UTILIZATION OF THE HOT WEDGE TEST IN RESEARCH OF HOT FORMABILITY OF FREE-CUTTING STAINLESS STEELS

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POUŽITÍ KLÍNOVÉ ZKOUŠKY ZA TEPLA PRO VÝZKUM TVAŘITELNOSTI AUTOMATOVÝCH KOROZIVZDORNÝCH OCELÍ

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Abstrakt

Na základě válcování klínových vzorků v laboratorních podmínkách byla vyvinuta nová metodika zkoumání tvařitelnosti materiálu. Klínová zkouška válcováním je vhodná pro rychlé vyhodnocení válcovatelnosti a s následnými metalografickými analýzami i ke studiu vybraných strukturotvorných procesů. Pomoci této zkoušky byla získána kritická velikost deformace do lomu. Výsledky závisí, z vyjímkou termomechanických podmínek, na stavu napjatosti a proto mají často pouze kvalitativní charakter ve vztahu k reálných technologickým procesům. Nicméně podobnost laboratorního a provozního válcování umožňuje výsledky kvantitativně porovnávat a aplikovat v praxi. Protože oceli jsou za tepla většinou natolik plastické, že ani jednorázové výškové úběry nad 70 % při klínové zkoušce válcováním nevedou k praskání, je vhodné zavést při výrobě výchozího vzorku dodatečné úpravy, napomáhající snadnějšímu vzniku trhlin. Tato modifikace spočívá ve vyfrézování svislých vrubů na boční stěně vzorku. Hloubka těchto vrubů je pohyblivá a závisí na typu zkoušeného materiálu. Vruby slouží coby iniciátory trhlin pro zcitlivění aplikované metody zkoušení tvařitelnosti. Vlastní experiment byl proveden na válcovací stolici K350 v konfiguraci duo při různých tvářecích podmínkách. Byly zkoumány dva nové typy vysoce legovaných ocelí. Pro určení geometrických rozměrů vývalků a výpočet deformačních charakteristik byl vyvinut speciální počítačový program KLIN, který pracuje na základě počítačové analýzy obrazu (skenovaný půdorys vývalku). Jeho účelem je vedle zpřesnění výpočtů poskytnout uživateli maximální jednoduchost, komfort a automatizaci všech prací spojených se získáním a výpočtem informací o válcovaném materiálu Po válcování byla provedena metalografická analýza pomocí optického mikroskopu.

Abstract

The new methodology of determination of hot formability of metallic materials was developed, based on application of the wedge rolling test in laboratory conditions. The wedge rolling is suitable for quick evaluation of rollability and in co-operation with the following metallographic analyses for study of selected structure-forming processes as well. By means of this test data on the deformation limit of the structure may be obtained. In both cases the results depend, except for thermodynamic conditions, on stress state and therefore they often have only a qualitative character in relation to real technological processes. However, similarity of the laboratory and operational rolling creates conditions also for a quantitative comparison and application of the results in practice. As steels are in hot state mostly so plastic that not even single height reductions above 70 % during the wedge rolling test lead to cracks, it is advisable to carry out in manufacturing of initial samples additional modifications enabling easier development of cracks. This modification consists in milling out the defined notches on a side wall of the sample. The experiment was made with new types of high-alloyed steels. A special computer program KLIN was developed for determination of geometric dimensions of the rolled stock and calculation of its deformation characteristics, on the basis of the computer raster image analysis – scanned plan of the final rolled material. After taking samples from the rolled material a metallographic analysis of microstructures by means of optical microscopy was carried out.

Keywords: wedge rolling test, free-cutting stainless steel, hot formability

1. Introduction

The wedge rolling test is neither a standard test nor is carried out in accordance with conventional rules of technical practice. Therefore with results of this test all conditions of testing (temperature, speed and geometric dimensions) have always to be stated. During the wedge rolling test a continuous increase of deformation degree up to the selected maximum occurs [1]. By this laboratory method there was studied hot rollability of two free-cutting stainless materials – ferritic steel 17043STi and austenitic steel 17247CuS.

2. Materials and experimental procedures

Based on empirical experience in the Institute of Modelling and Control of Forming Processes at VŠB-TUO, the wedge-shaped samples for testing are generally provided with notches of „V“ shape, always on one of their side walls (Fig. 1) [2]. These notches fulfil the function of initiators for crack development. Samples are rolled in one pass on the plain symmetric rolls. The single-pass rolling of samples in the laboratory mill stand K350 in the arrangement of a two-high mill was used, after heating directly to the forming temperature [3,4].

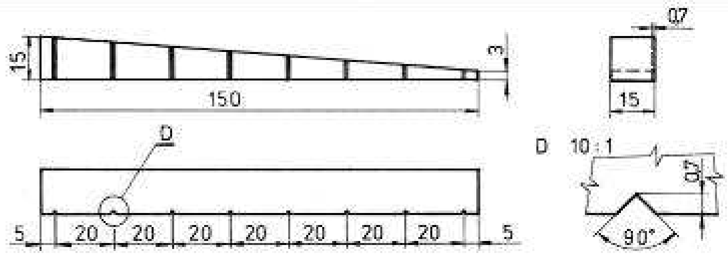


Fig.1 Initial shape of a wedge-shaped sample (side wall and ground plan)

The ferritic steel 17043STi had been heat treated before by the mode 1150 °C / 0.5 h / water, whereas in case of the austenitic steel 17247CuS the annealing mode 1200 °C / 0.5 h / water was chosen. The chemical analysis of the tested steels is given in Table 1.

Table 1 Chemical analysis of the tested steels in wt. %

	C	Mn	Si	P	S	Cu	Ni	Cr	Ti
17 043STi	0,05	0,31	0,11	0,006	0,51	-	-	16,28	0,44
17 247CuS	0,06	0,35	0,17	0,01	0,27	1,42	8,96	17,11	0,44

A test with an austenitic steel at the lowest requested temperature (800 °C) led to so high forces and torques that all screws connecting cardanic joints with spindles were cut off. As only a limited number of samples was available the following procedure had to be selected for further investigation: samples rolled at temperature T = 900 °C (or 800 °C) were first of all shortened to the length L = 112 mm (or 94 mm). It is clear that it was accompanied by achievement of smaller deformation size for these samples, but all experiments were managed from the power and force viewpoint. The rolls with diameter of 140 mm rotated at nominal speed of 110 min^{-1}.

Each sample was immediately after rolling cooled down in a water bath with the aim of fixing of the structure. As development of hardening phases can virtually be excluded in the given steel grades, the rolled products were carefully levelled under a press. Then their plans could be scanned to the form of bit maps which (after some modification and import into a specially developed program KLIN [5,6]) enabled calculation of deformation and speed relations along the length x [mm] of the rolled product. Accuracy of calculation of the relative height reduction ε_h [%], equivalent strain S_e and equivalent strain rate $S_{\acute{e}}$ [s^{-1}] is incomparably higher in applying this approach against the conventional procedure of „manual measurements“. In the case of occurrence of a rolled product with a more pronounced irregular shape the conventional procedure of evaluation of the wedge test cannot virtually be applied at all. An example of shape of the rolled product and evaluated strain/speed parameters are given in Fig. 2. It is necessary to hint that values of S_e and $S_{\acute{e}}$ calculated for the most deformed tail end of the sample and freely extended into the shape of „tongue“ (with possible cracks) should not be taken for certain. It is evident that samples with length of 150 mm underwent the maximum height reduction ca 80 %, whereas samples with length of 112 mm only ca 75 % and samples with length of 94 mm only ca 71 %.

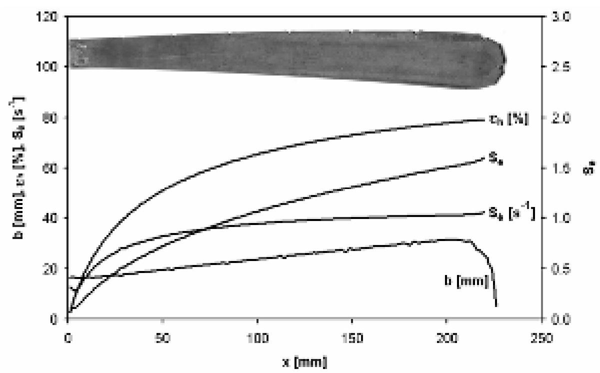


Fig.2 Plan shape of the rolled out wedge and strain/speed relations along the rolling stock (sample No. 94 – steel 17247CuS, 1000 °C)

3. Discussion of results

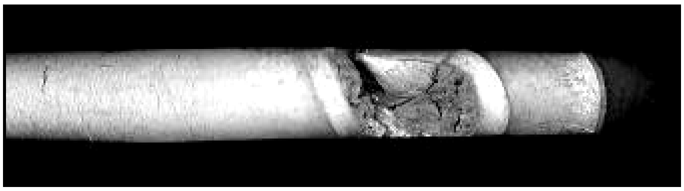
The austenitic steel 17247CuS was characterized by relatively good plastic properties even though a crack occurred at the highest forming temperature 1250 °C. With decreasing rolling temperature frequency of cracks raised – see Table 2 summarizing the achieved results.

In the material corresponding to sample No. 94 (see Fig. 3) the most significant occurrence of cracks initiated by a notch was observed, even cracking of the more formed tail end of the wedge occurred. This sample was different also by the fact that fine cracks were observed, initiated not only by milled notches but also by scratches caused by cutting the other side surface of the sample.

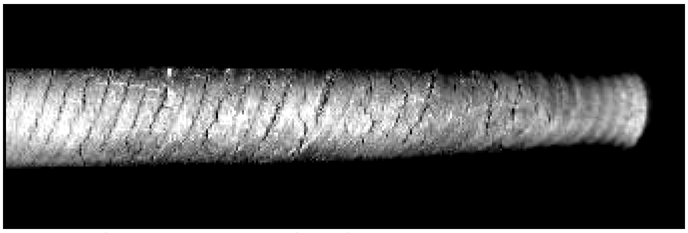
Table 2 Occurrence of cracks in particular rolled out samples near notches V1 to V8 (X = an evident crack; - = absence of notch due to shortening of the sample)

Steel Grade	Sample	L [mm]	T [°C]	V1	V2	V3	V4	V5	V6	V7	V8
17 043STi	81	150	1100								
	82	150	1000					X	X	X	X
	83	112	900					X	X	-	-
	84	94	800				X	X	-	-	-
17 247CuS	91	150	1250						X	X	X
	92	150	1200					X	X	X	X
	93	150	1100				X	X	X	X	X
	94	150	1000			X	X	X	X	X	X
	95	112	900			X	X	X	X	-	-
	96	94	800			X	X	X	-	-	-

The ferritic steel 17043STi (see Fig. 4) was characterized by much better plastic properties. Cracks were not developed at all at the highest forming temperature 1100 °C. With decreasing rolling temperature the number of cracks initiated in the area of notches increased but differences observed at forming temperatures 800 °C to 1000 °C are by no means considerable. The flow of the material spread, appearance of side surfaces and character of cracks are very different as compared with the investigated austenitic steel.



a) notch No. 8



b) fine cracks on side surface of sample without milled notches

Fig.3 Steel 17247CuS – details of cracks after rolling of sample No. 94 (1000 °C)

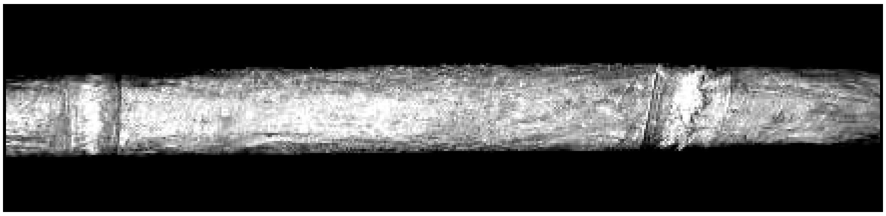
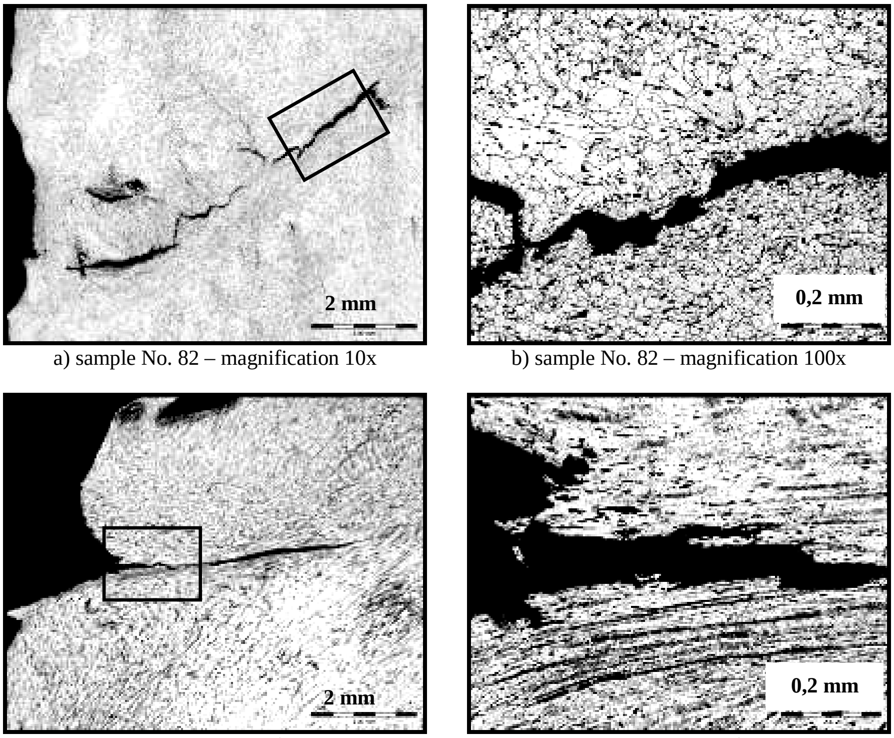


Fig. 4 Steel 17043STi – detail of notches Nos. 4 (left) and 5 of rolled sample No. 84 (800 °C)

Subsequently the rolled out wedges were subjected to investigation by means of the optical microscope. Photographs of the structure were made – metallographic ones in the longitudinal direction, in the area of the last notch near the tail end of the rolled out wedge, i.e. in the area that was subjected to the highest deformation. From the metallographic photos the structure close to a crack was evaluated, as well as influence of deformation on a change of the structure. Figure 5 demonstrates shapes of selected cracks under notches that were subjected to the highest deformation size and in the area marked by the black square (Fig. 5 a,c); a more detailed metallographic analysis of zones close to developed cracks was carried out (Fig. 5 b,d).



a) sample No. 82 – magnification 10x

b) sample No. 82 – magnification 100x

c) sample No. 92 – magnification 10x

d) sample No. 92 – magnification 100x

Fig.5 Metallographic photographs of cracks under last notches – area of wedge with largest deformation

Structure of the sample No. 82 is created purely by ferrite with separated sulphidic inclusions (Fig. 5 b). It is very probable that the main crack was developed under the surface of the material, it does not ascend to surface in the area of the notch. Even a more detailed study of the structure does not indicate that the crack could start at the surface and then was closed by spread of the material. The main crack is accompanied by fine cracks in direction perpendicular to the direction of the propagating crack. The developed crack is created by a mixed (transcrystalline and intercrystalline) tough fracture. In the vicinity of the crack in sample No. 82 (Fig. 5 b) refinement of the structure is observed due to a high reduction rate. The grain is refined by the stress induced recrystallization.

Sample No. 92 has an austenitic structure with enormous occurrence of large sulphidic inclusions. Evident deformation zones are visible in the surroundings of the propagating crack, pronounced by deformed and elongated sulphides (Fig. 5 d); this phenomenon is influenced by a high reduction rate. Fine cracks, perpendicular to the axis of the main crack, occur again.

4. Conclusions

The wedge rolling test has advantages consisting in similarity of its prevailing stress state with the state which can be achieved in real rolling and in a chance of evaluating the influence of very different deformation sizes on the microstructure of a single „hardened“ or annealed (in an appropriate way) sample – these advantages should be used also for explanation of deformation behaviour of investigated steel grades.

Relatively low formability was found out in both two investigated free-cutting steels due to the high content of sulphur, nevertheless differences exist in their deformation behaviour. The resulting structure close to the propagating crack was markedly influenced by this crack. In the surroundings of the crack a refinement of the structure was observed due to the stress induced recrystallization and occurrence of deformation zones that were pronounced by the rolled out and stretched sulphides. As a rule, cracks were created by a tough – both intercrystalline and transcrystalline – failure with visible pits, caused by tearing of sulphides from the material (in samples from the ferritic and also austenitic stainless steel).

It results from a comparison of both steel grades regarding their resistance against crack development that the wedges made of steel 17043STi appear better than the wedges made of austenitic steel 17247CuS. It shows that samples from the ferritic steel have better plastic properties in comparison to the austenitic steel.

Acknowledgements

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