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Influence of the V microaddition on the structure and mechanical properties of 60CrV7 spring steel

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Properties

ABSTRACT

Purpose: Influence of vanadium microaddition on structure and mechanical properties of the constructional spring steel was investigated.
Design/methodology/approach: Metallography, transmission electron microscope, tensile test, hardness measurements have been used.
Findings: Microaddition of V introduced to the steel allows to obtain the fine-grained structure, and gives elastic elements obtaining: apparent elastic limit $Rp_{0.05}$ over 1800 MPa, proof stress $Rp_{0.2}$ over 1900 MPa and ultimate tensile strength over 1960 MPa after tempering at 450 °C temperature.
Research limitations/implications: TEM investigations on structure of the elastic elements after heat treatment were predicted.
Practical implications: The carried out investigations showed a full suitability of the steel for production of springs and suspension springs witch high strength properties, operating under conditions of high elastic strains.
Originality/value: Conditions of heat treatment of elastic elements with the high strength properties were presented.
Keywords: Mechanical properties; Ductility; Heat treatment; Spring steels

1. Introduction

The special technical importance have steels used for responsible elements of machines with a high operating durability, for example, under conditions of high elastic strains. A refers to spring steels used for production of springs and suspension springs, which after the heat treatment should characterize very good elastic properties, i.e. high elastic limit and high ratios elastic limit to yield stress and tensile strength. The spring steels should also characterize high fatigue strength and good plastic properties [1,2]. The spring steels of the chemical composition given in the PN-EN 10132-4:2002U standard contain 0.48 to 1.25% C, 0.3 to 0.9% Mn, 0.25 to 1.8% Si, ≤ 0.025% P,≤ 0.025% S, 0.4 to 1.5% Cr, and some of them to 0.2% V or 2% Ni. The springs and suspension springs of small sections or made of strips with a small thickness are produced from silicon steels with low hardenability containing 0.45 to 0.6% C, to 0.8% Mn and about 1.8% Si. Silicon dissolved in the γ and α solid solutions contributes to essential hardening of steel, in the heat treated state, too. Increasing the hardenability can be attained by Cr, V and Ni, the simultaneous increased carbon concentration about 1% and limitation of the Si and Mn concentration to 0.25% and 0.4%, respectively.Vanadium introduced into the steel at the content to 0.2%, characterizes the high chemical affinity to C and N assuring the fine-grained structure of the metallurgical products with high strength properties.

Vanadium in spring steels decreases a rate of strength properties changes during tempering and limits an inclination of steel to decarburization [3]. The fatigue strength of spring steels depends on a structure of the surface layer. For this reason during the hot working of steel and heat treatment, the protection of springs against decarburization using the protective atmosphere or salt bath is required [4].

The aim of the work is to investigate the effect of the V microaddition on the structure and mechanical properties of the 60CrV7 structural spring steel.

2. Experimental procedure

The subject of the experimental is structure and mechanical properties of the 60CrV7 spring steel with the V microaddition. The steel was smelted by the use of the secondary metallurgy and continuous casting of slabs with the 100x100 mm section. After solidification the slabs were hot-rolled for the bars with a diameter of 13 mm. The chemical composition of the investigated steel is shown in Table 1.

Table 1.
Chemical composition of the tested steel

Chemical composition, wt. %					
C	**Mn**	**Si**	**S**	**P**	**Cr**
0.62	0.55	1.56	0.006	0.011	0.660
Ni	**Mo**	**Cu**	**Al**	**V**	**N**
0.05	0.01	0.11	0.230	0.190	0.012

In order to examine the interaction of the V microaddition in forming the fine-grained structure, an analysis of the precipitation kinetics of VN nitride and VC carbide in austenite as a function of temperature was carried out. The logarithmic equation used for determination of a suitable temperature range of hot working for microalloyed steels was applied [5-9]. The calculations showed that the V microaddition introduced into the steel hampers effectively an austenite grain growth to a temperature of about 950 °C. At a temperature of 1050 °C, the vanadium is bounded as VN at about 50% only and has a weaker influence in fine-grained structure creation. The stronger influence, the vanadium can have on precipitation hardening of steel caused by the dispersed VN and V(C,N) particles precipitated during cooling the products. The process can be enhanced by VC particles after the lack of nitrogen. The total dissolving of VN and VC phases in the austenite occurs at the temperatures of 1125 and 980 °C respectively.

The soaking temperature of the specimens was selected on the basis of the investigations of the primary austenite grain size of the steel quenched from an increasing austenitizing temperature (Fig.1). From figure 1 is apparent that the grain growth of the γ phase for the investigated steel occurs for a temperature higher than 950 °C. It is in agreement with the carried out analysis of the dissolution kinetics of the VN nitride in the austenite. On the basis of preliminary investigations, the austenitizing temperature of 850 °C for the specimens was chosen.

Heat treatment of the steel consisted in oil quenching of the specimens from 850 °C temperature after their austenitizing for 30 min. The tempering was carried out in a temperature range of 350 to 550 °C.

Metallographic investigations of the quenched and tempered specimens under pointed conditions were conducted by the use of the LEICA MEF 4A light microscopy. In order to reveal grain boundaries of primary austenite the polished specimens were etched at a saturated aqueous solution of the picric acid with the $CuCl_2$ addition at a temperature of about 60 °C. Hardness of the specimens was measured by the HRC method.

Observations of thin foil structure were carried out in the JEOL JEM-200CX transmission electron microscope using an accelerating voltage of 200 kV.

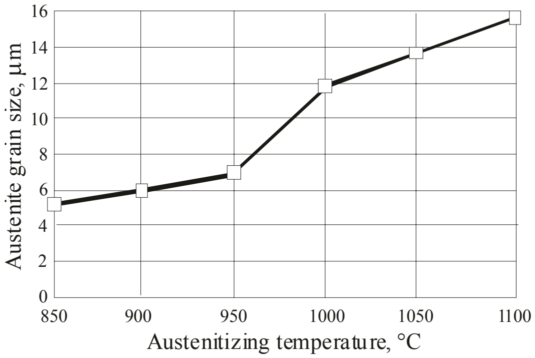

Fig. 1. Influence of the austenitizing temperature on the grain size of austenite

In order to determine the effect of heat treatment parameters on mechanical properties of the steel, the tensile test was used. The specimens with a diameter of 6 mm and a gauge length of 30 mm were stretched using the INSTRON 1115 machine.

3. Results of investigations

Metallographic investigations of the quenched specimens showed that after austenitizing at 850 °C temperature, the steel has a grain size of primary austenite of about 5 µm (Fig.2) and the martensitic structure (Fig.3). Hardness of the specimens after quenching is 67 HRC.

Investigations of the thin foil structure revealed that the steel quenched in oil from 850 °C temperature after austenitizing for 30 min has a structure of lath martensite. It was found using an electron diffraction that the martensite laths contain dispersed Fe_3C particles (Fig.4) formed during self-tempering of the steel.

The specimens quenched after tempering in a temperature range of 350 to 550 °C possess a diversified structure.

After tempering at 450 °C temperature, it is the tempered martensite with the granular and lamellar Fe_3C particles, located inside grains and on boundaries of ferrite laths (Fig.5). The specimens tempered at 550 °C temperature contain the dispersed V_4C_3 carbides (Fig.6).

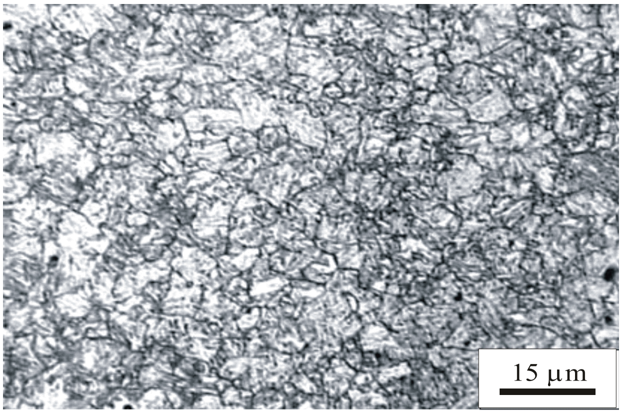

Fig. 2. Fine-grained structure of the primary austenite; austenitizing at 850 °C temperature

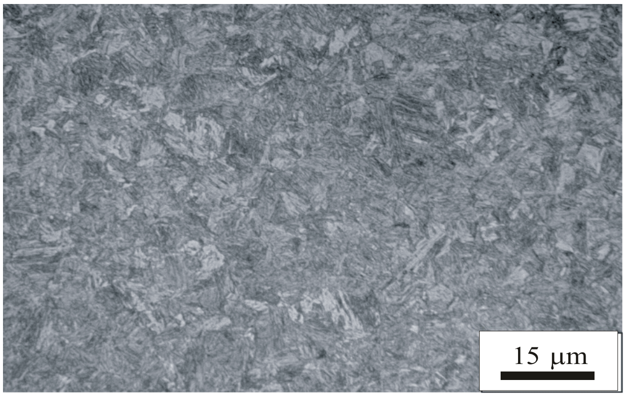

Fig. 3. Martensitic structure of the steel quenched from 850 °C temperature

Due to the tensile test, it was possible to determine an effect of the tempering temperature on mechanical properties of the investigated steel. Data listed in Table 2 shown that the samples quenched in oil from 850 °C temperature and after tempering in a temperature range of 350 to 550 °C have: apparent elastic limit $R_{p0,05}$ from 2222 to 1330 MPa, proof stress $R_{p0,2}$ from 2238 to 1403 MPa and ultimate tensile strength R_m (UTS) from 2347 to 1472 MPa. The ductile properties of the specimens after tempering in the indicated temperature range area: total elongation A from 5 to 11%, and reduction in area Z from 9 to 28%. The high values of the $R_{p0,05}/R_{p0,2}$ ratio – from 0.94 to 0.96 and the $R_{p0,05}/R_m$ ratio - from 0.90 to 0.93 should be pointed, too. Very high strength properties indicate a possibility of the application of the investigated steel for responsible elastic elements with a high operating durability. The hardness of the specimens in a range of the tempering temperature of 350 to 500 °C decreases from about 56 to 50 HRC, and then increases to about 54 HRC – after tempering at 550 °C temperature. This effect is a result of the presence in a structure of the steel tempered in a higher temperature range the dispersed V_4C_3 carbides.

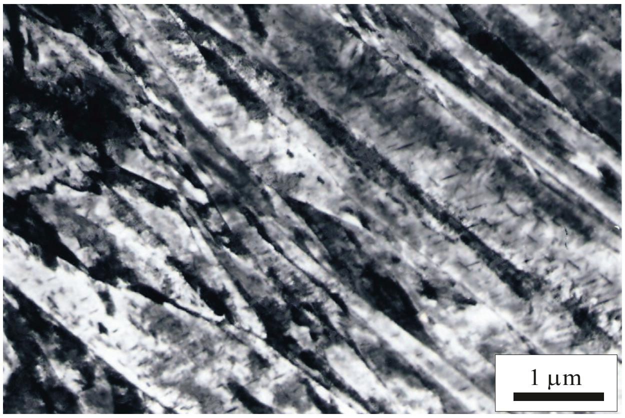

Fig. 4. Lath martensite structure with the dispersive Fe_3C precipitations; quenching from 850 °C temperature

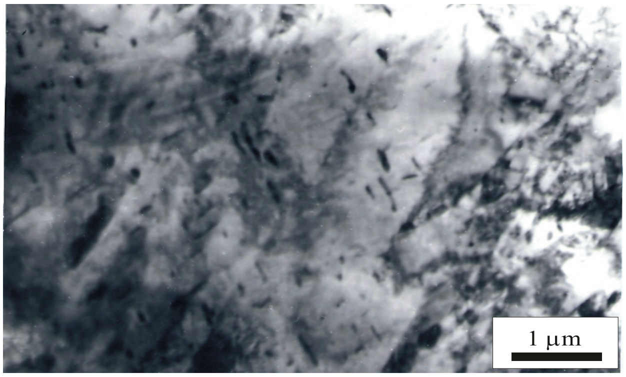

Fig. 5. Tempered martensite structure with lamellar and coagulated Fe_3C particles after tempering the steel at 450 °C temperature

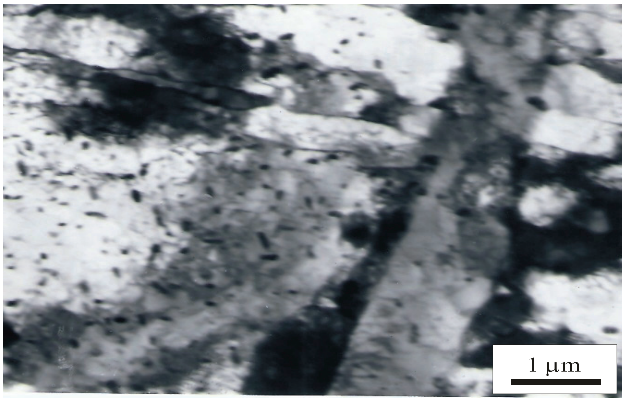

Fig. 6. Tempered martensite structure with the dispersive V_4C_3 carbide precipitations after tempering the steel at 550 °C temperature

4. Conclusions

The relationship between a grain growth of the γ phase and an austenitizing temperature was determined. The results of the analysis indicate that the vanadium microaddition introduced into the steel can efficiently hamper the grain growth of austenite by VN nitrides precipitating in a solid solution to a temperature of about 950 °C. At the higher temperature the interaction of vanadium in forming a fine-grained structure is weaker. For this reason designing of the technology for elastic elements must take into account a suitable selection of conditions of the charge heating without allowing for a grain growth of the γ phase [10-15].

The investigated steel after the heat treatment has very high strength properties and required ductile properties. The steel quenched in oil from 850 °C temperature and after tempering in a temperature range of 350 to 550 °C have: apparent elastic limit $R_{p0,05}$ from 2222 to 1330 MPa, proof stress $R_{p0,2}$ from 2238 to 1403 MPa and ultimate tensile strength R_m (UTS) from 2347 to 1472 MPa. The ductile properties of the specimens after tempering in the indicated temperature range area: total elongation A from 5 to 11%, and reduction in area Z from 9 to 28%.

The carried out investigations showed a full suitability of the steel for production of springs and suspension springs witch high strength properties, operating under conditions of high elastic strains.

Table 2.
Results of the mechanical properties

Tempering temperature	Mechanical properties											
	$R_{p0,05}$, MPa		$R_{p0,2}$, MPa		$R_{p0,05}/R_{p0,2}$	R_m, MPa		$R_{p0,05}/R_m$	A, %		Z, %	
350 °C	2158	**2222**	2236	**2238**	**0,96**	2345	**2347**	**0,91**	5,23	**5,12**	9,01	**8,87**
	2166		2247			2342			5,15		8,77	
	2150		2232			2345			4,99		8,84	
400 °C	2111	**2113**	2222	**2220**	**0,95**	2287	**2281**	**0,92**	6,07	**6,10**	12,98	**13,21**
	2119		2219			2277			5,99		13,09	
	2109		2220			2279			6,24		13,56	
450 °C	1829	**1823**	1899	**1900**	**0,95**	1966	**1964**	**0,92**	8,00	**8,06**	25,25	**25,09**
	1822		1890			1964			8,16		24,89	
	1818		1911			1962			8,04		25,15	
500 °C	1507	**1505**	1605	**1599**	**0,94**	1670	**1666**	**0,90**	9,25	**9,10**	27,05	**26,90**
	1499		1601			1662			9,17		26,67	
	1510		1590			1666			8,88		27,00	
550 °C	1333	**1330**	1403	**1403**	**0,94**	1470	**1472**	**0,90**	11,1	**11,0**	28,78	**28,21**
	1327		1409			1476			10,9		27,90	
	1331		1397			1470			11,0		27,95	

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