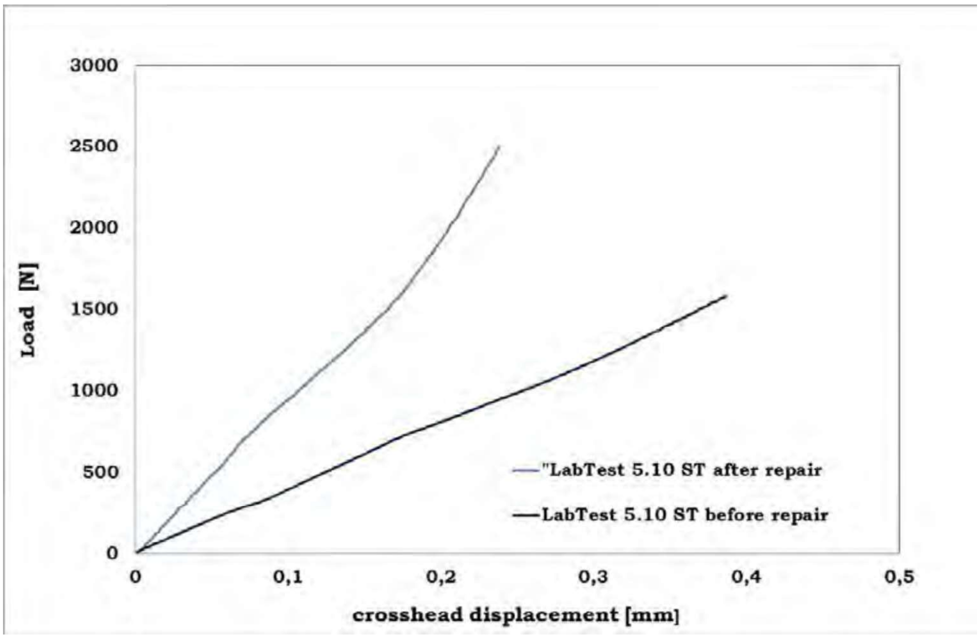

Fig. 7 Effect of the bearing replacement on the stiffness of servo-mechanical testing machine Lab Test 5.10 ST (capacity of 5 kN)
Obr. 7 Vliv výměny ložiska na tuhost servo-mechanického zkušebního zařízení Lab Test 5.10 ST (kapacita 5 kN)

Table 1 summarizes the parameters F_e, F_m and u_m of the load displacement curves monitored before and after bearing replacement. The values shown in Table 1 are average of three punch tests. From Table 1 it is evident that the monitoring of the load-deflection curve suppresses the effect of stiffness of the testing machine.

Tab. 1 Parameters of load displacement curves before and after repair of servo-mechanical testing machine Lab Test 5.10 ST
Tab. 1 Parametry křivek zatížení – posunutí před a po opravě servo-mechanického zkušebního zařízení Lab Test 5.10 ST

Stiffness of the machine	Load – crosshead displacement curve			Load – deflection curve		
	F_e [N]	F_m [N]	u_m [mm]	F_e [N]	F_m [N]	u_m [mm]
before repair	412	1759	1,544	368	1759	1,213
after repair	450	1729	1,210	366	1729	1,206

Effect of punch diameter

Punch diameter affects mainly the membrane stretching part of the load displacement curve and the maximum load F_m (Fig. 8 and 9).

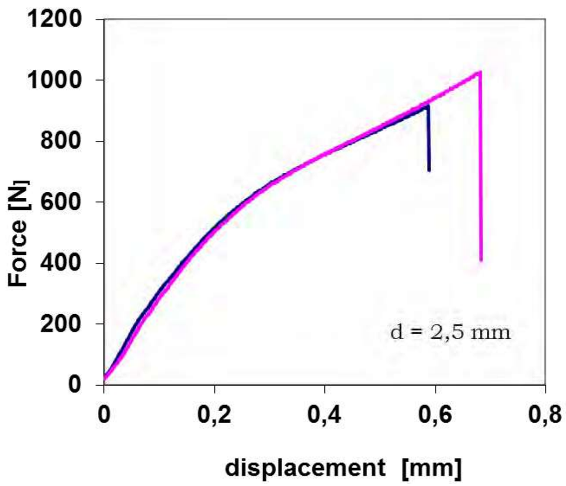

Fig. 8 P 92 steel at -180°C
Obr. 8 Ocel P 92 při teplotě -180°C

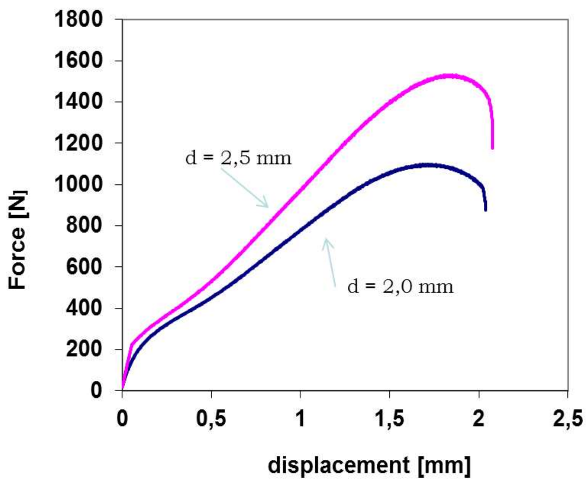

Fig. 9 P92 steel at laboratory temperature
Obr. 9 Ocel P 92 při laboratorní teplotě

For this reason, the temperature dependence of fracture energy in the transition region and transition temperature T_{SP} is not affected significantly by punch tip diameter.

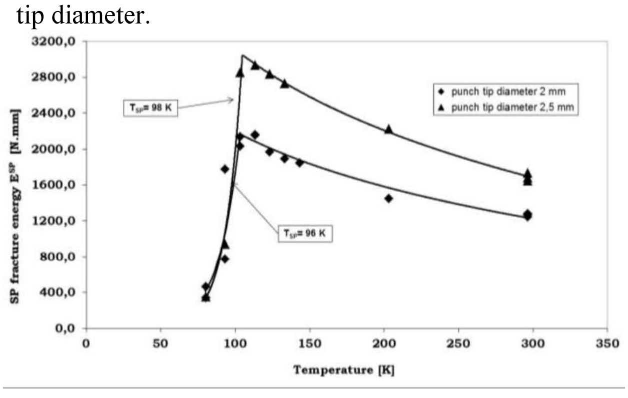

Fig. 10 Effect of punch tip diameter on temperature dependence of SP fracture energy E^{SP}, crosshead speed 1.5 mm·min^{-1} (14MoV-3 low alloy steel in as received state)
Obr. 10 Vliv průměru razníku na teplotní závislost lomové energie penetračního testu. Rychlost pohybu příčníku 1.5 mm/min., (nízkolegovaná ocel 14MoV6-3 v dodaném stavu)

Effect of chamfer radius of the receiving hole

Table 2 shows some early results to study the effect of chamfer radius of receiving hole on the parameters F_e, F_m and u_m of load – crosshead displacement curve at ambient temperature. It is evident that the chamfer radius of receiving hole affects both load F_e and the displacement corresponding to the maximum load F_m.

Tab. 2 Effect of the chamfer radius of the receiving hole on the parameters of load – crosshead displacement curve at ambient temperature. Carbon steel of grade 22K, punch diameter 2.0 mm, h_0 = 0.5 mm, crosshead displacement rate 1.5 mm·min^{-1}
Tab. 2 Vliv poloměru zaoblení otvoru spodní opěrné matrice na parametry křivky zatížení - posunutí příčníku při laboratorní teplotě. Uhlíková ocel značky 22K, průměr razníku 2,0 mm, h_0 = 0,5 mm, rychlost posunu příčníku 1,5 mm·min^{-1}

Chamfer radius of receiving hole	F_e [N]	F_m [N]		u_m [mm]
448 µm	174	1215		1.828
336 µm	185	1221		1.774

Effect of orientation of the disc test specimens

Fig. 11 and table 3 show the effect of disc specimen orientation on the shape and the parameters of load – deflection curves obtained at ambient temperature. Conventional disc test specimens were cut from the centre of the wall thickness of the P91 steel tube, ø 272 x 32 mm in the as received state.

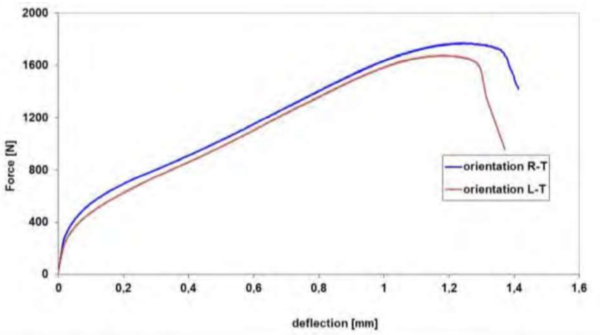

Fig. 11 Effect of the disc specimen orientation on the shape of load deflection curve. Tube ø 272 x 32 mm made of P91 steel. Punch tip radius 2 mm, crosshead speed 1.5 mm·min^{-1}
Obr. 11 Vliv orientace disku na tvar křivky zatížení – posunutí. Trubka ø 272 x 32 mm zhotovená z oceli P91. Poloměr razníku 2 mm, rychlost pohybu příčníku 1,5 mm·min^{-1}

Tab. 3 Effect of orientation of the disc test specimens on the parameters of load – deflection curve at ambient temperature
Tab. 3 Vliv orientace zkušebních vzorků na parametry křivky zatížení – posunutí při pokojové teplotě

Orientation of disc specimen	F_e [N]	F_m [N]	u_m [mm]	$\frac{F_e}{h_0^2}$ [MPa]	$\frac{F_m}{u_m \cdot h_0}$ [MPa]
R-T	327	1764	1,228	1308	2873
L-T	295	1689	1,177	1180	2870

It is evident from the table 3 that the orientation of the disc test specimen can affect significantly the empirical correlation for the determination of yield strength from the results of SP tests.

Conclusions

1. Empirical correlation for determination of material yield strength from the results of SP tests should be expressed as a dependence of yield strength on $\frac{F_e}{h_0^2}$ because this parameter $\frac{F_e}{h_0^2}$ eliminates any differences in disc specimen thicknesses on load F_e.

2. Empirical correlation for estimation of material tensile strength from the results of SP tests should be expressed as a dependence of tensile strength on $\frac{F_m}{u_m \cdot h_0}$ because this parameter $\frac{F_m}{u_m \cdot h_0}$ eliminates any differences in disc specimen thicknesses on F_m and u_m.

3. Monitoring of the load – deflection curve during the SP test, unlike the monitoring of load – crosshead displacement curve, suppresses the effect of stiffness of the testing machine on the parameters used for the determination of YS and UTS from the results of SP tests.

4. Punch diameter mainly affects the membrane stretching part of the load displacement curve and maximum load F_m. For this reason, the temperature dependence of fracture energy in the transition region and transition temperature T_{SP} is not affected significantly by punch tip diameter.

5. Orientation of the disc test specimen can affect significantly the empirical correlation for the determination of yield strength from the results of SP tests.

Acknowledgement

The paper has originated in the Framework of the solution of „Competence Centres“, programme of the Technology Agency of the Czech Republic TE 1020068.

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Ocelářský koncern Salzgitter znovu dosahuje zisk

Die Welt *15. 5. 2015*

U druhého největšího výrobce oceli v Německu, firmy Salzgitter, roste naděje na trvalejší zotavení. Základ pro návrat koncernu do ziskové zóny byl vytvořen, tvrdý úsporný program se vyplatil. Salzgitter vykázal v prvním čtvrtletí 2015 zase černá čísla. Po zdanění vydělal koncern 32,7 mil. €, po ztrátě 13,3 mil. € ve stejném období předcházejícího roku. Pro rok 2015 koncern vychází ze stabilního obratu a zisku před zdaněním ve výši několika desítek milionů €. Kromě mimořádně pozitivního vývoje výsledků v oboru ploché oceli, vč. tlustých plechů, a profilové oceli přispěly k dobrému výsledku také všechny ostatní oblasti obchodu.