LABORATORY ANALYSIS OF HARDFACING MATERIAL APPLIED BY PLASMA AND TIG WELDING

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There is not so much research on the issue of the wear of forestry tools as on tools used in agriculture, mining or construction. However, in a heterogeneous environment, they are subject to abrasive and shock loads. The large number (48 pieces) of tools used at the same time, based on base machine adapters, their rapid wear and the high price of a new tool (approx. 70 Eur), is the reason why it is necessary to deal with this issue. One solution is to apply hardening materials to exposed parts of the tools. These could prevent rapid decommissioning due to the loss of functionality of the tool due to their structure, more resistant to adverse working environments. Methods of applying such a deposit are different. From classical welding methods for example TIG method, up to unconventional, where also plasma welding belongs. The aim of this paper is to present partial results of laboratory experiments of plasma welding and TIG welding with HR MAG welding wire on the tool base material, 16MnCr5 steel. Specifically, the hardness as well as the hardness of the hard-facing material to abrasive wear by the GOST method were examined. Subsequent evaluation of the surface after this test as well as the microstructure itself can give us information on the suitability of the selected material for practical application in forestry.

KEYWORDS

plasma welding, TIG, abrasive wear, forestry tools, microstructure, microcutting, microgrooving

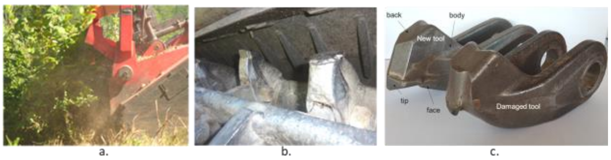
1 INTRODUCTION

There are several methods and procedures to increase tool wear resistance. By selecting those that will change the structure more resistant to abrasive wear of the tool body to crush unwanted growths, we can extend its use in service. This creates a presumption of increasing its service life. This will reduce costs for forestry operators hospodárstve [Wiesik 2011] [Schwarz 2013]. Frequently used methods include welding hard-facing materials to the exposed surface. Plasma welding is also progressive. During plasma welding, a plasma arc is formed in the welding torch by the passage of so-called. plasma gas through an electric arc. TIG welding is a related process. This method is a welding process that uses the heat released from the ignited arc maintained between the non-fusible electrode (tungsten) and the workpiece [Sugar 2009]. Creating a suitable structure on the surface of the exposed surfaces of the tool should ensure that the tool does not succumb to early wear and thus rapid decommissioning. Such structures should consist of suitable types of carbides in the softer matrix to ensure sufficient hardness and a certain toughness of the applied layer [Kalincova 2016].

2 MATERIAL AND METHODS

The undesirable surge crusher as a base machine adapter (for example a forestry tractor) is widely used, among other things, for the treatment of areas under high-voltage power lines, where it is legally necessary to provide protection zones for overhead power lines without any vegetation. Often it is a terrain with a high slope and ruggedness where other ways of removing the seedbed are not possible for technical reasons [Tavodova 2018a].

Tools for crushing unwanted gains are attached to the rotor of the base machine adapter. It rotates at 1000 rpm. The tools work in a highly heterogeneous environment. It is made up of wood matter and soil. There are minerals and rocks of varying size and hardness in the soil, randomly occurring in the working environment, which are often not visible in the crop. Figure 1a shows the base machine adapter in the stand, a new and damaged tool based on the adapter rotor (Figure 1b) and Figure 1c a new and decommissioned tool after decommissioning with a tool description. The tool is discarded after a short time, in the order of several days. The price of one tool is 70 Eur.



a. b. c.

Figure 1. Adapter in undergrowth (a.), new and damaged tool set (b.), comparison of new and damaged tool (c.)

The tool body material consists of a ferritic-pearlitic structure, in an unprocessed state. This is not able to withstand abrasive loads after loss of WC tips. Significant plastic deformation at a depth of approx. 0.2 mm, generated below the surface from the cyclically repetitive abrasive load on the tool surface (high rotational speed of the adapter rotor), caused the surface to become stiffened, resulting in the separation of parts of the material [Tavodova 2018b]. Over time, the material on the back surface of the tool is lost after the WC tips are lost. Therefore, as stated in the works [Tavodova 2018b] [Falat 2019] on concrete exposed places on the tool different types of hardfacing deposit were applied by different welding technologies. Welding can be defined as deposit welding, where the base material is melted at high temperatures by the metallurgical process, while the weld material (filler material) is melted and added to the melting bath. The welding results in a homogeneous metal or alloy layer. When welding, the most common goal is to form a layer with a low mixing coefficient with the base material. The aim is to eliminate the amount of heat introduced into the base material, thereby reducing internal stresses and deformations in the material during the welding process. The weld deposit thus formed can provide a protective layer with desirable properties such as corrosion resistance, thermal stress, abrasive and adhesive wear, cavitation, erosion, abrasion, and other adverse factors [Brezinova 2016] [Zdravecka 2013] [Team of authors 2003].

By applying suitable deposits, we can obtain greater resistance to individual types of wear and corrosion [Tavodova 2018b]. Welding metals can be divided into groups according to their characteristic properties and wear resistance. Iron-based alloys are divided into martensitic, austenitic and alloys with high carbide content. The latter are characterized by excellent abrasion resistance, good heat resistance, acceptable corrosion resistance and weaker impact resistance. In works [Buchley 2005] [Falat 2019] it is stated that the abrasive wear resistance is also strongly influenced by the size of carbides. They are best resistant to long M_7C_3 carbides because they have better bonding to the matrix and do not break out as easily as shorter carbides.

According to [Buchley 2005], the WC deposit has a typical composition - 50-60% of the WC particle and the rest is low carbon steel. It is characterized by excellent resistance to abrasive and erosive wear, but during welding it will usually crack.

Increased hardness does not always mean better wear resistance or longer life. The amount of alloys that, although having the same hardness, varies greatly in terms of wear resistance [Team of authors 2003].

Plasma welding technology combines the advantages of TIG welding and the advantages of high energy concentration technologies (LASER, electron beam, ...). Compared to laser and electron devices, plasma welding equipment is significantly cheaper. The main advantages of plasma welding are small deformations, good weld appearance, welding of refractory metals and the possibility of welding very thin materials [Sebek 2017].

The disadvantages are higher equipment costs compared to TIG welding equipment and higher qualification requirements for welders.

Abrasive wear is defined in [STN 01 5050] as the segregation of particles from the functional surface by the effect of the hard and rough surface of the second body. It is an intense degradation process, mostly due to the effect of hard, mainly mineral particles. In this case, the particles of material are separated and moved.

In the case of abrasive wear, two crucial stages must be distinguished:

• the process of injecting the abrasive into the surface, where hardness is the decisive factor;

• surface disruption process, where interatomic bonds and the strength of the bond between the structural components at the grain boundaries play a decisive role.

Typical situations that occur during abrasive wear can be divided into:

• micro-grooving (Figure 2a),

• micro cutting (Figure 2b),

• micro cutting associated with fatigue fracture (Figure 2c),

micro cutting associated with micro cracks (Figure 2d) [Choteborsky 2009].

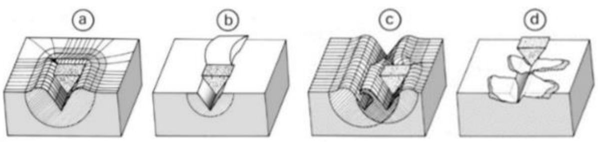


Figure 2. Schematic representation of various interactions between abrasive particles and surface [Choteborsky 2009]

Ideally, micro-scoring, the passage of a single abrasive particle does not result in any separation of material from the surface. The material is continuously moved to the sides, forming peaks adjacent to the already formed groove (Figure 3a). Over time, there may be a loss of volume due to the action of additional abrasive particles or repeated action of a single particle.

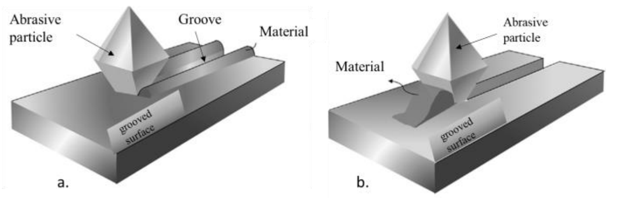


Figure 3. Scheme of micro-scoring mechanism (a.) and micro-cutting (b.) [Jahaveri 2018]

In the formation of micro-cracks, a considerable plastic deformation occurs, with transverse micro-cracks forming at the bottom of the cracks, which are the seeds of further disruption. The material may be grooved by repeatedly passing particles. Due to low cycle fatigue, parts of the material on the sides of the groove may tear off (Figure 2a). The result of micro cutting is a loss of volume in the form of a chip that is equal to the volume of the grooves formed (Figure 3b). Micro-cracks formed by the abrasive particles cause highly concentrated stresses, especially on the surface of brittle materials. In this case, the wear is high due to the formation and propagation of cracks. Microcutting and microgrooving are the dominant processes on ductile materials (Figure 4a).

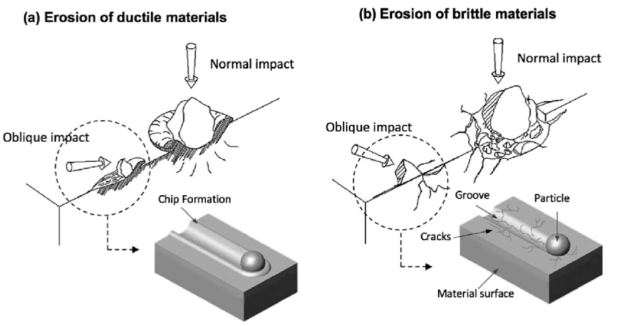


Figure 4. Impact of particle impact on different types of materials [Jahaveri 2018]

HR MAG hardfacing material, applied to material samples by plasma welding and TIG, was evaluated under laboratory conditions by the following methods:

- HRC hardness measurement,
- evaluation of abrasion resistance through K_T - coefficient of hardness,
- light and electron microscopy.

3 EXPERIMENT

Tools for crushing unwanted growths are made of structural low alloy cemented chrome-manganese steel 16MnCr5, Wr. Nr. 1.7131. It belongs to the group of low carbon steels. The microstructure of the tool was ferritic-pearlitic, without heat treatment. The tool was made by hot bulk forming technology. So it's a forging.

The results of the experiment mentioned in the article1 [Tavodova 2018a] show low efficiency of thermal or chemical-thermal treatment of exposed tool surfaces. For this reason, the experiments of hard facing materials were determined by various methods.

Hardfacing Capillary HR MAG (DIN 8555 MF 21GR-55 G) has been investigated under laboratory conditions to increase tool life for crushing unwanted growths. It is a hard welded wire tube material – special alloy - consisting of WSC carbides in a steel matrix. It is designed for welding on surfaces exposed to abrasion. The manufacturer declares the hardness in the second layer 58-62HRC. The chemical composition of the base material and weld deposit is given in Table 1 [Capilla 2019].

Chemical composition of 16MnCr5 base material [wt%]					
C	Si	Mn	Cr	WSC	Fe
0.212	0.24	1.30	1.22	-	rest
Chemical composition of HR MAG surfacing material [wt%]					
0.05	0.1	0.3	-	50	rest

Table 1. Chemical composition of base material and hardfacing material

In Figure 5a. - plasma welding sample No.1 and 5b. - TIG welding sample No. 2 is based on samples of the base material to which the HR MAG hardening material has been applied in two layers. The welding material selection, the welding conditions as well as the welding itself were carried out by professional welders, who were consulted on all expert work related to the experiment. Samples for analysis were taken by EDM.

Figure 5. Application of HR MAG to the base material with indication of sampling

The abrasive wear test was performed according to [GOST 23.208-79] methodology. Loose abrasive particle wear resistance testing of materials. The essence of the method is to compare the loss of the test material and the loss of the standard material under the same test conditions. The test device is shown in Figure 6. OTTAWA silica sand with a grain size of 0.1-0.3 mm, SiO_2 content above 96% was used for testing. The hardness corresponds to the seventh degree of Mohs mineral hardness [Benson 2015]. From the literature data, the seventh degree of hardness corresponds approximately to the hardness values according to the hardness assessment methods used in the technique, namely 450 HB, 500 HV and 54 HRC [Taylor 1949]. Testing of the abrasion resistance of the hard weld deposits according to the methodology given in this standard was chosen because of the similarity of the working conditions of the tool tested and the abrasion test conditions.

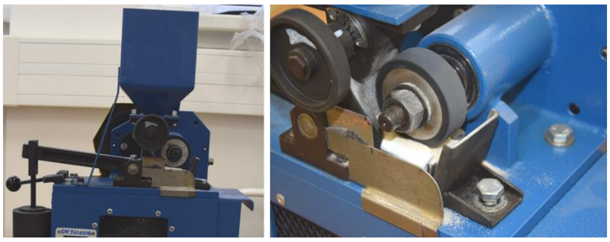


Figure 6. Abrasive wear test equipment

In the Rockwell hardness measurement the methodology according to [STN EN ISO 6508-1:1999] was used. The measurement was performed on a universal hardness tester UH250. Load force F=1 471 N.

Specimens for microstructure analyses were prepared in conductive dentacrylic, sanded on abrasive paper of 240, 400, 600 and 800 grain, moistened with water, polished with diamond emulsions, grain size 0.9, 0.3 and 0.1 µm on appropriate substrates, washed and rinsed with alcohol. Experimental light microscopy technique, Olympus GX71 inverse metallographic microscope with Olympus DP12 camera was used for the analysis. Cor etching (120 ml CH_3COOH, 20 ml HCl, 3 g picric acid, 144 ml CH_3OH) was used to etch the surfacing.

4 RESULTS AND DISCUSSION

Table 2 shows the measured hardness values of HRC and K_t as well as, for comparison, the values of the standard. This was the basic material of 16MnCr5. The hardness coefficient K_t represents the hardness ratio between the abrasive material and the loaded surface.

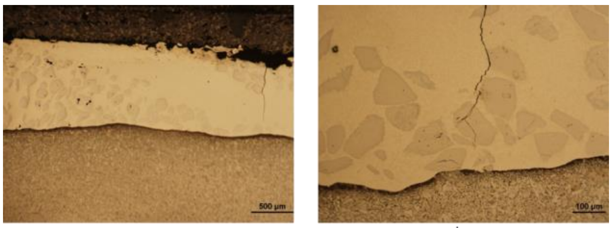
	HRC	K_T (-)
Standard 16MnCr5	18	0.4
Sample No. 1 - plasma	62	1.1481
Sample No. 2 - TIG	61	1.1296

Table 2. Values of hardness coefficient K_t and hardness HRC.

As shown in Table 2, both HRC and K_T values increased significantly over the etalon. HRC corresponds to the values given by the wire manufacturer. Both HRC and K_T increased three-fold over the standards.

After the abrasive wear test, the test sample at the spot on the test disc was analysed by light and electron microscopy methods. The purpose was to examine the surface of the material in terms of micro-scoring and micro-cutting mechanisms to which the tool is exposed in operation.

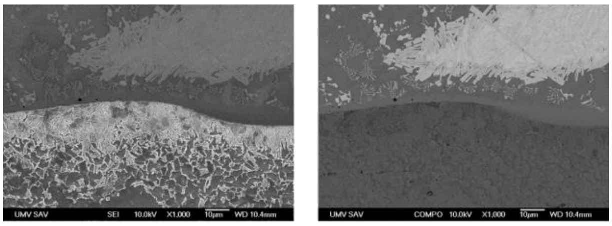
Figure 7 shows a bilayer deposit applied to sample No. 1 (plasma welding). The cracks in the two-layer surfacing (Figure 7b) are oriented perpendicular to the surfacing layer. The microstructure of the base material in the melting zone is pearlitic-ferritic formed by ferrite and perlite with a small inter-lamellar distance. The trajectory of the crack did not favour a specific phase of the structure, it was branched locally on solid carbides (Figure 7a and 7b). A crater is visible on the surface of the deposit after the hard particles have been peeled off (Figure 7a).



a. b.

Figure 7. Plasma surfacing of HR MAG material on 16MnCr5 steel base material, surfacing and base material interface (a.), details - cracked edge; crack in 1/2 thickness of weld deposit (b.)

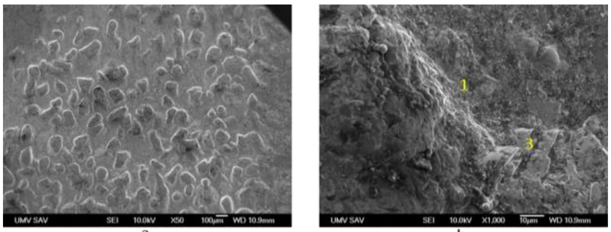
In Figure 8 is a microstructure observed by a JEOL JSM-7000F scanning electron microscope (SEM). In the underlying material in the heat affected zone, the structure was pearlitic with cementite deposited in the perlite with a small inter-lamellar distance (Figure 8a). The microstructure of the deposit showed the appearance of dendritic cells, massive carbide particles and residual eutectic formations (Figure 8a, b).



a. b.

Figure 8. Plasma surfacing of HR MAG on 16MnCr5 steel base material observed by SEM in SEI (a.) and COMPO (b.) modes

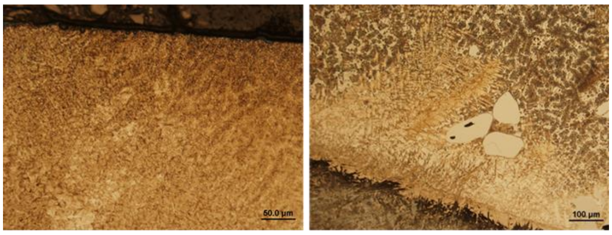
Degradation of the deposit in the abrasive wear test was controlled by a creasing and micro-cut mechanism associated with local depletion of the plastic surface of the deposit and subsequent fragmentation of this zone (Figure 9).



a. b.

Figure 9. Abrasive wear of investigated plasma cladding: overall disposition (a.), abrasive micro-cut wear mechanisms, self-carbide fragments (1), carbide fragmentation (3) (b.)

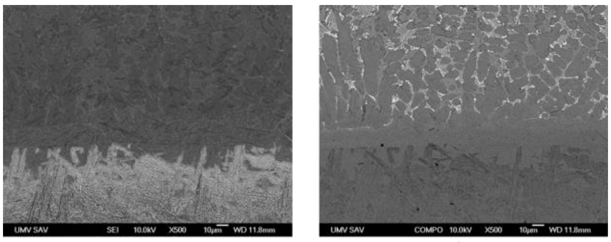
The cracks in the two-layer overlay after application of HR MG by the TIG method are oriented perpendicular to the overlay layer (Figure 10). Their incidence is relatively low as well as their size. The microstructure of the base material in the melting-down zone was pearlitic-ferritic formed by ferrite and perlite with a small inter-lamellar distance. In the base material in the thermally affected zone, the structure was pearlitic with cementite deposited in the perlite with a small inter-lamellar distance.



a. b.

Figure 10. Layout of TIG HR MAG surfacing on 16MnCr5 steel base material, surfacing and base material interface (a.), material mixing detail (b.)

In Figure 11 shows the good and satisfactory mixing of the base material and the weld deposit observed by SEM. Carbides or clusters of carbides are present in the weld deposit matrix. It is a typical morphology - fish bone, characterized by an increase in the form of dendrides.



a. b.

Figure 11. TIG mixing zone of HR MAG material and 16MnCr5 steel base material shown by SEM in SEI (a.) and COMPO (b.) modes

In Figure 12, degradation of the weld deposit is observed after the abrasive wear test. Again, as in the previous case, a creasing and micro-cutting mechanism has been identified, coupled with local depletion of the plasticity of the surface layer of the deposit and subsequent fragmentation of this zone.

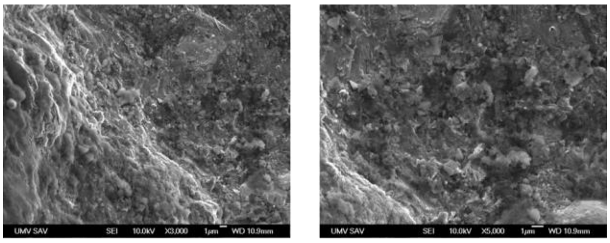


Figure 12. Abrasive wear of examined TIG deposit by micro-cutting mechanism by abrasive and self-carbide fragments

HR MAG filled wire is a specific weld material with a high WSC content (50%), but with a low number and also other chemical elements (C - 0.05%, Si - 0.1%, Mn – 0.3%, Fe - rest). Thus, a high proportion of carbides in the soft ferritic matrix has a major role. These carbides in the steel matrix can cause cracking during welding, as confirmed by microscopic analysis of the samples (Figure 7), mainly by plasma hardfacing. However, they have resistance to abrasive and erosive wear [Buchley 2005] [Falat 2019].

The HR MAG hardness is 3 times higher than the 16MnCr5 base material for both hardfacing methods. HRC measurements as well as K_T calculation confirmed this (Table 2). At a hardness coefficient K_T greater than 0.5 to 0.6, there is a relatively sharp increase in wear resistance [Blaskovits 1990]. However, increased hardness does not always mean better wear resistance or longer life. The metal matrix must resist the scoring effect of the particles and at the same time prevent carbide breakout [Team of authors 2003] [Choteborsky 2009].

By evaluating the samples using both SEM and light microscopy (Figures 7, 8, 10 and 11), it can be said that the base material has been mixed by mixing it with the first overlay layer and the overlay layers between each other in both welding methods. Using SEM, it is possible to analyse in detail the disturbances, errors or deformations on the worn surface with greater magnification as possible by light microscopy [Naprstkova 2016].

Cracks in the hard weld deposit by plasma method near the carbide particles can cause the carbides to crumble and peel from the matrix, which can lead to faster wearing of hard weld deposit (Figure 7a, 7b.). Cracks themselves do not significantly affect particle wear resistance, but can initiate fracture under static or dynamic stress. An unsuitable particle shape can cause the matrix to peel off at high loads [Choteborsky 2009] [Jahaveri 2018].

When welding by the TIG method, cracks in the bilayer cladding occurred in low to negligible amounts, as well as their size. In the base material in the thermally affected zone, the structure was paerlitic with cementite deposited in the perlite with a small inter-lamellar distance.

When evaluating the surfaces after the abrasive wear test, it can be noted that the degradation of the weld deposit during the test was controlled by the creasing and micro-cutting mechanism associated with local depletion of the plastic surface of the surfacing and subsequent fragmentation of this zone by micro-abrasive and self-carbide fragments (Fig. 9 and 12).

It can be stated that plasma cladding reached higher hardness values HRC as well as coefficient K_T. However, the separation of large carbides in the hard surfacing can predict their shedding from the softer matrix in the mass crushing process and thus confirmed by the images in Figures 7a. and b., faster wear.

On the basis of the above, in the laboratory conditions, sufficient information on the behaviour of the deposits in the abrasion conditions was obtained by experiment. However, the relevant results will be obtained only after the modified tools have been put into operation of the forestry company.

5 CONCLUSIONS

Ensuring the extension of the life of tools for crushing unwanted increases is important both economically and ecologically. The use of suitable surfacing as well a welding technique is a prerequisite for meeting these conditions of market retention as well as ensuring the requirements for forestry.

ACKNOWLEDGMENTS

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