HOT FORMABILITY OF LEDEBURITIC TOOL STEEL X155CrVMo12.1

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TVAŘITELNOST LEDEBURITICKÉ NÁSTROJOVÉ OCELI X155CrVMo12.1 ZA TEPLA

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Abstrakt

Tvařitelnost za tepla ledeburitické nástrojové oceli X155CrVMo12.1, určené k práci za studena, byla studována třemi experimentálními metodami. První z nich spočívala v jednoprůchodovém válcování klínovitých vzorků opatřených na bočních stěnách vruby frézovanými do tvaru V. Tyto vruby plní funkci iniciátorů pro rozvoj trhlin. Pro určování rozměrů hotového vývalku a výpočtu jeho deformačních charakteristik byl využit speciální software, založený na počítačové analýze rastrového obrazu vývalku. Byly porovnávány výsledky klínových válcovacích zkoušek a vysokoteplotních zkoušek tahem. Doplňkové informace byly získány pomocí diferenční termické analýzy (DTA).

Výsledky obou mechanických metod zkoušení vykazují shodné trendy, ukazující na ztrátu soudržnosti studovaného materiálu v oblasti teplot asi nad 1160 °C vlivem přehřátí a spálení – viz výsledky SEM analýz lomových ploch. Nejvyšší válcovatelnost vykázala zkoumaná ocel při teplotě 1050 °C. Hodnoty plasticity vycházející z kontrakce v místě lomu vykazují v celém rozsahu studovaných teplot nízké hodnoty (max. 60 %), při teplotách asi nad 1130 °C pak dochází k zániku plasticity. Výsledky diferenční termické analýzy ukazují na ovlivnění vlastností matrice postupným rozpouštěním vyloučených karbidů, přičemž při teplotách nad 1150 °C je tento děj ukončen.

Provedené experimenty potvrdily sníženou tvařitelnost zkoumané ledeburitické nástrojové oceli 155CrVMo12.1 za tepla a vedly k návrhu optimalizace tvářecích teplot. Zatímco běžně doporučované jsou pro tuto ocel teploty 1050 – 850 °C, z hlediska plastických vlastností ukazují provedené experimenty reálnou možnost zvýšit válcovací teploty až o 100 °C.

Abstract

Hot formability of the ledeburitic tool steel X155CrVMo12.1, which is determined for cold working, was investigated by means of three (3) methods. The first of them consisted in one-pass rolling of wedge-shaped samples provided with V-shape notches, produced by milling, on their side walls. These notches function as initiators for crack development. The special software, based on the computer raster image analysis of the rolled stock, was used for determination of geometric dimensions of the final rolled stock and calculation of its deformation characteristics. The results of wedge-shaped rolled samples were compared with those obtained by high-temperature tensile tests. Additional information was gained by means of the differential thermal analysis (DTA).

Results of both mechanical test methods exhibit identical trends, showing a loss of cohesiveness of the investigated material in the temperature region above ca 1160 °C due to overheating and burning – see results of SEM analysis of fracture surfaces. The highest rollability was found with a sample of the investigated steel at the temperature of 1050 °C. Plasticity values, based on reduction of area in the place of fracture, are low (max. 60 %) in the whole range of the studied temperatures, at temperatures above ca 1130 °C no plasticity can be registered. Results of the differential thermal analysis demonstrate an influence of the matrix properties by progressive dissolving of the precipitated carbides; this process is finalized at temperatures above 1150 °C.

The executed experiments confirmed a reduced hot formability of the ledeburitic tool steel 155CrVMo12.1 and led to a proposal of optimization of forming temperatures. Whereas normally recommended temperatures for this steel are 1050 – 850 °C, the carried out experiments show that with regard to plastic properties a real chance of increasing rolling temperatures by up to 100 °C exists.

Keywords: tool steel, hot formability, tensile test, DTA, rolling temperature

1. Introduction

The ledeburitic tool high-alloyed Cr-V-Mo steel X155CrVMo12.1 is used for tools determined for cutting and cold working (e.g. knives of table shears, tools for pushing-through, drawing dies, swages, plain rolls and grooved rolls), strongly strained moulds (e.g. for forming of plastics) and cutting tools for machining of materials with low strength [1]. This steel exhibits high strength, wear resistance, toughness and dimension stability at the room temperature [2]. The task of the presented work was to study deformation behaviour and hot technological formability of this material by means of two methods of investigation of plastic properties, namely laboratory rolling and measurement of strength and plastic properties at increased temperatures by tensile test. The main aim was to compare results of these available experimental methods and evaluate their contribution for optimisation of forming temperatures of the investigated steel with low formability.

2. Experimental program

The investigated material had the following chemical composition in wt %: 1.56 C – 0.45 Mn – 0.28 Si – 11.2 Cr – 0.25 Ni – 0.67 Mo – 0.94 V. Results of the differential thermal analysis (DTA – see e.g. [3]) show that phase transformations in intervals of 560 – 840 °C (α-ferrite → austenite) and 1237 – 1404 °C (austenite → δ-ferrite + molten metal) are in progress in the investigated material. In the temperature region 840 – 1230 °C a progressive process is running, with no thermal effects, which corresponds to dissolving of carbidic particles in the metallic matrix – see Fig. 1.

Wedge-shaped samples with length of 110 mm, width of 14.8 mm and height that varied in the range of 4 to 12 mm were manufactured from the delivered material by cutting and milling. Vertical notches of V-shape (with depth of 0.5 mm) were machined by milling into one of vertical side surfaces of each sample. These notches served as initiators of cracking for making the applied method of formability testing sensitive. A set of samples was hot rolled in the laboratory rolling mill K350, arranged as a two-high mill stand with plain steel rolls of nominal diameter of 140 mm [4]. In the first phase the samples were heated to temperature 1060 °C and then rolled in the temperature range of 1050 – 1080 °C. The second, additional, phase included the high-temperature deformation of samples that were heated directly to the rolling temperature (1100 – 1250 °C).

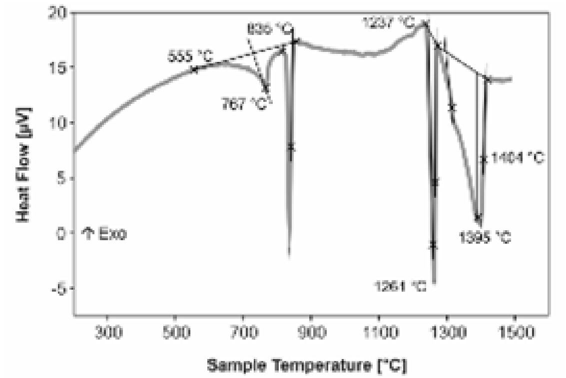


Fig.1 Results of DTA (temperature increase at speed of 7 °C/min)

After carrying out the wedge test the plan views (section plans) of particular rolled stocks were scanned and the spread and deformation relations along their length x [mm] were determined by a specially developed program KLIN. An example of information that was obtained by means of the program KLIN is illustrated in Fig. 2. The strains corresponding to relevant places of individual notches, produced by milling, may be derived from the given graph. Details about the applied method of carrying out the wedge tests and computer evaluation of their results are given e.g. in [5, 6].

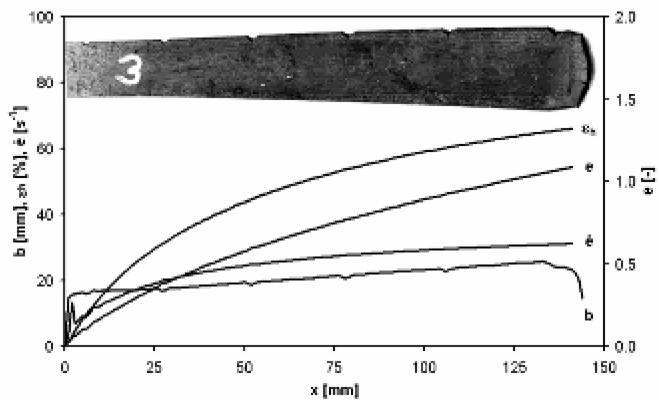


Fig.2 Section plan of rolled sample at temperature of 990 °C and corresponding data on deformation conditions along the rolled stock x [mm] (b [mm] is width of sample, ε_h [%] is relative height reduction, e [-] is total equivalent strain, $\dot{e}$ [s^{-1}] is mean equivalent strain rate in given cross section)

The high-temperature tensile tests were executed on the tensile testing machine TSM 20 of the company INOVA Praha, which consists of the loading frame and a dynamometer module of 20 kN. Displacement of the suspension bridge and hence speed of loading are adjustable in the range of 0.001 mm/min to 500 mm/min. The equipment proper, adjustment (setting) of the course of testing and recording of measured data are carried out by computer [7]. The equipment with the original software makes it possible to perform the tensile test according to ČSN 42 0310 and so called general test, which enables to set testing conditions in broad bounds in six separated stages. The test under higher temperatures is implemented as a general one. The software is completed by calculation of the fracture energy. The tensile facility itself is equipped with the furnace with temperature control, measurement and registration of the sample temperature. The acoustic emission sensor, which records the released elastic waves in the frequency band of 30 – 400 kHz, can be added to the tensile testing system.

3. Discussion of results

3.1 Wedge rolling tests

Technological formability was evaluated on the basis of crack occurrence on side surfaces of rolled stocks. The most favourable rollability was found in the sample that was formed at temperature 1050 °C – cracks were formed in the case of notches with the highest deformation (sequential number 5 and 6), in a lesser extent also on the face of the rolled stock (in place of the greatest height reductions). All other samples that were rolled at lower temperatures exhibited more pronounced cracks on faces of rolled products and also in the case of notches No. 4, 5 and 6 – see Fig. 3 and 4. Samples that were rolled at the temperature 870 – 850 °C had cracks already also on side surfaces in places without notches, which documented lowered plastic properties of the investigated material. It is unambiguous that the given ledeburitic steel is suitable to form under high temperatures (best of all above 1000 °C). With temperatures roughly above 1150 °C rollability of the material was already fiercely falling down due to overheating. At temperature 1250 °C burning of steel resulted in the total loss of plastic properties of the investigated steel – see Fig. 5.

Fig.3 Detail of cracks on side surfaces of the rolled stocks; areas with the highest deformation –notches with Nos. 4 (left), 5 and 6 (right)

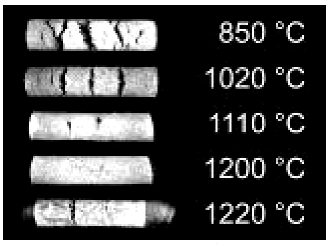
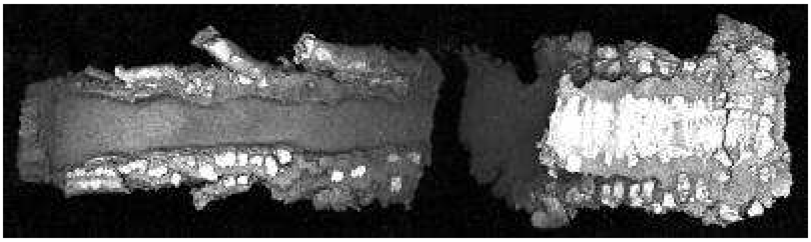
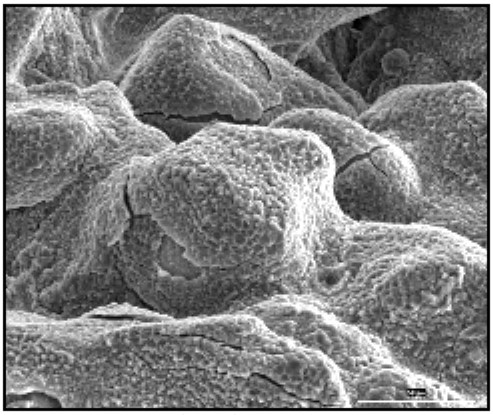


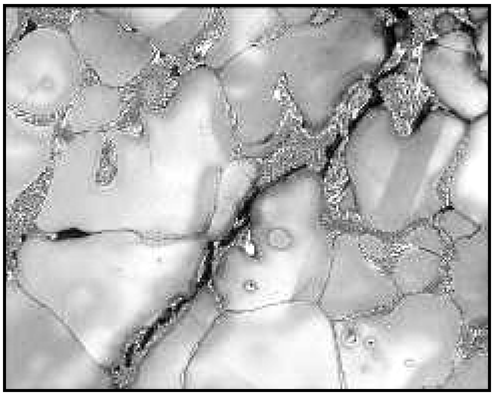
Fig.4 Faces of the rolled stocks – place of the greatest height reduction



a) sample broken into pieces by rolling



b) surface of grains – SEM



c) overheating and intergranular cracking estimated by metallography (magnification 200x)

Fig.5 Shape and structure of the sample rolled at 1250 °C

Interesting knowledge can also be gained from power/force parameters of rolling of wedge-shaped samples. Reading of roll force *F* [kN] for time of deformation, e.g. 0.1 s, made it possible to derive a simple relation for expression of temperature dependence of roll forces in the form which is visible from Fig. 6. The derived relation is valid only for the area of work hardening of the material and can be utilized for a quick prediction of influence of temperature *T* [°C] on deformation resistance, or roll forces, but exclusively for temperatures 850 to ca 1160 °C. Decrease of roll forces with higher temperatures indicates a fierce fall of plastic properties of the investigated steel.

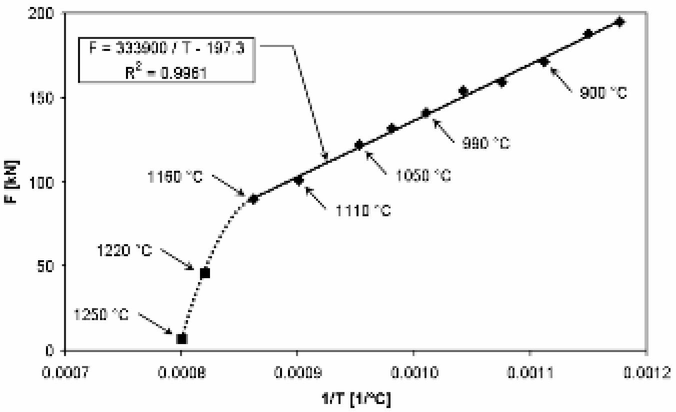


Fig. 6 Regression dependence of roll force on reciprocal temperature

3.2 High-temperature tensile tests

Strength and plastic properties of steel X155CrVMo12.1, measured at speed of displacement of the cross arm of 6 mm/min, are given in Fig. **7**. Strength in temperature region of 800 – 1300 °C decreases quite uniformly, plasticity – judged based on the reduction of area in the place of fracture – increases mildly in the area of temperatures up to 900 °C, with higher temperatures to 1130 °C is constant, however, reaches only 60 %. With still higher temperatures (1200 °C) the plastic properties drop substantially and gradually disappear.

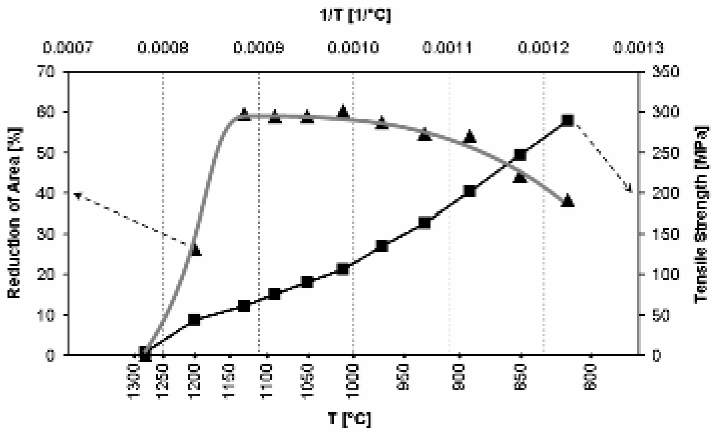


Fig.7 Temperature relation of plastic properties determined by tensile test

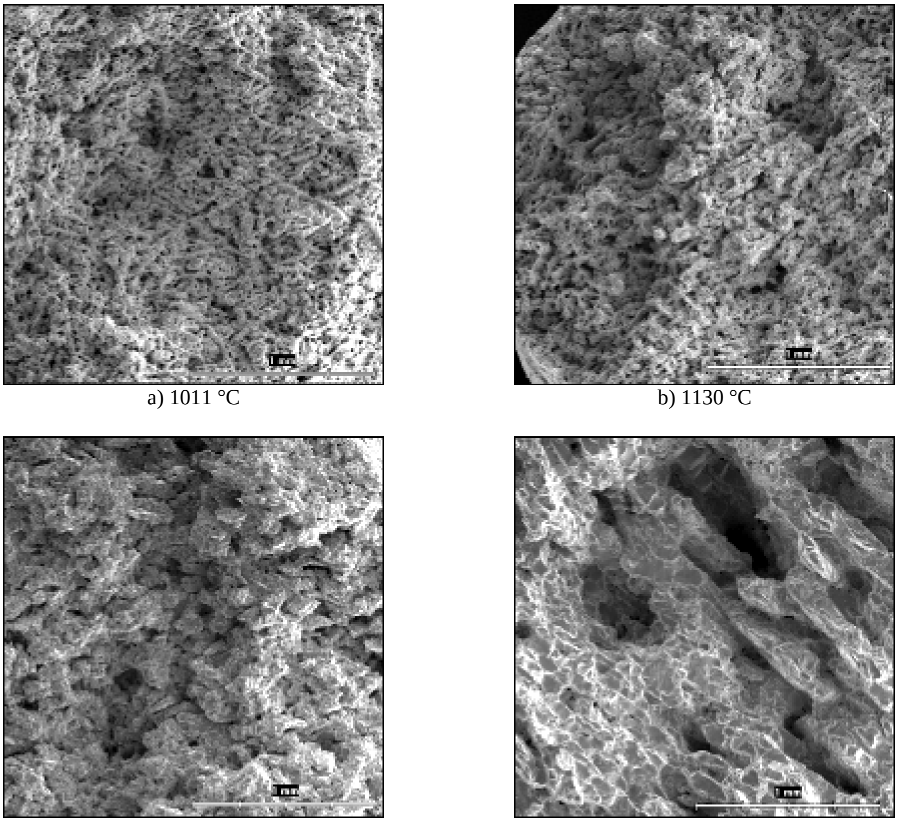
Evaluation of fracture surfaces of the tensile tested samples shows some changes of their appearance in the course of monitored temperatures – as follows from Fig. 8. With temperatures to 1130 °C the fracture area exhibits rather the ductile fracture, with a pronounced pit character. With rising temperature only the size of pits has been changing, which corresponds to coarsening of precipitated carbides with the rising temperature. Samples, which exhibit failure at temperatures above 1200 °C, have the brittle fracture, occurring along plain surfaces. Gradually marks of overheating (grain coarsening) and burning of the material (melting down the grain boundaries) are visible.

4. Summary

Results of both mechanical testing methods exhibit identical trends, showing the loss of cohesiveness of the investigated material in the temperature region above ca 1560 °C – compare graphs in Figs. 6 and 7. Technological formability, determined by means of wedge rolling tests, was evaluated on the basis of crack occurrence on side surfaces, or faces (unlimited spread), of rolled stocks. The given material features generally a restricted suitability for forming, the sample that was deformed at temperature 1050 °C had a relatively highest rollability. It is clear that the given ledeburitic steel is suitable for forming in high temperatures (best of all above 1000 °C), of course not in the area of overheating and burning (above ca 1160 °C) when rollability drops steeply.

These conclusions confirm results of the tensile tests. Plasticity values, based on reduction of area in the place of fracture, are low (max. 60 %) in the whole range of the studied temperatures, at temperatures above ca 1130 °C no plasticity already occurs. Results of DTA demonstrate an influence of the matrix properties by progressive dissolving of the precipitated carbides; this process is finalized at temperatures above 1150 °C.

The normally recommended forming temperatures for this steel are 1050 – 850 °C [1]. However, from viewpoint of formability the carried out experiments show the real chance of increasing the rolling temperatures by up to ca 100 °C.



a) 1011 °C b) 1130 °C

c) 1200 °C d) 1281 °C

Fig.8 Fracture surfaces in case of selected tensile tested samples – SEM

The performed experiments confirmed a lowered hot formability of the ledeburitic tool steel 155CrVMo12.1 and led to the recommendation of optimum forming temperatures. Results of the wedge rolling tests and tensile tests are very comparable as far as quality is concerned (when trends of strength and plastic properties are evaluated), their quantitative comparing is naturally very difficult.

Acknowledgements

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