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. Therefore, 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

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.

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 M2C 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].

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.

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. Micromachining and microgrooving are the dominant processes on ductile materials (Figure 4a).

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 Kt - 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, W. 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 article [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].

![Figure 2. Schematic representation of various interactions between abrasive particles and surface.](image)

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

![Figure 4. Impact of particle impact on different types of materials.](image)
The abrasion 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, SiO₂ 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.

**Table 1. Chemical composition of base material and hardfacing material**

|          | C | Si | Mn | Cr | WSC | Fe |
|----------|----|----|----|----|-----|----|
| Base     | 0.212 | 0.24 | 1.30 | 1.22 | -   | rest |
| Hardfacing | 0.05 | 0.1 | 0.3 | - | 50 | rest |

**Table 2. Values of hardness coefficient Kₚ and hardness HRC.**

| Standard 16MnCr5 | HRC | Kₚ (−) |
|------------------|-----|--------|
| Sample No. 1 - plasma | 62 | 1.1481 |
| Sample No. 2 - TIG | 61 | 1.1296 |

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

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).

**Table 5. Representative microstructures of 16MnCr5 steel base material.**

| Representative microstructures | SEM image |
|-------------------------------|-----------|
| Sample No. 1 - plasma | (a) Details - cracked edge | |
| Sample No. 2 - TIG | (b) Details - cracked edge | |
| Sample No. 3 | (c) Details - cracked edge | |
| Sample No. 4 | (d) Details - cracked edge | |

**Figure 8. 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).
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).

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.

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].

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 or deformations on the worn surface with greater magnification as possible by light microscopy [Naprstkova 2016].

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 dendrites.

In Figure 12, abrasion of the examined TIG deposit by micro-cutting mechanism by abrasive and self-carbide fragments.
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
„This work was supported by the Slovak Research and Development Agency under the contract No. APVV-16-0194“.

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