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RESEARCH INTO POSSIBILITIES OF REDUCING THE X155CrVMo12-1 TOOL STEEL FRAGILITY

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This research varies the parameters of austenitization and quenching of the tool steel X155CrVMo12-1. It also focuses on investigation of the structure, hardness and impact energy. It was determined that the cracks were generally intercrystalline, with carbide deposition. It was observed that quenching at the temperature interval from ≈ 700 °C to ≈ 600 °C, at a speed greater than 15 °C/s, achieved higher impact energy with about the same hardness. It was concluded that prevention of carbide coalescence had influence on the reduction of steel fragility.

Key words: X155CrVMo12-1 steel, fragility, cracks, structure, hardness

INTRODUCTION

Ledeburitic cold-work tool steel is fragile because of high portion of alloy elements [1]. The resistance of high-alloyed tool steel X155CrVMo12-1 to impact load may vary in dependence to the performed heat treatment [2]. After hardening and tempering, this steel is characterized by high hardness and wear resistance [3, 4]. However, the properties of this steel are significantly influenced by structure anisotropy [5]. Under impact load, especially in tools, cracks can occur and coalesce to consequently cause one part of the work surface to tear off. The aim of this research was to determine which parameters of austenitization, quenching speed and tempering temperature could influence the toughness while maintaining the high hardness required for the tool resistance to wear.

ASSESSMENT OF CONDITIONS

As a typical example, the research was performed on the damage caused on the tool for manufacture of nails. The tool was made out of two pieces, composed of two jaws. The Figure 1 presents the tool damaged after shorter service time.

The Figure 2 presents characteristic crack on the tool work surface.

After visual control, there were characteristic parts of the tool selected and the test samples were cut out. Detailed metallographic inspection showed expressed advancement of cracks from the surface at the point of the rounded slot for holding the nail head, the Figure 3a.

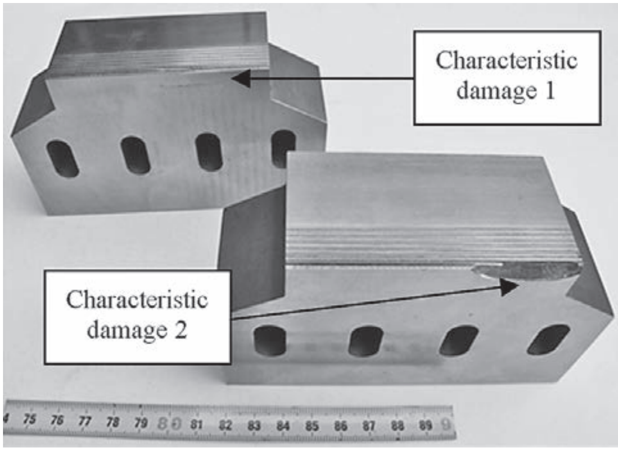


Figure 1 Nails making tool, jaws damaged while service

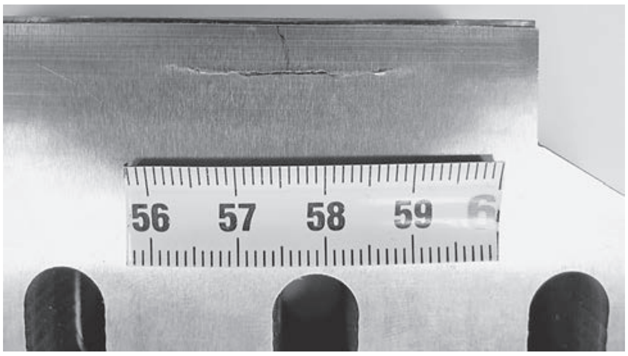
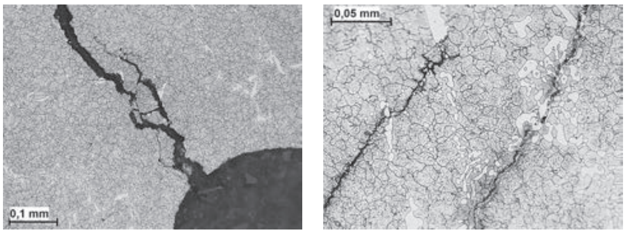


Figure 2 Characteristic cracks at work surface of the jaw 1

The cracks were present also toward the tool middle, the Figure 3b. It is noticed that the progression was intercrystalline, mostly along the carbides that were arranged by coalescence causing their “concretion”.

Surface hardness was measured on both jaws, the values of which ranged from 60 to 63 HRC. Semi-micro hardness was measured from the surface to the core. It was determined that the measured values varied from ≈ 860 HV1 at a depth of 0,5 mm to ≈ 770 HV1 at a depth

V. Marušić (vmarusic@sfsb.hr), A. Milinović, I. Opačak,
I. Putnik. Faculty of Mechanical Engineering in Slavonski Brod, J. J. Strossmayer University of Osijek, CROATIA.



a) b)

Figure 3 Characteristic cracks on the tool part a) crack start; b) crack progression toward the middle of the tool

of 15 mm from the surface. This indicates good hardenability of the tool. It was concluded that the presence of cracks at the transversal cross-section of the tool was most likely a consequence of dynamic stresses that progressed relatively intensively because of the fragility of carbides distributed by coalescence. Due to joining of such cracks, local parts of the work surface were torn off.

EXPERIMENT PLAN

The experiment was performed on the base material X155CrVMo12-1, of round cross section ø15 mm, one annealed rod. The chemical composition was overviewed in the Table 1. It was determined that the steel corresponds to the declaration [6]. Testing of the structure was performed on one sample before the heat treatment.

Table 1 **Chemical composition of the sample X155CrVMo12-1**

Share of elements / %						
C	Cr	V	Mo	Ni	Si	Mn
1,58	11,87	0,89	0,76	0,18	0,35	0,38

As of the delivered state, it was determined that the ferrite-pearlite structure had present carbides $(Cr, Fe)_7C_3$ eutectoid, secondary and eutectic [4]. For the purpose of testing the toughness, the test samples were prepared in the following dimensions: 10 x 10 x 55 mm, depth of the "U" slot 2 mm. Each combination of heat treatment parameters was tested on 5 samples.

The temperature of austenitization υ_a and temperature of tempering υ_p were selected for varying. Oil was selected as a means of quenching. Furnace temperature was additionally controlled by NiCrNi thermocouple connected to a measuring device used for recording of parameters: temperature - time.

The following heat treatment parameters were selected:

- temperature of pre-heating: first υ_{pr1} = 670 ˚C, second υ_{pr2} = 870 ˚C, holding 10 minutes;
- temperature of austenitization: υ_{a1} = 1 030 ˚C and υ_{a2} = 1 060 ˚C, holding 30 minutes;
- temperature of tempering: υ_{p1} = 220 ˚C and υ_{p12} = 190 ˚C; υ_{p2} = 400 ˚C and υ_{p21} = 370 ˚C and υ_{p3} = 500 ˚C and υ_{p31} = 470 ˚C, holding at the temperature 1 h, slow air-cooling.

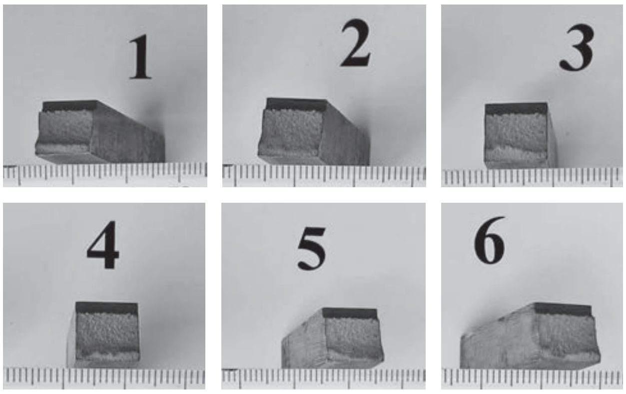


Figure 4 Characteristic appearance of broken sample surfaces for toughness

Table 2 **Results of testing the surface hardness and toughness after heat treatment**

Heat treatment parameters / ˚C		Mean value of 5 test samples	
Austenitization / 30´	Tempering / 1 h	Hardness / HRC	Toughness / J/cm²
υ_{a1} = 1 030	υ_{p1} = 220	59	13
	υ_{p12} = 190	61	11
υ_{a2} = 1 060	υ_{p1} = 220	57	10
	υ_{p12} = 190	58	12
υ_{a1} = 1 030	υ_{p2} = 400	56	18
	υ_{p21} = 370	55	16
υ_{a2} = 1 060	υ_{p2} = 400	55	15
	υ_{p21} = 370	57	14
υ_{a1} = 1 030	υ_{p3} = 500	54	9
	υ_{p31} = 470	56	8
υ_{a2} = 1 060	υ_{p3} = 500	56	5
	υ_{p31} = 470	57	7

RESEARCH RESULTS

Due to the steel specificity, i.e. its good hardenability, the testing was performed at the impact energy of 150 J. Toughness J/cm² was determined by reading the impact. The Figure 4 presents characteristic appearance of the broken surfaces of test samples. On cross-sections, values of hardness HV0,5 were measured from the surface to the core.

Values measured on all tested samples ranged from 820 to 850 HV0,5 at a depth of 0,5 mm from the surface, with gradual decrease to 760 - 780 HV0,5 at a depth of 15 mm from the surface.

The Table 2 overviews the results of measured surface hardness HRC and of toughness calculated from the impact energy.

ANALYSIS OF RESEARCH RESULTS

The research results confirmed that:

- achieved values of surface hardness were depending on the temperature of tempering, ranging from ≈ 60 HRC at tempering to around 200 °C, around

58 HRC at tempering to around 500 °C to around 56 HRC at tempering to around 400 °C,

- results of hardness HV1 at the transversal cross-section were from 820 ÷ 850 HV0,5 at the surface to 760 ÷ 780 HV0,5 at a depth of 15 mm from the surface, indicating good, almost complete hardenability,
- within the same quenching conditions, temperatures of austenitization did not have significant influence on the values of surface hardness,
- the highest toughness was achieved by tempering at a temperature of around 400 °C, while maintaining satisfactory surface hardness.

CONCLUSION

It is observed that the temperature of austenitization did not have significant influence on the toughness. The υ_a = 1 030 °C is recommended, as this temperature with tempering of υ_p = 400 °C contributes to two or even three times higher toughness. Therefore, it is not recommended to perform tempering at 200 °C, and especially not at 500 °C. The steel X155CrVMo12-1 is susceptible to occurrence and accumulation of carbides at the temperature interval from ≈ 700 °C to ≈ 600 °C. Oil quenching achieved cooling speed greater than 15 °C/s and reduced the risk of bainite formation into the grain interior, as well as formation of martensite around these grains.

Nevertheless, there is still a perceived danger of negative influence of residual austenite. Further research should focus on prevention of carbide coalescence by thermal cyclic treatment and to achieve complete martensitic transformation by additional subcooling.

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Note: Responsible translator: Martina Šuto, MA in English and German language, University of Osijek, Osijek, Croatia