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Analysis of the Low Service Life of a Planing Knife – A Case Study

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The presented work deals with an analysis of causes of the very low service life of the new version of hand woodworking planing knife, which has replaced the original version of a planing knife. Based on the performed experimental works, chemical analysis, macroscopic and microscopic observation, SEM, diffractometric analysis, and Vickers hardness test it was concluded that the cause for the very low service life (practically the nonexistent one) of the new version of a planing knife are significant features of overheating. During the heating to the hardening temperature used steel was overheated, the cementite carbides dissolved, and the austenitic grains became coarse. The final microstructure of the used steel after hardening and tempering consists of brittle coarse martensitic needles, without any presence of the fine globular cementite carbides, accompanied by a very high amount of retained austenite. Thus, the chipping of the knife's cutting edge took place and the planer was unusable.

Keywords: planing knife, low service life, causes, analysis.

1. INTRODUCTION

The tool steels are an important group of materials used in engineering. These steels must meet high requirements, such as high strength, yield point, hardness, tempering resistance, toughness, cutting ability, wear resistance, hardenability, and dimensions stability. The requirements are often contradictory so due considerations need to be given to the choice of appropriate tool steel. The basic grades of tool steels are carbon tool steels, low-alloy tool steels, and high-speed steels (high-alloy steels). Carbon tool steels concerning carbon content can be divided into groups of steels with low carbon content (max. 0.25 % C), medium carbon content (0.25 – 0.60 % C), and high carbon content (more than 0.60 % C). Hand tools and less demanding tools, such as woodworking tools, screwing taps, drills, milling cutters, and metal saws are produced from carbon tool steels or non-alloyed tool steels [1 – 11].

The decisive factor in steels is the carbon content and the optimally chosen heat treatment, namely hardening and tempering. However, it is necessary to take into account the accompanying, and harmful chemical elements. The accompanying elements, such as Mn and Si support hardenability, but on the other hand with the increase of the Mn amount the proportion of retained austenite in the matrix increases, as well. Micro-purity is very important for the tool steels, harmful elements such as P and S impose a negative effect on fracture behavior and brittleness [1, 4, 10]. The structure of tool steels is formed after hardening and tempering with tempered martensite or a mixture of tempered martensite and bainite, retained austenite and cementite carbides. Martensite needles must be fine because coarse martensite needles degrade the mechanical properties, and the steel becomes very brittle. Retained austenite is undesirable in most tool steels [12 – 16]. Inadequate choice of material (chemical composition), heat treatment, grinding conditions, etc. lead to degradation of tools and a significant reduction in their service life [17 – 19].

There are plenty of great planing knives (hand planes) on the market, produced by various well-known manufacturers. On the other hand, this study shows that there are also some low-quality knives, at the same price as high-quality ones.

This paper presents the results of experimental research dealing with the analysis of causes of very low service life of the new version of the hand woodworking planing knife. Due to possible problems with the trademark reputation damage, the manufacturer of the examined planing knives is not mentioned.

2. EXPERIMENTAL PART

Experimental works were carried out to determine the causes of the very low service life of the planing knife, both on the original and the new version of the hand woodworking planing knife, Fig. 1. The original version has been replaced by a new version of the planing knife. The original version was designed as a composite tool made of two steels (marked as A and B), the new version uses a single type of steel (marked as C), Fig. 2.

The original version of the planing knife has been used reliably for more than three years and no degradation mechanisms have been recorded. The knife has been only regularly sharpened to the desired sharpness. The planing knife of the new version immediately after the first use showed the damage due to the chipping of the cutting edge.

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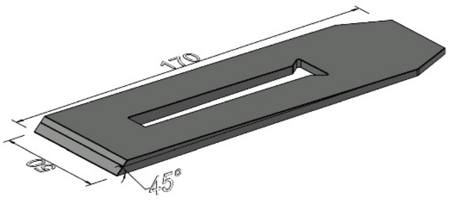
The chip size of the cutting edge ranged from 0.21 mm to 0.92 mm, Fig. 3.



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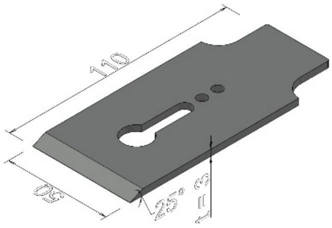

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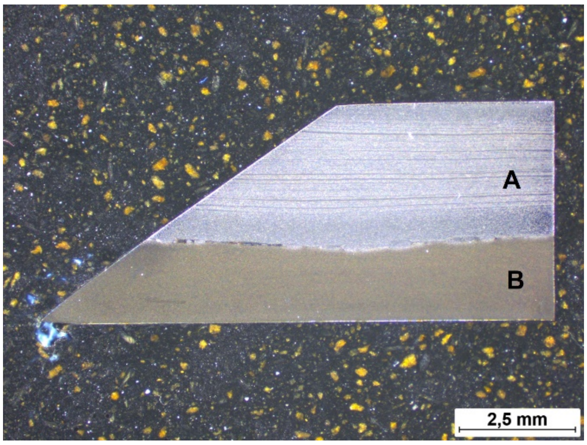
Fig. 1. Planing knives: a – original version; b – new version



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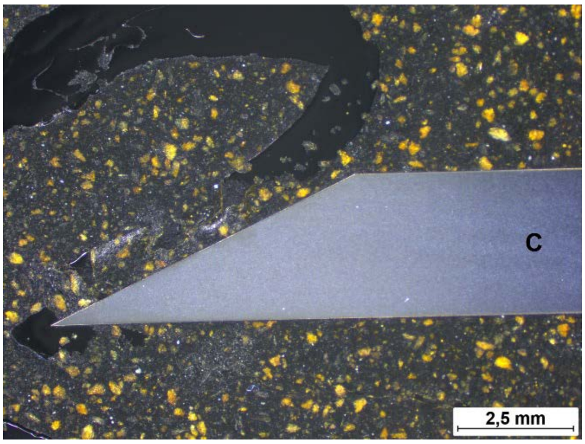

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Fig. 2. Macrostructure, planing knives: a – original version, b – new version

For investigation of causes of the low service life of a new version of the planing knife, the qualitative and quantitative chemical analyses were conducted by spark emission on a SPECTROMAXx instrument to verify the chemical composition; macroscopic observation (Leica S9D microscope) to observe chipping of the cutting edge; optical light microscopy to study microstructure (Zeiss Axio Observer microscope); electron microscopy for studying the fracture surfaces (Vega Tescan LMU II microscope); RTG diffractometric analysis to determine the amount of retained austenite (Proto iXRD device using the CrKα radiation, $\lambda = 2.2910 \times 10^{-10}$ m, rotation collimator with an irradiated area 2 mm^2, Average Peak Method) and Vickers hardness tests (equipment INNOVATEST 400) to measure the hardness HV1. Samples for the study of macro and microstructure were prepared by cutting and then ground, polished, and possibly etched (0.5 % Nital).

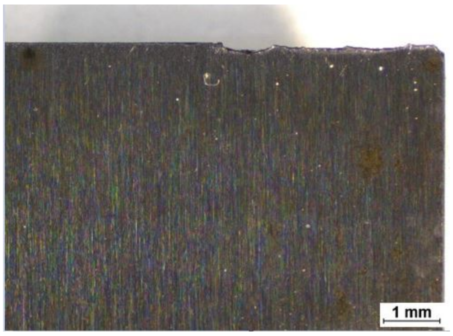

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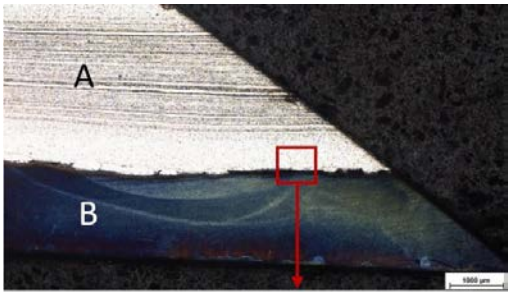
Fig. 3. Planing knife, new version: a – chipping of the cutting edge; b – detail of chipping

The HV1 hardness tests were performed through the cross section of samples taken from both planing knives. It should be emphasized that the results of experimental investigations are presented for a single sample, while the tests were performed on 50 knives, which all broke at the first attempt of cutting the wood.

3. RESULTS AND DISCUSSION

The original version of the planing knife was designed as a composite tool made of two steels (marked A and B), which was created by manual forging welding, Fig. 2 and Fig. 4.

Plain carbon steel with the chemical composition given in Table 1 was used on the upper part of the tool (marked A). The microstructure is ferritic-pearlitic, the texture is visible including decarburization caused by welding, heating to the welding temperature in the blacksmith's fire, Fig. 2 and Fig. 4. The lower part of the tool (marked B), the planning knife itself, was made of non-alloyed tool steel, Table 1. The new version of the planing knife (Fig. 2 b) was made of non-alloyed tool steel, Table 1 (marked C).



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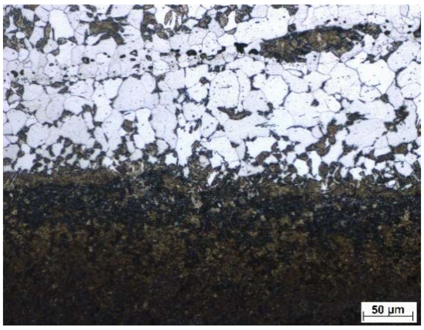

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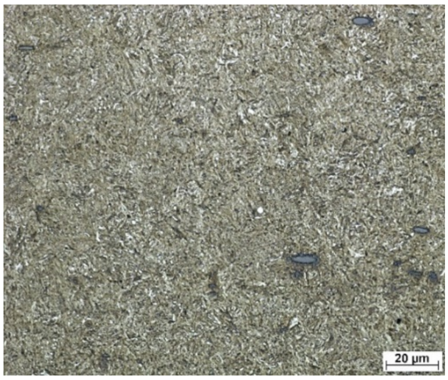
Fig. 4. Planing knife, original version: a – welding; b – detail

Table 1. Chemical composition of knives (in wt.%)

Steel marked	C	Si	Mn	P	S	Cr	Ni	Fe
A	0.130	0.005	0.379	0.02	0.033	0.038	0.0539	99.157
B	1.020	0.082	0.245	0.013	0.058	0.026	0.0567	98.224
C	0.943	0.313	0.424	0.038	0.010	0.150	0.107	97.718

Hand woodworking planing knives are usually produced from non-alloyed tool steels with the carbon content ranging from 0.95 to 1.20 % [1 – 3, 7, 8, 12]. As the carbon content increases, the wear resistance increases, as well, but the fracture toughness decreases. The highest cutting property have hypereutectoid carbon steels, in which the small globular cementite carbides remain in the matrix after hardening. Those globular cementite carbides have higher hardness than martensite. The Si content of the non-alloyed steels is limited to a max of 0.35 – 0.40 %. The Mn content must be low, as well (max. 0.40 %), because Mn stabilizes the austenite and in the case of steels with a higher C content, the retained austenite content increases after hardening. Plastic properties are adversely affected by P. The desired content of P is lower than 0.02 – 0.03 %. In the production of steels from secondary raw materials, a certain amount of Ni, Cu, and Cr gets into the melt from the steel scrap. The Ni and Cu (max. 0.20 %) and Cr (max. 0.15 – 0.20 %) is permissible concerning the hardenability of the tools [1, 4, 5]. As can be seen from the chemical compositions, given in Table 1, in the case of a new version of the planing knife, (marked C), permissible values are exceeded for Mn (negative influence on the amount of retained austenite) and P (increase the brittleness of steel). From the measured values is also clear that the steel of this knife was produced by recycling the secondary raw materials.

Microstructures of the planing knives are shown in Fig. 5.



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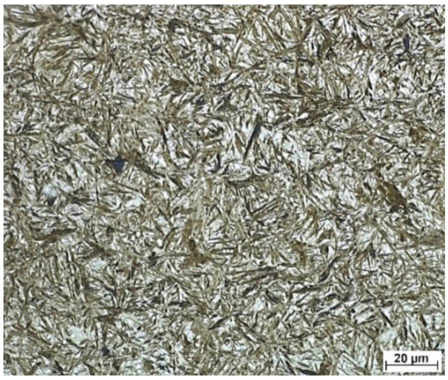

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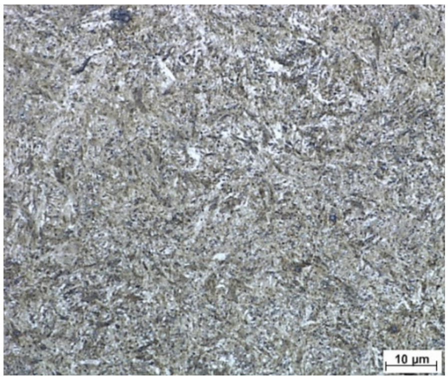

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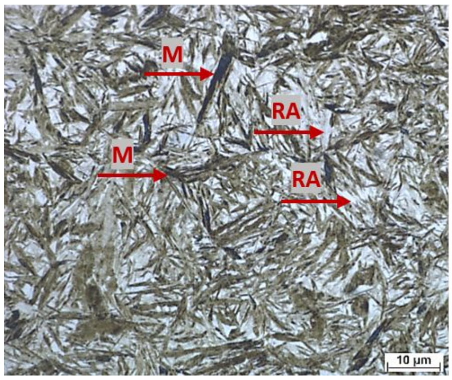

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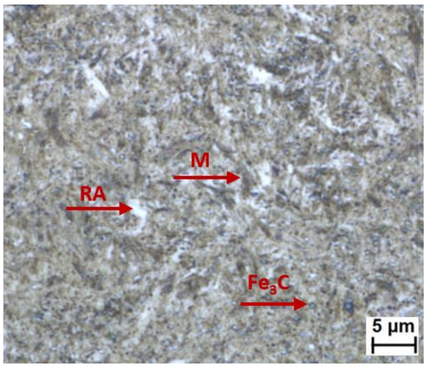
Fig. 5. Microstructure of planing knives: a, c – original version (steel marked as B in Fig. 1); b, d – new version (steel marked as C in Fig. 1), etch. 0.5 % Nital

The microstructure of the original planing knife (Fig. 5 a, c, marked as steel B) consists of the fine needles of low-tempered martensite, very fine globular cementite carbides, and retained austenite. The microstructure corresponds to a suitably chosen procedure of heat treatment, hardening and low tempering. The microstructure of the new version of the planing knife (Fig. 5 b, d, marked as steel C) consists of the coarse needles of martensite, accompanied by increased amount of retained austenite. The coarse martensitic microstructure is very brittle. During the heating to the hardening temperature, the steel was overheated, the fine cementite carbides dissolved, and the austenitic grain became coarse [12 – 15].

In a detailed view of the original planing knife microstructure (Fig. 6) a homogenous distribution of very fine globular carbides (about 0.2 – 0.5 μm) is visible.



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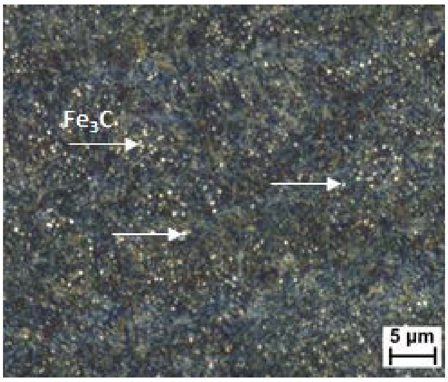

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Fig. 6. Microstructure of planing knives, original version: a – detail from Fig. 5; b – homogenous distribution of globular carbides: white particles after etching to make carbides visible

The Vickers hardness tests HV1, were conducted through the cross-section of both planing knives. The results of the hardness measurement, HV1 in terms of a distance from the surface, are shown in Fig. 7.

For the complete information, the hardness HV1 is also measured in the part of the original version of the planing knife, consisting of plain carbon structure steel (marked as A in Fig. 2 a). The hardness HV1 of the cutting edge of the original knife (marked as B in Fig. 2 a) was in the range from 726 HV1 to 777 HV1 (average value from 7 measurements was 756 HV1 what represents 62 – 63 HRC). In the case of the new version of the planing knife (marked as C, Fig. 2 b) hardness was in the range from 720 HV1 to 742 HV1 (average value from 12 measurements was 732 HV1 which represents 61 – 62 HRC). The hardness, of the original version vs. the new version of the planning knife is almost the same, Fig. 7 (marked B, C). However, it should be noted that exceeding the correct hardening temperature produces coarse, brittle martensite and an increased amount of residual austenite, Fig. 5 d. The coarse, brittle martensite compensates with its hardness, the hardness of residual austenite [12]. The hardness of the planing knives is chosen according to use and the required properties of steel. If a high cutting ability is required, the planing knife should have a minimum hardness of 62 – 63 HRC [1]. The authors [8] reported hardness for the cutting edge of the planing knife of 52 – 58 HRC.

The chemical composition of the steel marked as C, Table 1, is comparable to steel W. Nr. 1.1645 or DIN-C105W2, EN-CT105, GB-T10, AISI-W1. Recommended heat treatment for this steel is hardening in water at 770 to 800 °C, then tempering at temperatures of 180 to 300 °C. Concerning the measured hardness values of 61 to 62 HRC, the tempering temperature had to be lower, below 180 °C, see Fig. 8. However, at those temperatures the residual austenite in the non-alloyed tool steel (with carbon content higher than 0.765 %, hyper-eutectoid steel) is not removed, so it is very important to reduce its content by quenching from the correct temperature [1, 12 – 15].

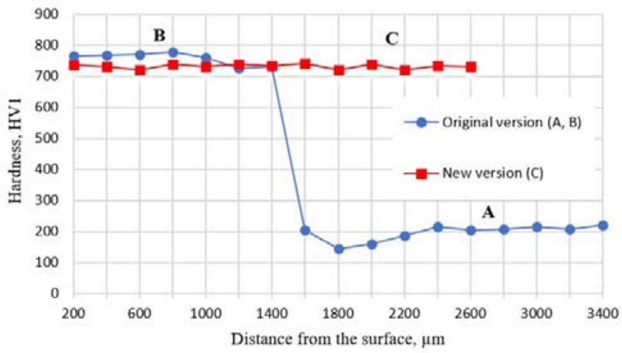


Fig. 7. Dependence of HV1 vs. distance from the surface

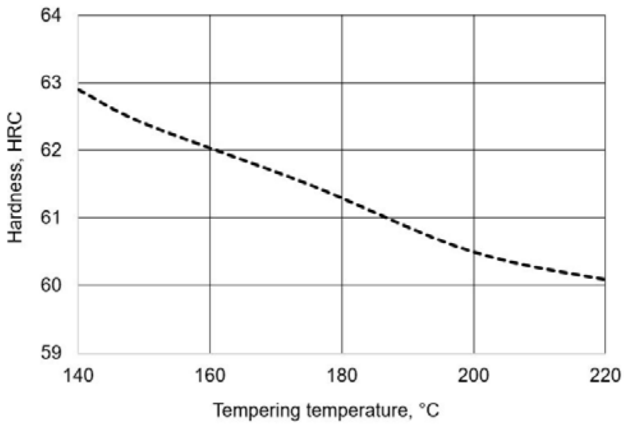
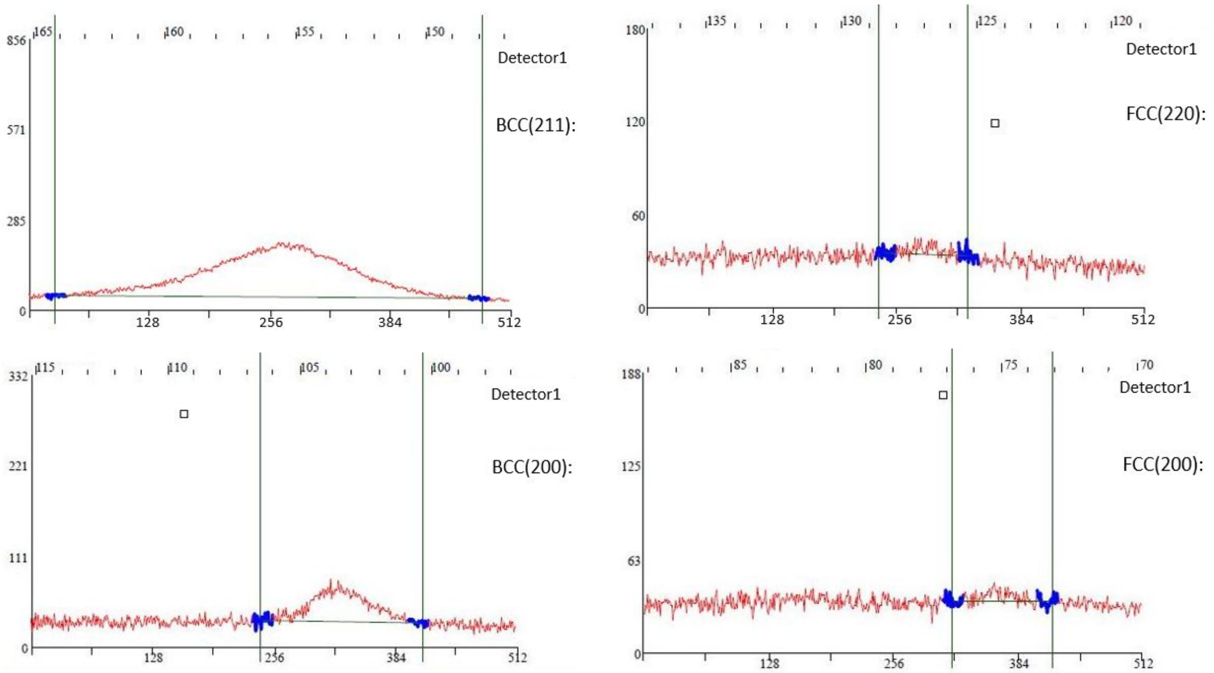


Fig. 8. Influence of tempering temperatures on hardness (HRC) of non-alloyed tool steels

The retained austenite content was determined for both tool steels (Fig. 1, marked as steels B and C) used for the production of the planing knives. The recommended content of retained austenite in non-alloyed tool steels is about 5 – 8 %. The results obtained using the Average Peak Method (partial diffraction analysis of BCC and FCC lattice component) are shown in Fig. 9. In the case of the original planing knife the content of retained austenite was 4.78 % (standard deviation 2.82), while in the case of the new version of the planing knife the content of retained austenite was 26.85 % (standard deviation 3.79). That content of retained austenite significantly exceeds the recommended value. The retained austenite is a soft phase, which is undesirable in most tools. It reduces the yield strength, matrix hardness, deteriorates the sharpening ability of the tools, the tools are easily blunted and do not hold the cutting edge. After exceeding the retained austenite content of 10 – 12 % in the matrix, the tendency to crack occurs during the grinding.

BCC(211) vs FCC(220): 2.32% BCC(200) vs FCC(220): 2.24% BCC(200) vs FCC(200): 7.03% BCC(211) vs FCC(200): 7.29%

Standard deviation: 2.82



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BCC(211) vs FCC(220): 22.68% BCC(200) vs FCC(220):24.89% BCC(200) vs FCC(200): 31.18% BCC(211) vs FCC(200): 28.62%

Standard deviation: 3.79

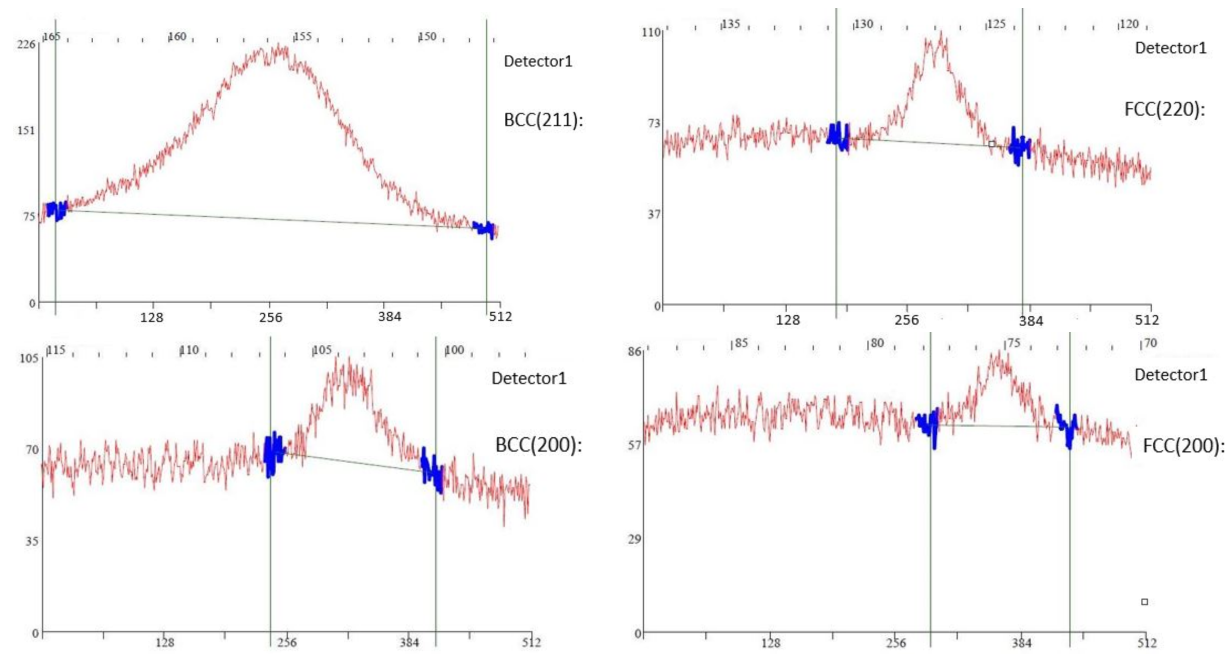

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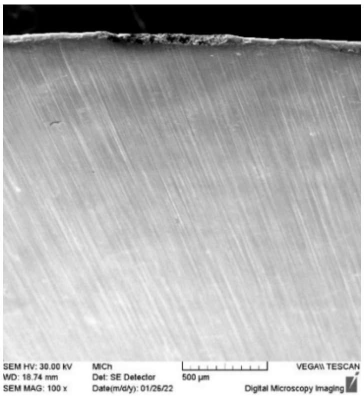
Fig. 9. Determination of the residual austenite content: a – original version; b – new version

At retained austenite content of about 6 – 8 %, the hardness of the matrix decreases for about 0.5 HRC; at a content of 10 – 18 % for about 1 – 2 HRC [1, 13 – 15]. Chipping of the cutting edge together with grinding marks is documented in Fig. 10.



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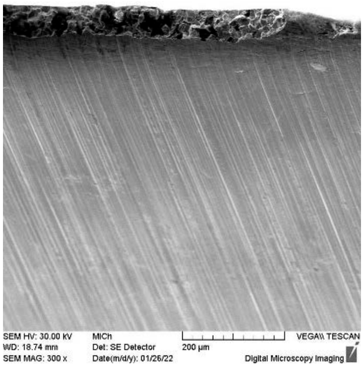

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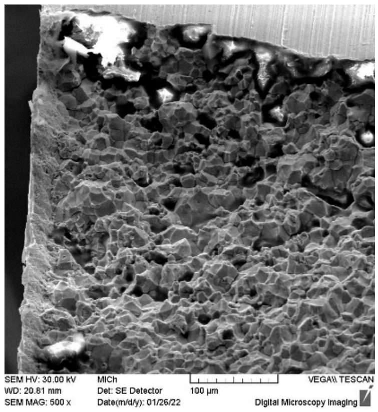
Fig. 10. Planing knife, new version: a – damage of the cutting edge; b – detail, SEM

Fractography analysis of the damaged cutting edge of the new version of the planing knife revealed intercrystalline brittle fracture, Fig. 11. Pure intercrystalline brittle fracture, without any indication of the transition into transcrystalline ductile fracture, is present. Moreover, due to the very low cohesion of grains, the intercrystalline propagation of dominating brittle crack is accompanied by the creation of an intercrystalline secondary crack network (Fig. 11 b). This type of fracture indicates an extremely high brittleness of analyzed steel [12, 13].

The optimal selection of suitable material, qualified design and correct realization of heat treatment, respect for future working conditions and verification of useful properties are a guarantee of quality work tools [1, 12, 19].

It should be noted that only the recommended temperatures and times of the heat treatment are included in the material sheets for the tool steels. To prevent the failure (and reclamation of the final product), the recommended parameters of the heat treatment need to be verified in advance in terms of microstructure, as well as mechanical properties, especially before the mass production of the planning knives.



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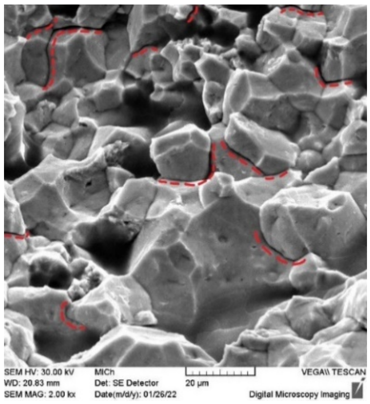

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Fig. 11. Fracture surface of the new version of a knife: a – view of intercrystalline brittle fracture; b – detail of the intercrystalline fracture, SEM

4. CONCLUSIONS

Based on the results of carried out experimental analysis, the following conclusion can be drawn:

1. The original version of the planning knife has a better service life than a new version of the planing knife, due to the significant microstructural differences in the new knife's material.
2. The microstructure of the original planing knife corresponds to a suitably chosen procedure of the heat treatment, hardening and low tempering and it consists of fine needles of low-tempered martensite, fine globular cementite carbides and a low amount of retained austenite.
3. During the heating to the hardening temperature, the steel of the new planing knife was overheated, the cementite carbides dissolved and the austenitic grains became coarse. The microstructure consists of coarse martensitic needles without any presence of the fine globular cementite carbides, accompanied by a very high amount of retained austenite. Such a coarse martensitic microstructure is very brittle and chipping of the knife's cutting edge took place very easily.
4. The overheated coarse martensitic structure was the cause of the pure intercrystalline brittle fracture, which is the result of incorrect heat treatment.

Those facts were the cause for the practically zero service life of the new version of the hand woodworking planing knife. The results are presented only for the single representative sample out of the 50 investigated pieces, which all broke at the first attempt of the wood cutting.

Acknowledgments

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