NEW POSSIBILITIES OF EVALUATION OF THE DEGREE OF SOFTENING FROM TORSION PLASTOMETRIC TEST

Kubina T.[1],Bořuta J.[2], Schindler I.[1]
[1]Department of Materials Forming, Faculty of Metallurgy and Materials Engineering, VŠB – Technical University of Ostrava, Czech Republic, e-mail: tomas.kubina@vsb.cz
[2]VÍTKOVICE – Research & Development, spol. s r. o., Ostrava, Czech Republic

NOVÉ MOŽNOSTI VYHODNOCENÍ STUPNĚ ZMĚKČENÍ Z KRUTOVÉ PLASTOMETRICKÉ ZKOUŠKY

Kubina T.[1],Bořuta J.[2], Schindler I.[1]
[1]Katedra tváření materiálu, Fakulta metalurgie a materiálového inženýrství, VŠB – Technická Univezita Ostrava, Czech Republic, e-mail: tomas.kubina@vsb.cz
[2]VÍTKOVICE – Výzkum a vývoj, spol. s r. o., Ostrava, Czech Republic

Abstrakt

V článku je rozebrána problematika určení stupně změkčení z plastmoterických zkoušek. Jsou popsány originální vyhodnocovací programy, vyvinuté autorským kolektivem na základech hlubokých znalostí problematiky krutových plastometrických zkoušek V článku jsou naznačeny především základní principy práce s programem *pyX* k vyhodnocení stupně změkčení. Byly provedeny přerušované krutové zkoušky na sadě vzorků z nízkouhlíkové oceli na torzním plastometru SETARAM-VÍTKOVICE. Po vyhodnocení závislostí přirozeného deformačního odporu na intenzitě deformace pomocí programu *SiPODeX* následovalo určení stupně změkčení X právě programem *pyX*. Ten pracuje na principu určení zbytkové deformace $\Delta\varepsilon$ mezi jednotlivými dílčími úběry. Z porovnání jednotlivých zkoušek je patrné, že na stupeň změkčení X má vliv jednak teplota, s jejím růstem se intenzita odpevnění zvyšovala, dále délka časové prodlevy při přerušení deformace a jelikož po druhých deformacích byla pozorována u všech vzorků větší míra odpevnění, tak má na inteznitu odpevnění vliv i velikost předchozí deformace.

Při sledování teploty u vzorků s 1 sekundovou prodlevou bylo zjištěno že míra odpevnění výrazněji rostla až nad teplotou 800°C, což potvrzuje předchozí tvrzení o závislosti uzdravení na teplotě. Nejintenzívněji u těchto vzorků probíhalo uzdravení při teplotách 860 – 1005 °C. U vzorků s 6 sekundovou prodlevou probíhalo uzdravení už nad 770°C, protože materiál měl více času pro proběhnutí metadynamického uzdravení. Z vyhodnocených výsledků v této práci lze konstatovat, že zkoušením na vyspělém torzním plastometru ve spojení s programy *SIPoDex* a *pyX* je možné kvalitně studovat uzdravovací procesy během deformací i mezipauz.

Abstract

The article analyses problems of defining the degree of softening from plastometric tests. There are described original evaluation programmes which have been developed by a composite author on the bases of deep knowledge of problems of the torsion plastometric tests. In the article, there are mainly suggested the basic principles of work with the *pyX* programme for evaluation of the degree of softening. Torsion intermittent tests have been carried out on a sample set of low-carbon steel on a torsion plastometer SETARAM-VÍTKOVICE. After evaluating of dependencies of the flow stress on deformation intensity with help of the *SiPODeX* programme, the definition of the degree of softening X followed by the programme *pyX*. This works on the principle of definition of residual deformation $\Delta\varepsilon$ between individual partial reductions. The comparison of the individual tests suggests that factors influencing the degree of softening are e.g. temperature, whose increase means intensifying of softening, the length of the time lag when deformation interrupted, and as there was noticed on all samples after second deformations a higher degree of softening, it is clear that the intensity of softening is influenced by the power of the preceding deformation. When observing temperature of samples with 1 second time lag, it was found out that the degree of softening sharply rose at temperatures over 800°C, which proves previous claim about dependency of recovery on temperature. The most intensive recovery of these samples took place at the temperatures 860-1005°C. Samples with 6 sec. time dwell recovered at over 770°C because the material had more time for metadynamic recrystallization. From the evaluation of results in this work, we can state that by testing on a developed torsion plastometer hand in hand with programmes *SiPODeX* and *pyX*, it is possible to study carefully softening processes during deformations and pauses.

Keywords: softening, recrystallization fraction, low-carbon steel, torsion test

1. Possibilities of evaluation of the degree of softening

Evaluation of the degree of softening is possible from metallographic scratch patterns of the tested material when there is to be compared the ratio of recovered and deformed structure. This comparison in case of some kinds of steel is very difficult or impossible, mostly due to impossibility of etching of the original size of austenitic particle. Samples for degree of softening evaluation can be obtained either by laboratory rolling or by devices for mechanical testing (pressure, torsion, tension). Even with those plastometers, it can be difficult to define the exact place for the correct metal-graphic evaluation. Here come indirect methods of defining of the recrystallized ratio from the volume of softening – decrease of the flow stress gained at an interrupted plastometric test usually constituting of two deformations.

There are several methods for conversion of the graphic record of plastometric test into numerical form usable for prediction of recrystallization fraction X. The summary of such processes was published e.g. in the article [1]. There is no point in their repeated description. They have a common base in definition of yield stresses of the first and second deformation curve and their comparison in the form of ratio.

In case of work with the graphic expression of dependency of the flow stress σ on the strain ε, it is far much better to use residual deformation after the first reduction $\Delta\varepsilon$ and strain during the first reduction ε_1. The evaluation of the degree of softening by value of recrystallization fraction X [2] will be carried out according to the following formula:

$$x = 1 - \left(\frac{\Delta\varepsilon}{\varepsilon_1}\right) \tag{1}$$

This approach is used in the new programme for definition of the degree of softening taking advantage of data already processed by the programme *SiPODeX* which serves to evaluate plastometric tests carried out on the torsion plastometer SETARAM-Vítkovice.

2. Programme equipment used

Within the programming language PYTHON, there was invented a Windows-type programme *SiPODeX* which enables complex and comfortable processing of output experimental data from the plastometer SETARAM-Vítkovice. This special computer programme was designed to obtain detail data about formability, flow stress, and kinetics of dynamic recrystallization of studied material. This programme was closely described in article [3].

Figure no.1 shows whole process of deformation, time lags included, after complex processing of the test including curve smoothing and correction. Data concerning dependency of the flow stress on the deformation intensity and other auxiliary measurements are stored in a special file format.

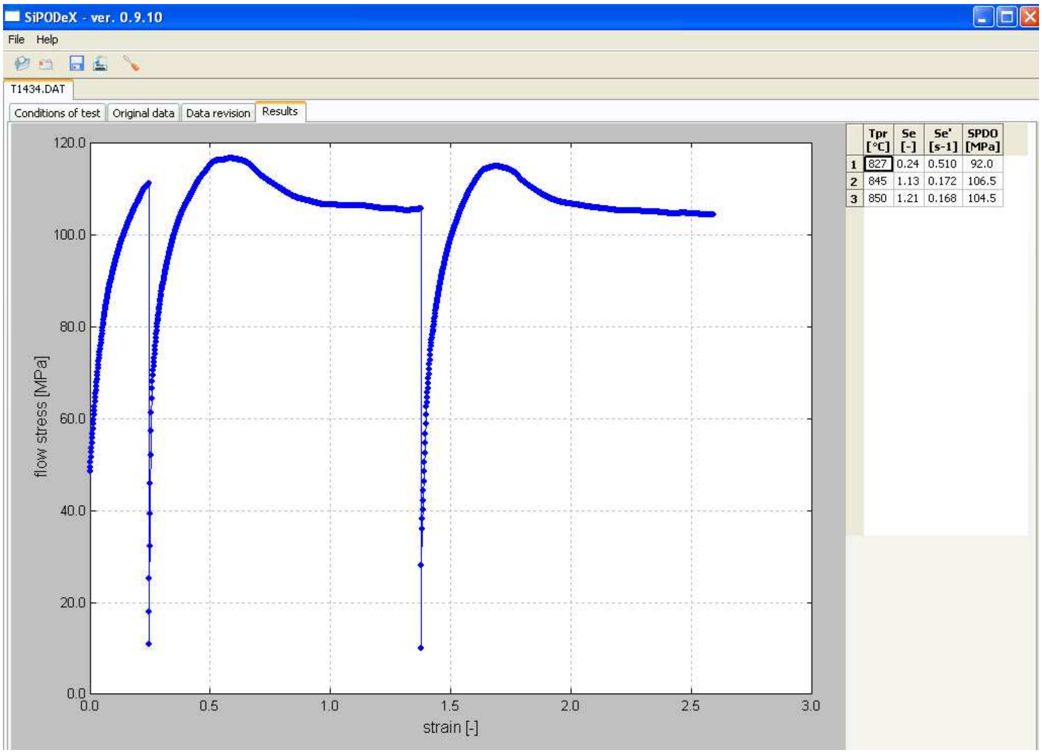

Fig.1 Course of interrupted deformation during torsion obtained by programme SIPoDex

The evaluating programme *pyX* was designed again in the environment of the programming language Python in order to evaluate the degree of softening in between deformations during an interrupted test of final (smoothed) dependencies flow stress σ and strain ε.

The philosophy of work in this programme is divided into two sections. In the first step, there is a curve describing the first deformation chosen. It is the upper one in the figure no.2. The source for this curve can be data taken at a continual or interrupted torsion test, yet always processed by the programme *SiPODeX*. The lower part then defines a curve of the second or –th deformation.

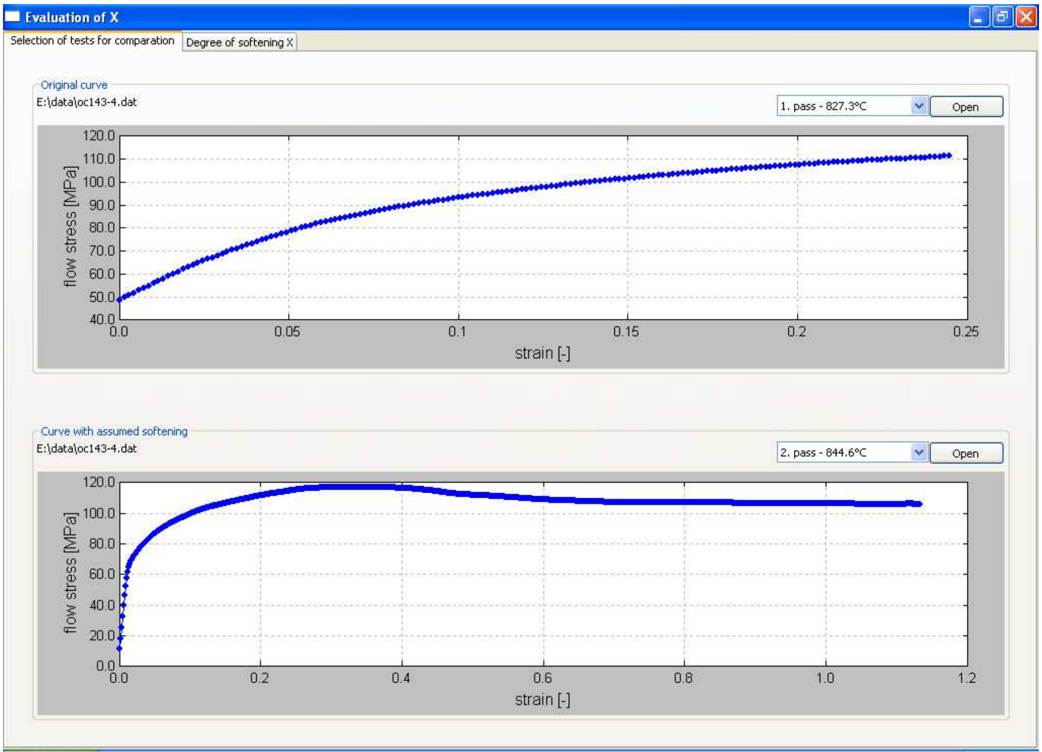

Fig.2 Introductory window of the programme *pyX* with choices of dependencies to evaluate

By choosing the fold “Degree of Softening X”, you get to calculation itself, see figure no.3. This is firstly done automatically with usage of algorithm comparing measurements of the flow stress power of both curves. The operational staff has a possibility to influence the calculation by shifting the fix curve for the following deformation even across the arrows in the area below the diagram. The evaluation itself of the degree of softening X is fully dependent on experience of the operational staff and their subjective capabilities to set both curves into desired alignment. The evaluated value of residual strain ε and the degree of softening X is obviously at immediate disposal in the area above the diagram.

3. Plastometric experiment

Plastometric tests were carried out on low-carbon steel 698 VSZ which is primarily destined for rolling of cold-rolled deep-drawing sheets. The testing device was a torsion plastometer SETRAM-VÍTKOVICE. The steel studied had following composition: 0,007 wt.% C, 0,25 wt.% Mn, 0,02 wt.% Si, 0,009 wt.% P, 0,016 wt.% S, 0,021 wt.% Al, 0,005 wt.% N. The test itself consisted of heating on temperature 1150°C, 10 minute staying at this temperature and then decrease of the temperature on the temperature of constant deformation. Subsequently, three deformations of defined size strain (0,2;1;1) were carried out. The tests were done for two different time break values between the deformations of 1s and 6s.

Figures no.4 and no.5 show all courses of tests until their evaluation in the programme *SiPODeX*. On the assumption of the same deformation intensity in individual reductions, tests 4 and 10 were eliminated from the evaluation. Such a corrected data file is then homogenous for evaluation of the degree of softening by means of the *pyX* programme.

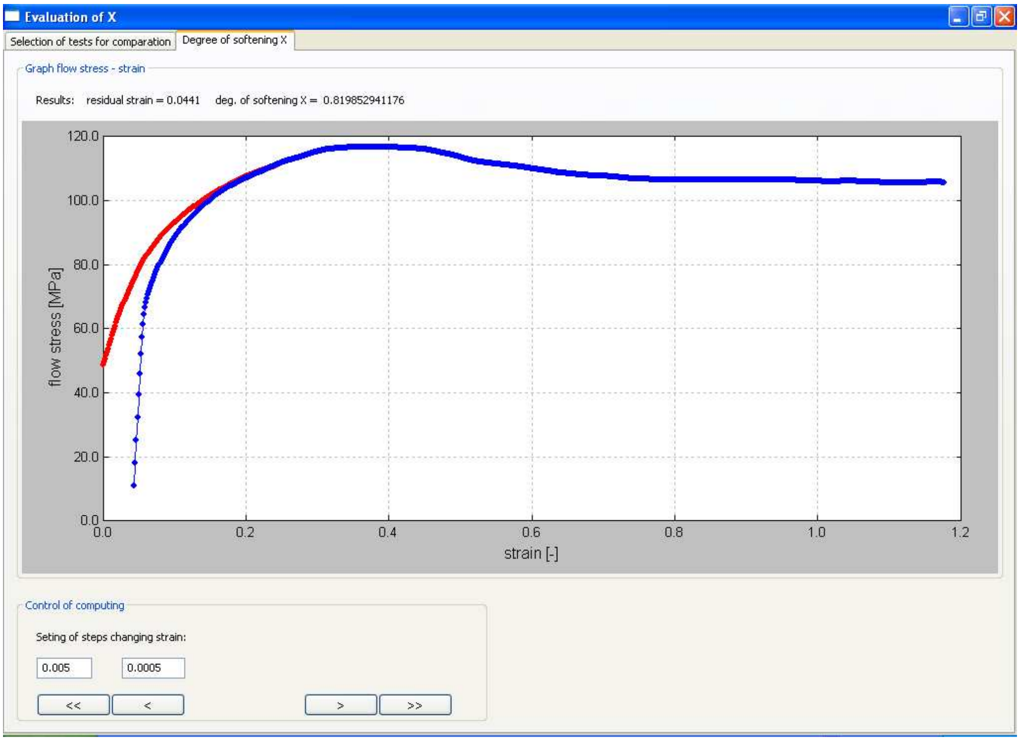

Fig.3 Deformation curve alignment when evaluating the degree of softening X

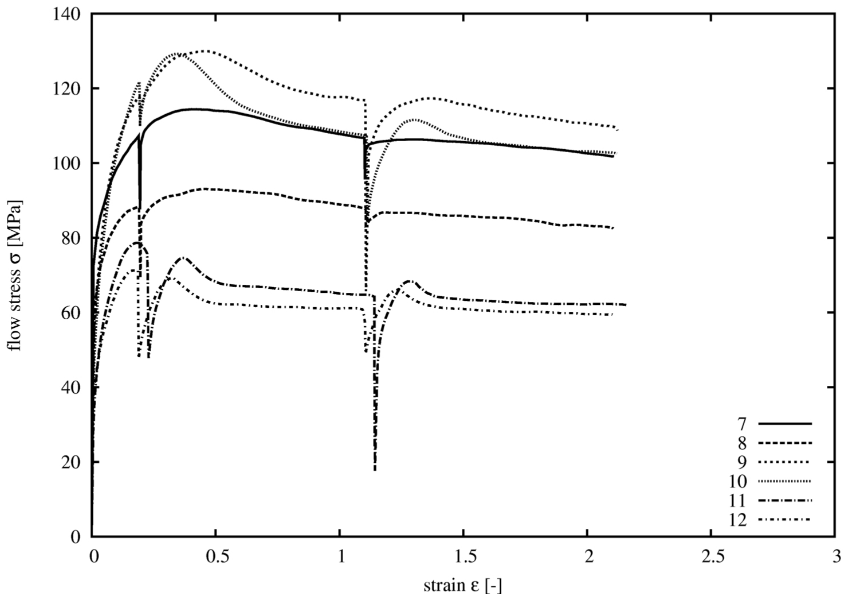

Fig.4 The course of flow stresses at the tests with 1s break between the deformations

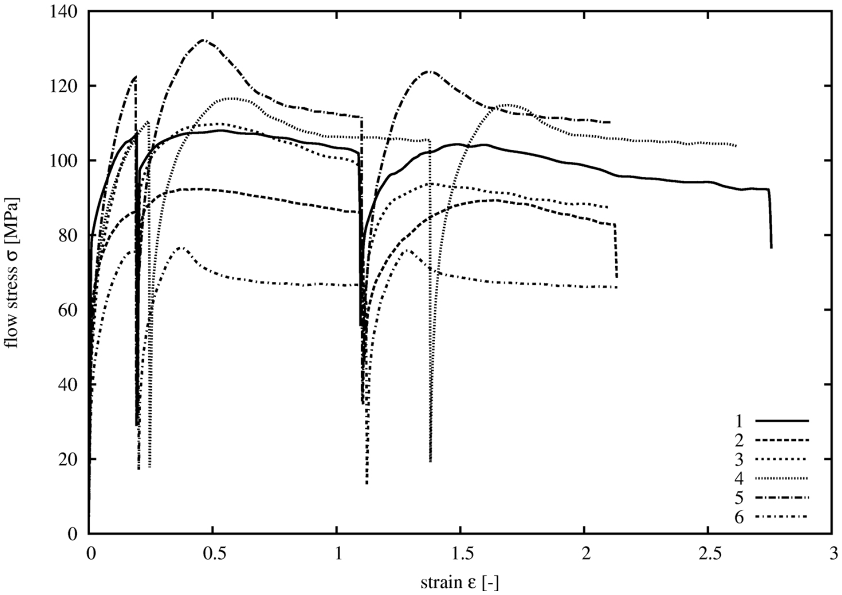

Fig.5 The course of flow stresses at the tests with 6s break between the deformations

4. Evaluation of the degree of softening

Figure no.6 shows the course of the degree of softening in dependency on deformation temperature. At samples with 6s dwell after the first deformation, there was no softening at 766°C, which was probably caused by deformation and interruption in a dual-phase area. This claim should be proved by a metal-graphic study. In a ferritic area (the temperature of the second deformation 719°C), the degree of softening was 0.58. With temperatures over

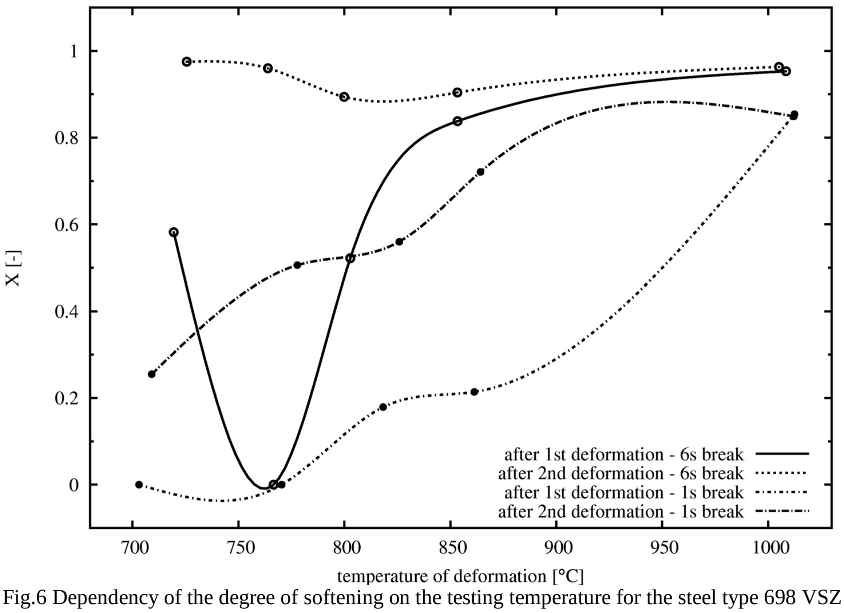

Fig.6 Dependency of the degree of softening on the testing temperature for the steel type 698 VSZ

800°C, we can observe increase of the degree of softening X up to the values close to 1, which suggests full recovery of the steel. We can say for this set of samples that after the second deformation the material is after 6s break nearly recovered, the value of softening X is touching 1.

Samples with the break time 1s did not reach any recovery up to the temperature 800°C and above this temperature the recovery increased with increasing temperature. After the second deformation, all samples experienced increase of softening, which was caused by dynamic recrystallization and higher amount of accumulated energy from previous deformation. Short time, however, did not allow full softening and the dependency curve X on temperature after the second deformation follows the curve after the first deformation.

If we compare the curves of 6s dwell samples (first group) and 1s dwell samples (second group) after the first and second deformation, it is seen that there was not such great softening in the second group as the time for the recovery development was shorter, c. by 5s. An exception is zero softening between the first and second deformation at 766°C and a 6s break. To find out whether it is not a fault measurement, it would be necessary to repeat the test with subsequent metallographic evaluation.

5. Conclusions

We have carried out evaluation of results of torsion tests in the new evaluation programme *pyX* for defining the degree of softening X. The experiment made on a set of low-carbon steel samples that were strained in torsion on the plastometer SETARAM-VÍTKOVICE.

The comparison of the individual tests suggests that factors influencing the degree of softening are e.g. temperature, whose increase means intensifying of softening, the length of the time lag when deformation interrupted, and as there was noticed a higher degree of softening on all samples after second deformations, it is clear that the intensity of softening is influenced by the power of the preceding deformation.

When observing temperature of samples with 1 second time break, it was found out that the degree of softening sharply rose at temperatures over 800°C, which proves previous claim about dependency of recovery on temperature. The most intensive recovery of these samples took place at the temperatures 860-1005°C.

Samples with 6 sec. time break recovered at over 770°C because the material had more time for metadynamic recrystallization. In order to define more precisely the recovery mechanism, it would be necessary to add to the experiment a metallographic analysis of given test.

The evaluation of the results in this work suggests that testing on a developed torsion plastometer hand in hand with the programmes *SiPODeX* and *pyX*, it is possible to study carefully recovery processes during deformations and pauses. However, it assumes deep knowledge of problems and sensibility of the operation staff when evaluating the tests with those new programmes.

Acknowledgement

The work was performed in the framework of solving the research plan MSM 6198910015 (Ministry of Education of the Czech Republic).

Literature

[1] Kliber J.: Stanovení stupně změkčení X u ocelí. In *FORMING 2004*. Štrbské Pleso – Vysoké Tatry : Slovenská technická univerzita v Bratislave, 2004, pp. 109-114.

[2] Schindler I., Kliber J., Bořuta J.: Mathematical description of static recovery of type C-Mn-Mo-Nb-V microalloyed steel. Steel Research, 1991, Vol. 62, No. 6, pp. 266-271.

[3] Kubina T. et al.: Experiences with new software for evaluation of interrupted torsion test. In *FORMING 2006*. Katowice : Politechnika Śląska Katowice, 2006, pp. 95-100.