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Department of Materials Engineering

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23rd International Seminar of Ph.D. Students

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prof. Dr. Ing. Milan Sága
Dean of the Faculty of Mechanical Engineering of the University of Žilina

Western Tatras - Zuberec, Slovakia
January 24 – 26, 2018

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MECHANICAL PROPERTIES OF HOT-WORK TOOL STEEL AT ELEVATED TEMPERATURES

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1. Introduction

With constant advancements in the field of mechanical engineering, there is a growing need for high strength tool steels, which could endure the high level of stresses and could be reliable in exploitation. The high quality steel H11- designation by AISI (X38CrMoV5-1 by DIN and EN), analyzed in our previous investigation [1], is aimed for manufacturing the tools, mostly for hot forging and extrusion. During the exploitation, those parts endure extreme pressures what leads to high wear and thermal fatigue. Since the forging process is mostly done at high temperatures, in order to reduce the strength of the forged material, the tool material has also to cope with the high temperature shocks with every stroke of the tool. In order to reduce the influence of the high temperatures on the tool, it is preheated to temperatures between 250 °C and 300 °C. In such a way the temperature gradient between the tool and the heated working piece is decreased, thus the temperature shocks to the tool are reduced. However, despite that, the pressures that the tool is subjected to are very high, so there exists a tendency to select the higher quality material, which would possess good stability primarily of tensile properties at elevated temperatures. For that reason, the authors of this paper were set to investigate the influence of the temperature increase on mechanical properties of the considered steel, trying to determine the limiting temperature to which the material can be heated without compomising the tool's integrity during the forging.

The tool life is also an element that affects the quality of the forged pieces, as too high and intensive wear/damage of the dies and stamps can cause a change in the geometry of the manufactured product, and any surface faults (cracks, defects) present on the forged product.

The similar problems were considered by authors of [2-3], which were investigating the possibilities of applying various methods with the purpose of increasing the life of the forging tools. They concluded that the compressive stresses higher than 1000 MPa and temperatures of about 800 °C appear at the tool surface and have shown the ways of solving many problems related to a short tool life.

Similarly to that, authors of [4] have analyzed the effect of loading cycles on behavior of the AISI H11 tool steel, commonly used for aluminum extrusion dies, working at high temperatures and under high, cyclic stresses. Tests were performed on a Gleeble thermomechanical simulator by heating the specimen using the Joule's effect and by applying loading for up to 6.30 h or until the specimen's failure. The displacements during the tests at 380, 490, 540 and 580 °C and under the average stresses of 400, 600 and 800 MPa, were determined. The results have shown that the test could physically simulate the cyclic loading on the hollow die during the aluminum extrusion and that the creep conditions represented the most severe working conditions. In addition, the tests could reveal the interaction between the creep and fatigue mechanisms.

Authors in [5] also analyzed the thermal fatigue of tools made of this steel but in temperature range 100 °C to 650 °C.

The objective of this research was to show the influence of the elevated temperatures on the tensile properties of the X38CrMoV5-1 steel and to establish the maximum temperaure at which it still possesses the acceptable properties. The tests were conducted according to appropriate standards on cylindrical samples and hydraulic testing machine equipped by the heating chamber.

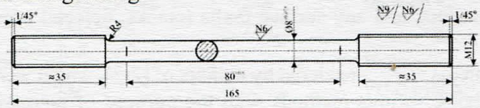
2. Preparation of samples

The 15 mm thick plate was used for preparation of samples. The plate was heat treated according to the proposed regime. The heat treatment technology assumed quenching and tempering at specific temperatures in order to obtain certain mechanical properties and structure, as same as those of the forging tools in the production process. The heat treatment regime was as follows:

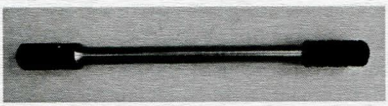
- heating up to 800 °C, pause, heating up to 1040 °C, heating through for 1 h and then quenching in oil at 40 °C. The quenching has to be as intensive as possible. Obtained hardness was ~ 55 HRC.
- tempering at 580 °C, heating through for 1 h, cooling within the furnace up to 300 °C and then in the air.

After the heat treatment, the hardness measurements have shown that hardness was about 45–48 HRC, what were the expected values and in fact, the hardness levels below 45 HRC are of no interest for steel's application.

According to some steel producers [6], expected tensile strength at room temperature, for that level of hardness, is $R_m \approx 1800$ MPa. Samples were prepared by turning with a diamond cutting tool and grinding.



a) drawing



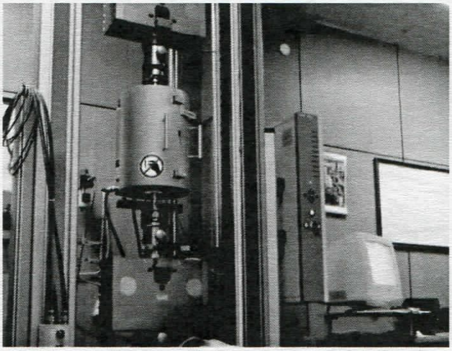
b) real sample

Fig. 1 *Appearance of a sample for tensile testing*

Specimens were cylindrical and were prepared according to appropriate standards [7]. Drawing of a specimen, as well as appearance of one prepared specimen are shown in

Fig. 1. Experimental determination of mechanical properties at elevated temperatures was performed on a universal testing machine Zwick Roell Z100, equipped with a special furnace for specimens heating, as shown in Fig. 2. Two test specimens were prepared for each testing temperature.

The tests were executed at 20 ºC, 300 ºC, 400 ºC, 500 ºC, 600 ºC, 650 ºC and 700 ºC.



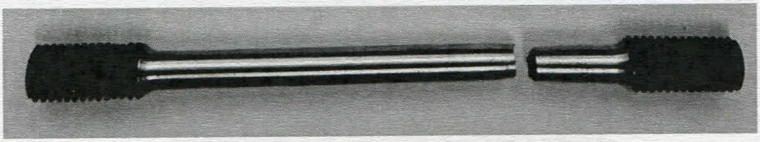
a) sample in the machine jaws

b) unit for control of the testing temperature

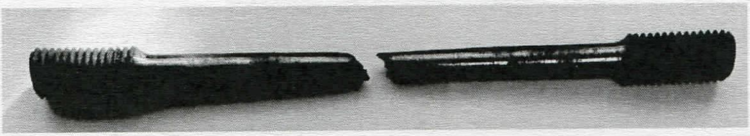
Fig. 2 *Appearance of a testing machine*

3. Results and discussion

Appearance of fractured samples is shown in Fig. 3. Obtained results are presented in Tab. 1 and as diagrams in Fig. 4. Analysis of those results shows that this steel possesses extremely high strength, but its plasticity is very small. Testing of the X38CrMoV5-1 tool steel has shown that a significant decrease in mechanical properties occurs at the temperatures higher than 650 °C (Fig. 4). Actually, the decrease of properties occurs already at 600 °C, however considering that the forged pieces are preheated prior to forging and that their strength in the hot condition is low anyway (usually it does not exceed 200 MPa), properties of this steel at that temperature can be considered as sufficient. The material strength decrease with increasing temperature is expected and normal, since the structure softening and recrystallization occur at that point.



a) at 20 °C



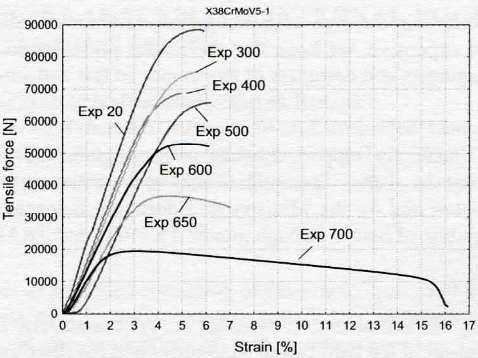
b) at 700 °C

***Fig. 3** Appearance of fractured samples*

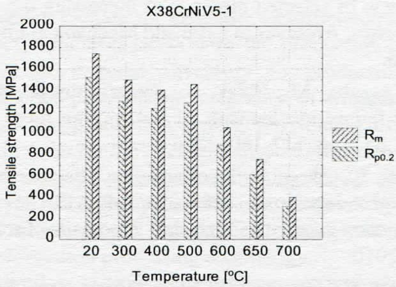
***Tab. 1** Experimental results obtained by tensile testing*

Steel	Sample No.	Testing temperature °C	Yield stress $R_{p0,2}$, MPa	Tensile strength R_m, MPa	Elongation at maximal force A_m, %	Elongation at fracture A, %
X38CrMoV5-1	1	20	1574	1806	1.62	1.85
	2	300	1300	1497	1.22	1.22
	3	400	1231	1401	1.33	1.42
	4	500	1151	1344	1.52	1.57
	5	600	909	1081	1.61	2.7
	6	650	614	756	1.51	4.1
	7	700	312	396	2.20	20.2

Various research by experts in the field of material properties and bulk machining have established that the tool surface is heated up to temperature levels between 500 °C and 550 °C, thus one can state that this steel can definitely be used for manufacturing the tools for hot forging.



a) force vs. strain



b) histogram of obtained properties at elevated temperatures [2]

***Fig. 4** Tensile test results*

4. Conclusions

The results obtained in this paper show the influence of elevated temperatures on mechanical properties of the steel X38CrMoV5-1. Due to the supposed applications of this steel, the samples were tested within the temperature range 20 ºC to 700 ºC. The obtained results have shown that this steel's mechanical properties are high and that they remain as such all the way up to temperatures of 550 ºC to 600 ºC, when the decrease of the properties occurs. Considering that this steel is aimed for manufacturing the tools for the hot forging, as well as that they are preheated prior to forging to temperatures between 250 ºC to 300 ºC, one can reliably state that the strength level of this steel is sufficient for the safe tool exploitation.

Taking into account that the type of investigation, conducted within this research, is time-consuming and expensive, we hope that the results presented in this paper will be useful for process engineers and designers of tools made of this and similar steels.

Acknowledgement
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