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DEFORMATION OF EXPOSED TOOL PARTS FOR CRUSHING OF UNDESIRABLE ADVANCE GROWTH

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Tools for crushing of undesirable advance growth and mulching wood are subjected to heavy wear in operation with the need for their frequent replacement shortly after deployment. It is important to address the problem of their wear due to price of tools, as well as the time necessary for their replacement. Tool life is shortened because of deformation taking place due to the loss of wolfram-carbide (WC) tips, what is an undesirable phenomenon. Solutions for increasing the tool lifetimes were designed on the basis of analysis of wear mechanisms that cause this deformation. Furthermore, effect of deformed layer was evaluated by measuring hardness and microhardness. It was found that there was a strain hardening the surface due to cyclic loading. Size and extent of deformation of the entire tool with the loss of material on the functional part were documented using an optical scanning sensor system. Effect of the deformation on the material structure change, as well as topography and extent of surface area affected by abrasive wear under impact loads, were assessed by means of light and electron scanning microscopy. On the basis of these analyses, an option for increasing the lifetime of exposed areas on the tool by application of hardfacing to increase the tool wear resistance was proposed. Prerequisite for extending their work lifetime in the field is creation of a sufficient coarse layer or multiple layers of wear resistant material at specific tool areas.

Keywords: tools for crushing of undesirable advance growth; plastic deformation; wear; structure; hardfacing

Terrains requiring forest maintenance work are frequently very rugged and sloppy. Moreover, forestry technique must operate in demanding terrains and diverse environments (Hnilica et al., 2015). Nevertheless, tools necessary for such maintenance are not given as much attention as tools used in agriculture, road construction or mining industry. Their operation is characterised by increased load in a non-homogeneous working environment – including wood mass – uniform load, and diameter (Kalincová et al., 2016). The second important component of this environment is soil. It contains various components, especially rocks and minerals of different hardness and structure. These protrude above the terrain and are often not visible from the ground. The high rotor speed (1,000–1,300 RPM) at which the tools are mounted, uniform load of individual tools depending on their location in the rotor, as well as potential defective tools, contribute even more to their early wear, and thus affect their lifetime. Tools themselves are produced as monolithic, however, usually they are composed of several materials. Tips from sintered carbides are soldered to the tool body by forging (Ľuptáčiková, 2016). In practice, it often happens that the tool is worn for such long that the tool tip is torn off. Consequently, tool body is further deformed mainly by abrasive wear due to impact loads. This deformation is evident after a short time. It is possible to identify the basic mechanisms causing deformation by analysing the tool deformation after loss of WC tips. This will lead to designing the potential solutions to increase their operation lifetime, such as appropriate thermal or chemical-thermal processing of the entire tool or application of hardfacing layer to the exposed areas on the tool.

Material and methods

For treatment of forest areas, a crusher of undesirable advance growth is used as additional equipment carried on the three-point support base-machine with forest wheeled skidder. Crusher tools for treatment of undesirable advance growth are located at the back of this adapter and work approx. 0.25 m above the ground level. Firstly, the machine beats down the growth by moving backwards approx. 20 metres with the help of a roller and, subsequently, it moves 20 metres forward and crushes and mulches the beaten growth. Working width of the rotor is 2,750 mm and the working width is 2,300 mm. Number of tools per cylinder (rotor) is 54 pieces (1,000 RPM) (Fig. 1).

Fig. 2 shows a tool for crushing of undesirable advance growth and an adapter rotor with tools at various stages of wear.

After losing the WC tips, the tool body deformation is related to milling of its surface. Fig. 3a demonstrates tool part showing wear due to extensive milling; the sample has numerous visible holes due to pressing of hard elements into

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Fig. 1 Basic machine with adapter and treated forest stand with increased incidence of rocks

Fig. 2 Tools and roller with working tools

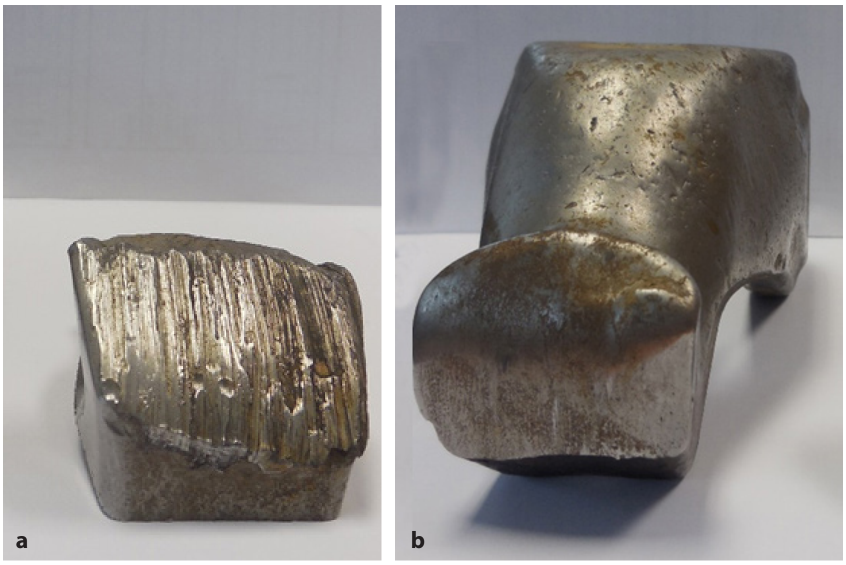

Fig. 3 Tool wear after loss of WC tips

the material. Fig. 3b shows a sample which was smoothed and showed no significant milling for a short time (Ťavodová et al., 2018).

Complex chemical elemental analysis of metallic samples taken from the tool body was determined by atomic emission spark discharge using spectrometer ARL 4460, THERMO ARL Company, and infrared spectroscopy. Analysis results are shown in Tables 1 and 2.

In addition to this, elements that make up WC (W and Co), as well as other elements, are also present in the material. Presence of Ag confirms that the tips have been brazed to the tool body by silver solder. Considering the brazing of sintered carbide elements, silver solders are utilized for this type of joint (Ťavodová et al., 2018).

On the basis of chemical analysis, we can state that the material of tool for crushing of undesirable advance

Table 1 Chemical elemental composition (wt. %)

C	Mn	Si	P	S	Al	Cu	Ni	Cr	As	Ti	V
0.212	1.302	0.241	0.012	0.006	0.028	0.125	0.131	1.219	0.004	0.003	0.004
Nb	**Mo**	**Co**	**Sn**	**Sb**	**W**	**B**	**Ca**	**Zr**	**N2**	**O2**	**Als**
<0.002	0.035	0.009	0.007	0.003	<0.003	0.0002	0.0017	0.001	0.0108	0.0028	0.027

Table 2 Chemical composition of tool tip (wt. %)

W	Co	Fe	Ag	Ni	Zn	Mn
84.32	11.2	2.89	0.64	0.39	0.36	0.2

Table 3 Hardness values HB30

Indenter	1	2	3	Average value
HB30	229	285	255	256

Table 4 Results of measurement of hardness HV0.025

Indenters	1	2	3	Average value HV0.025
Surface	349	288	325	320.7
Core	311	289	301	300.3
Ferrite	309	278	223	270
Pearlite	380	369	354	367.7

growth is low-alloy cement chrome-manganese steel of class 14 220, (DIN 1.7131, EN 16MnCr5). It belongs to a group of low carbon steels with good weldability.

Tool body hardness was measured by means of the Brinell hardness test in accordance with STN EN ISO 6506-1:2005 in order to compare obtained results with the hardness values specified in the material standard. The standard states that the value for .1 forgings is at least 152 HB. Measured values are recorded in Table 3.

Measured values are higher than those specified in the material standard STN 41 4240.

Leco LM700AT Microtrusion Unit was utilized for measurement of micro-hardness (Vickers microhardness test) of plastically deformed tool surface areas. Measurement was performed according to STN EN ISO 6507-1:2018. Measurement of microhardness under a worn surface was performed in the line of the plastic-deformed microstructure 40–50 μm from the surface. Average values of ferrite and pearlite hardness were measured in this zone (Table 4). In the non-deformable central part, the hardness of HV0.025 was measured separately in ferrite grains and in pearlite columns (Fig. 4).

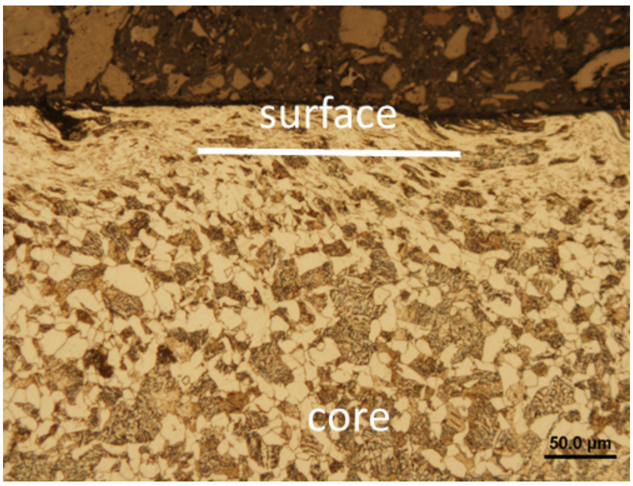

Fig. 4 Scheme of measuring the hardness HV0.025

Higher hardness values were observed in the material surface than in the tool centre, showing the strain hardening during plastic deformation of surface.

Fig. 5 documents the size and area of tool deformation assessed by optical and scanning probe system. According to the colour scale representing the deformation size, it is obvious that overpressure stress prevails over the tension stresses. Tension stress occurred on the side with the larger mass loss. By overlaying the new and worn tool, we can clearly see the amount of material loss from the body after loss of WC tips.

Sample was taken from a worn instrument for microscopic analysis, which was prepared by a standard procedure and etched in 2% NITAL. Fig. 6 shows worn tool, sampling scheme and morphology of tool wear surface (B1).

Structure was monitored by means of Olympus GX 51 light microscope. Tool body structure is ferrite-pearlite with a slight hint of linearity, what confirms that the forgings were probably not heat-treated (Fig. 7a). For obtaining more details on the microstructure, a scanning electron microscope JEOL JSM 7000F with analytical units EDX and EBSD Oxford Instruments was used. It also confirms that this structure corresponds with the material structure in a natural, unprocessed state (Fig. 7b).

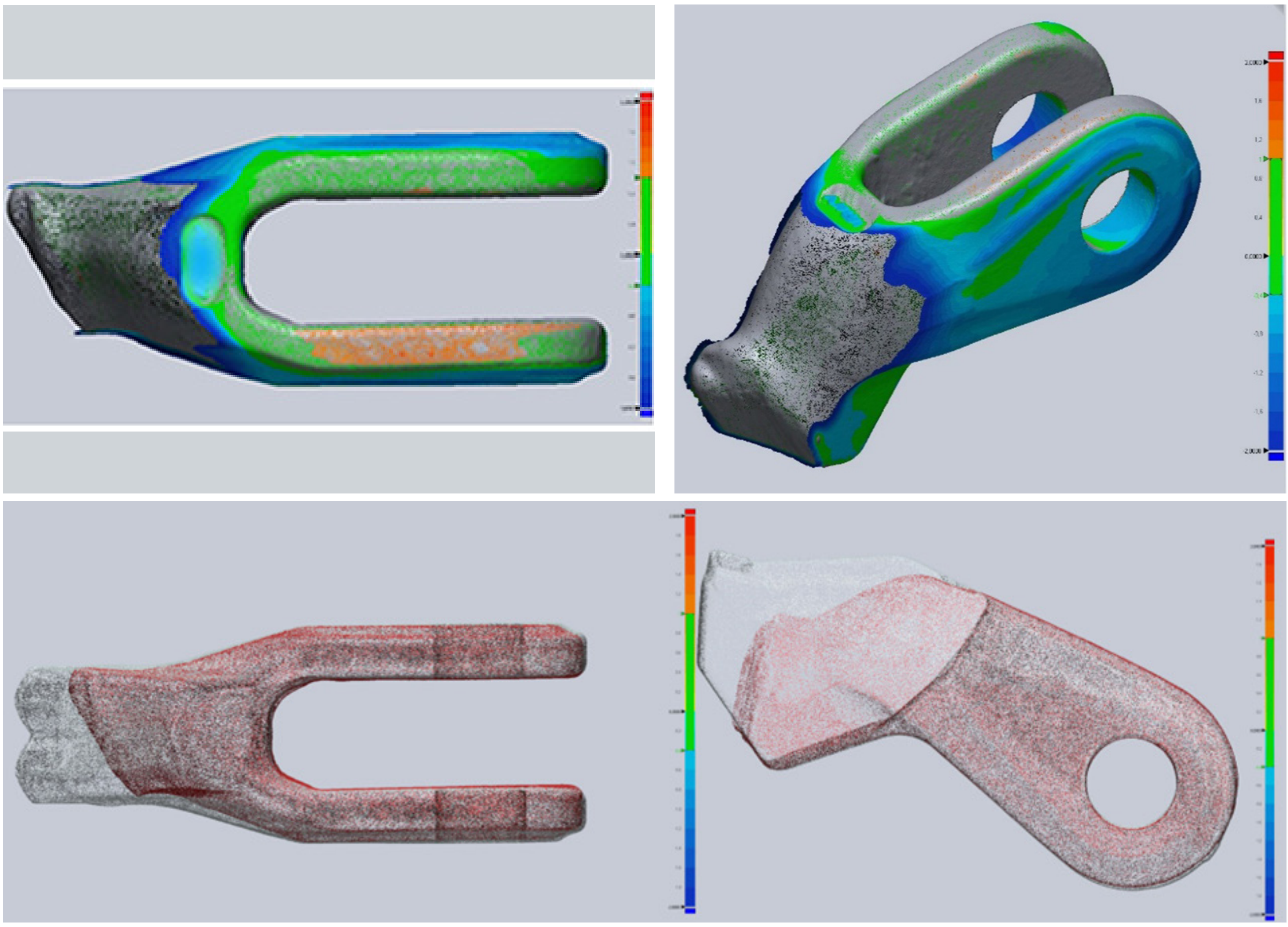

Fig. 5 Deformation and loss of tool material in a 3D scan

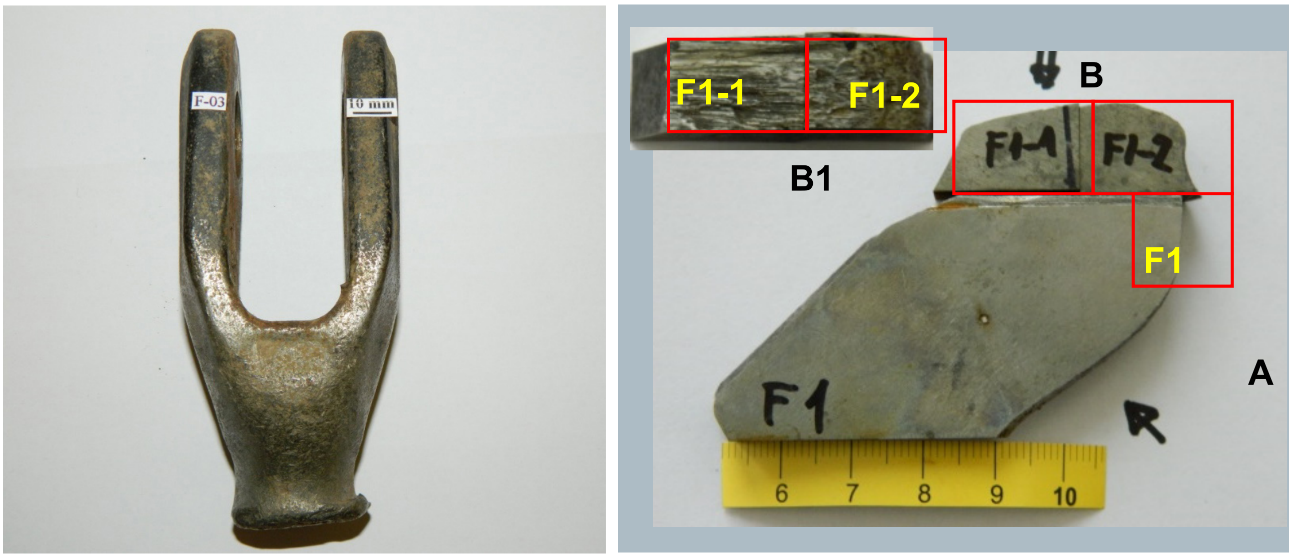

Fig. 6 Preparation of samples for metallographic analysis

Figs. 8 to 11 show microstructures of the deformed tool body, which were in operation even after losing the WC tips. Figs. 8 and 9 demonstrate a significant local deformation of the surface layer at a depth of up to 0.2 mm.

Figs. 10a and b show a visible riffle mark which was produced by a hard particle on the tool surface. Fig. 10c shows the microstructure outside the plastic-deformed tool surface.

Overall profile of the reference tool face after wear is shown in Fig. 11.

Scanning electron microscope Jeol JSM 7000F was used for observing of microstructure details. As claimed by Náprstková et al. (2016) and Svobodová (2014), it is possible

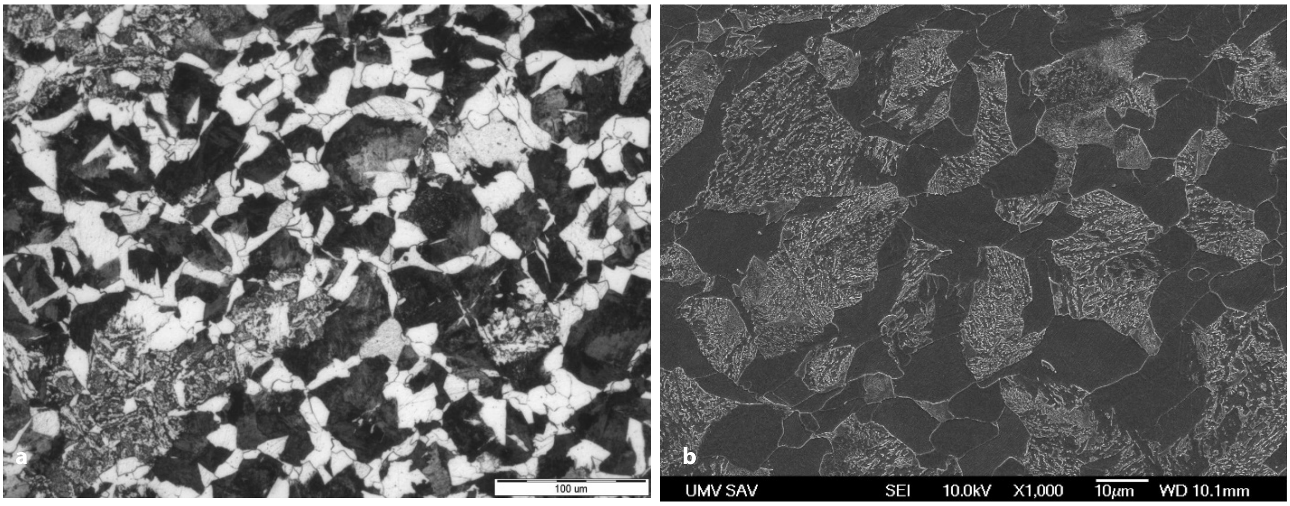

Fig. 7 Detail of the tool body microstructure – a) light microscope; b) scanning electron microscope (SEM)

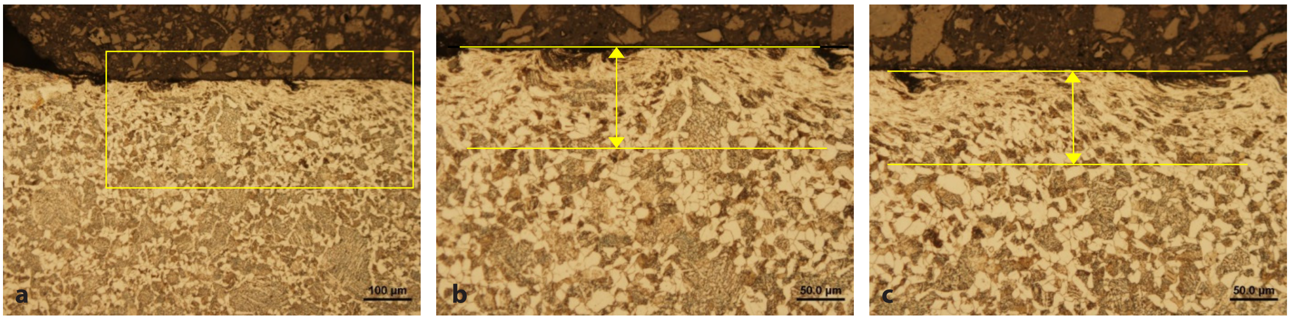

Fig. 8 Plastic deformation at up to 0.12 mm on the face place of the tool

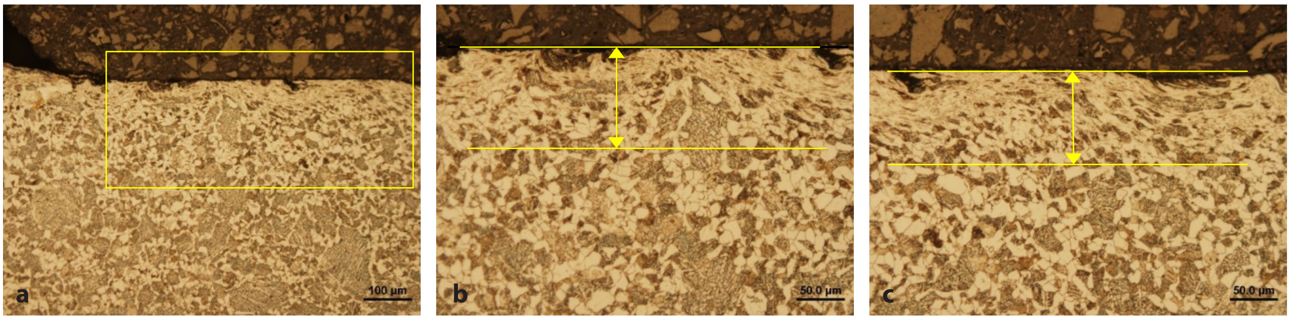

Fig. 9 Plastic deformation (0.13–0.18 mm) on the face place of the tool

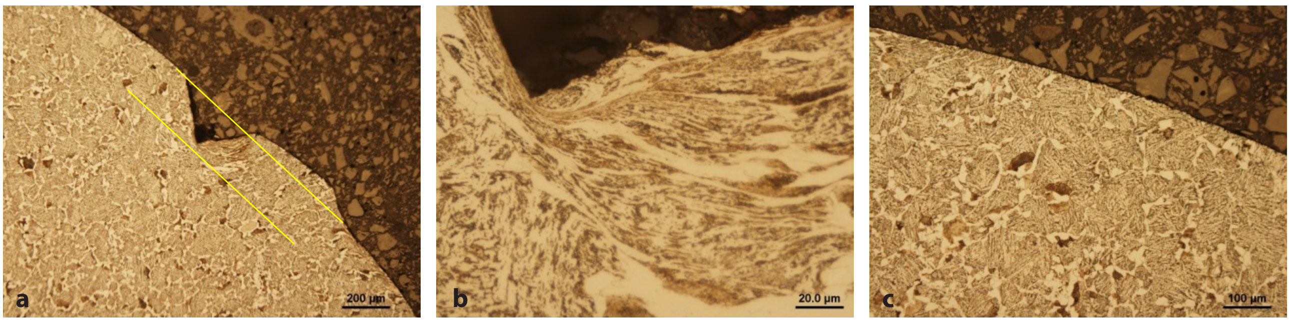

Fig. 10 0.2 mm plastic deformation on the face place of the tool

Fig. 11 Profile of the worn tool face

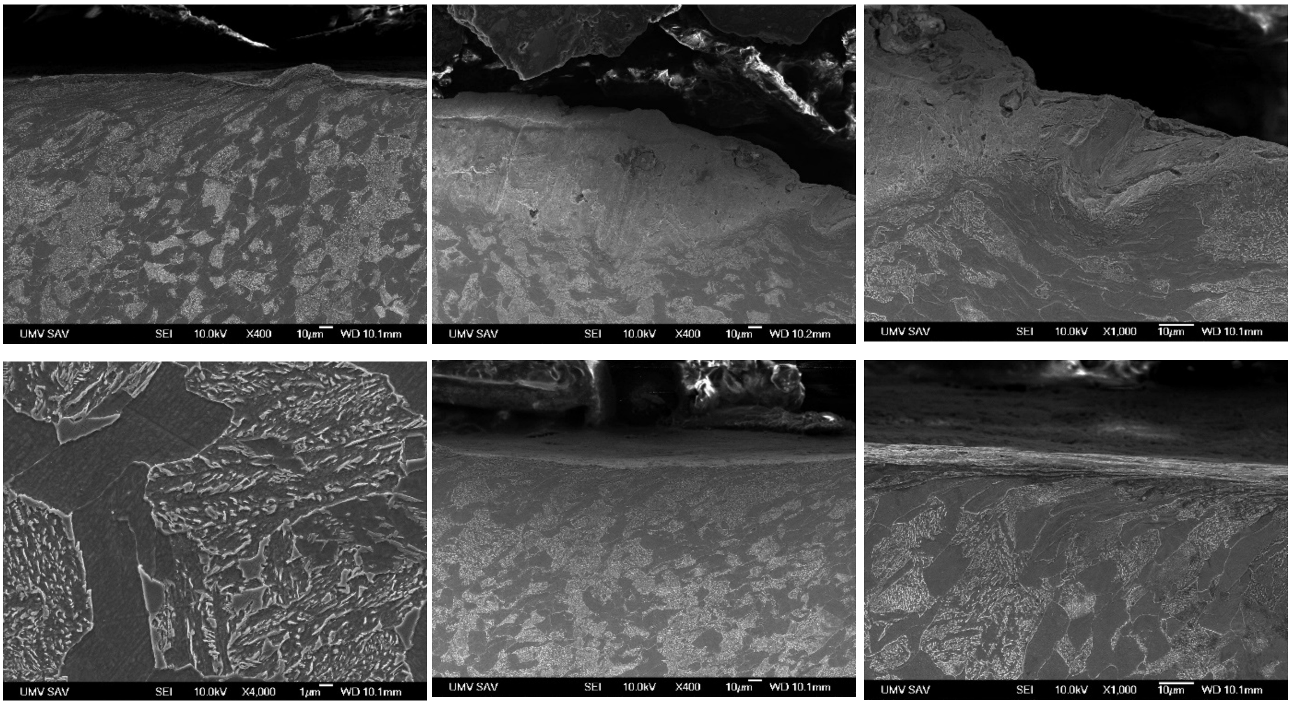

Fig. 12 SEM surface of the worn tool

to analyze the disturbances, errors or deformations on the worn surface by means of SEM with greater magnification than by light microscopy. Severe plastic deformation of the face place was identified on the tool surface (Fig. 12).

As a result of intense plastic deformation, integrity was impaired – surface integrity associated with the separation of those material parts, in which plasticity was locally exhausted by superposition of plastic deformation and local plastic deformation by foreign particles (Fig. 12a). Plastic deformation on tool face place – Figs. 12a, b, c, e, f – is characteristic by an unequal plastic deformation of the surface layers. Figure 12d shows a tool microstructure outside the plastically deformed surface.

Results and discussion

On the basis of analyses carried out, we can state that the tool body material is not capable of withstanding the deformation. This deformation is due to abrasive wear in the cyclic impact load in operation after loss of WC tips. Fig. 7 shows that the tool has a ferrite-pearlite structure, which

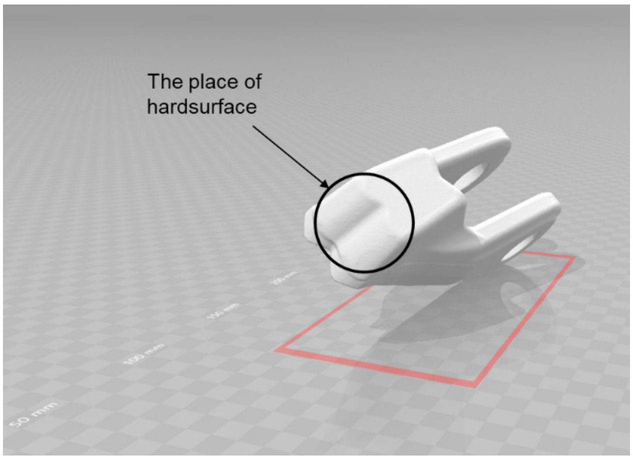

Fig. 13 Recommended place for application of hardfacing

is at least resistant to abrasion wear. This confirms that the forgings were not heat-treated. Figs. 8 to 11 show that there is an intense plastic deformation caused by pressing the foreign hard particles into the tool surface. Figs. 10b, 12c and 13 demonstrate that material is milling, i.e. is abrasively worn due to the contact with hard particles, such as rocks and minerals, occurring in heterogeneous working environment. Significant deformation of the soft ferrite-pearlite structure is visible in the cross-section. After hardening the material surface causing the repeated dynamic loading, plasticity is depleted. Tool surface integrity is disturbed by the action of further loading. Further separation of material particles is the final phase of deformation (Fig. 9a). Plastic deformation as a result of hardening on the face of the tool was identified at a depth of approx. 0.2 mm. Hardening of the material surface is confirmed by higher values of microhardness HV0.025 in the observed surface (Table 4). Tool is deformed and worn as these cycles repeat. This gradual loss of material surface is seen in Fig. 5. Original structure of the tool material is not sufficiently resistant to workload, what is also documented by the overall profile of observed tool face (Fig. 11).

Plastic deformation was identified at a depth of approx. 0.2 mm below the surface on the tool face. This can be considered a significant loss of material per particular time unit. In our opinion, mere heat treatment and potential case-hardening of tools are not sufficient for enhancing the abrasion resistance. We assume that it is possible to achieve sufficient hardness and wear resistance by application of a suitable hardfacing to the exposed area. This should prevent another gradual loss of material. According to Chotěborský et al. (2009a), Kotus et al. (2011), Žúbor et al. (2014), there is no unified view on the most appropriate type of structure in terms of resistance to abrasion wear. Some authors consider the austenitic-carbide structure to be the most appropriate, since it is resistant to high specific pressure in the presence of shocks. Others recommend a martensitic-carbide structure, which is more suitable for use under the high shock frequency conditions. Ferrite-carbide microstructure increases the hardness and abrasion resistance to 5÷6% proportion of carbide. A higher proportion of carbides do not significantly affect the resistance to abrasion wear. Resistance to steel wear is also given by the type of carbides contained in it, e.g. if M_3C carbides are changed to complex carbides M_7C_3, resistance to wear will increase. An example of complex carbide is a WC carbide produced by addition of the alloying vanadium element to ledeburitic chromium steel. Vanadium also provides more appropriate distribution of chromium carbides and their alloying with carbon and chromium (Stodola et al., 2008; Chotěborský et al., 2009b).

Currently, there are multiple forms and types of hardfacing materials. They are used in form of sticks, wires, coated electrodes, tube electrodes, powders, welding pastes and aluminotermic mixtures. Method of their application to the tool surface depends on selected type of welding material.

Results of analyses show that the largest wear is at the tool face. After losing the WC tips, the front surface becomes a new work surface. Fig. 13 shows a location on the tool, in which it would be appropriate to apply a layer of hardfacing.

According to numerous studies (Kováč and Tolnai, 2004; Müller et al., 2013; Brezinová et al., 2016), it is necessary to deal with not only the type of structure and type of hardfacing material, but also with the number of hardfacing layers. Additive material is melted during the hardfacing process and is simultaneously applied to the surface layers of basic material. In the transition region, both will be mixed together, resulting in changing the chemical composition and structure. For this reason, it is recommended to use multi-layer hardfacing, in which the required chemical composition and coating properties are achieved during applying the second and third layers. Application of the second or third layers may increase the resistance of tool components to adverse effects, such as abrasion, shocks and combination of the two, or other types of load causing wear, damage and destruction. In order to prevent the deformation and loss of tool material, it is possible to apply a layer of hardfacing to the exposed area of the new tool. Surface coating is possible solution when the tool is visibly worn after some time in operation, yet it still has its WC tips.

Conclusion

We can conclude that a significant deformation of the tool body accompanied by a material loss is a result of the cyclically repeating mechanism of deformation consolidation. Surface integrity is disturbed with the separation of those material parts in which the plasticity was locally depleted by the superposition of plastic deformations and local plastic deformations caused by foreign particles. By application of hardfacing on the tool face, we can obtain a structure which is more resistant to abrasion wear. In such manner, lifetime of the tool in operation will also be extended even after losing the WC tips. This will reduce downtime by frequent exchange of non-functional tools, as well as the costs for purchasing the new tools.

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