STRUCTURE AND TRIBOLOGICAL PROPERTIES OF SINGLE AND DOUBLE LAYER DEPOSITS

Róbert DRLIČKA[1], Radovan ŠOŠKA[2], Martin KOTUS[1], Peter ČIČO[1]

[1]Institute of Design and Engineering Technology, Faculty of Engineering, SUA in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovakia
[2]Technická inšpekcia, a.s., Trnavská cesta 56, 821 01 Bratislava, Slovakia

Abstract
The aim of the contribution was to assess the importance of the differences in the properties of single- and multi-layer coatings applicable to the renovation of elements of biomass processing equipment. The article deals with the comparison of the structure, hardness and resistance to abrasive wear in laboratory conditions of one- and two-layer hard deposits. Hardfacing powders NP 62, NP 60 WC 20 and hardfacing rod RD 571 were used for deposits. Due to the use of flame spraying technology for the first two materials, there is no significant mixing of the weld with the substrate in the first layer, therefore the differences between one- and two-layer deposits are small (in the order of one percent). We found greater differences in the layers when hardfacing the rod with an oxy-acetylene flame (up to 36.04%). However, the biggest differences naturally result from the different chemical composition and resulting structure of the deposits, while the highest wear resistance values are achieved by deposits with a high content of tungsten carbides.

Key words: *repair; hardfacing, hardness; abrasive wear resistance.*

INTRODUCTION

Biomass processing equipment is made mainly of common structural steels. The most exposed parts can be made of more resistant materials, e.g. stainless steels. In operation, due to combined biological, chemical-physical processes and mechanical effects, degradation occurs, which can lead to a reduction or loss of function. In some cases, it can also results in damages with effects on the environment and employees. Early detection using appropriate diagnostic methods (e.g. ultrasound measurement of the thickness of the vessels) makes it possible to carry out a repair by replacing the worn material with a new layer, for example by welding. Locally or even on a larger area, it is possible to apply a material with selected properties that better withstands the load.

The resulting chemical composition, mechanical properties and resistance of the weld deposit depend on the material used, the welding technology and the degree of mixing of the hardfacing material with the substrate, if it is a single-layer weld. In other layers, the composition of the deposit is close to designed, but its thickness increases, which can be limiting and costly (*Votava, 2014; Kalincová et al., 2018*).

The smallest mixing can be achieved by flame spraying, because here we can create a diffusion joint using the proper technological procedure. Welding using an electric arc leads to partial mixing of the welding material and the base material (*Ťavodová et al., 2018*).

Müller et al. (2018) in their experiment point to significant mixing of the substrate and hardfacing material of the hard deposit created by the welding rod. They state that the generally recognized fact that the higher hardness of the material also guarantees its higher resistance to wear was not demonstrably proven in the tests.

Jankura (2013) measured the hardness in laboratory tests, observed the relative wear resistance and analysed the microstructure of one-layer, two-layer and three-layer hardfacing deposits. He observed the behaviour of two additional deposits, obtained by hardfacing with welding rods E-B 508 and E-B 518. From the results, he expressed the conclusions that the optimal properties of hardness and wear of hardfacing deposits are achieved in the third layer only and it is necessary to apply the welding with parameters resulting in minimal melting of the substrate material.

The results from the authors *Zdravecká (2014), Kotus & Čičo (2005), Votava et al. (2020),* also indicate that high hardness does not automatically guarantee better wear resistance.

In this contribution, we will focus on the comparison of the chemical composition, relative wear resistance, hardness and microstructure of one- (single) layer and two- (double) layer deposits of 3 selected hardfacing materials.

MATERIALS AND METHODS

Individual single-layer and double-layer hardfacing deposits were applied to steel grade C45 substrate (samples size 150x45x10 mm) with a minimum deposit thickness of 2-4 mm.
For laboratory verification of resistance to wear, two metal hardfacing powders NP 62 and NP 60 WC 20 and filled rod RD 571 were selected.

Tab. 1 Typical chemical composition (wt.%) and hardness (HRC) of used hardfacing materials

Material	C	Si	B	Fe	Cr	WC	Ni	W_2C	Hardness
NP 62	0.9	5.5	4.0	5.0	20.0	-	rest	-	58-65
NP 60 WC 20	0.6	5.0	3.9	5.0	20.0	20.0	rest	-	75-82
RD 571	0.1	0.8	0.3	-	5.0	-	15.0	60.0	min. 65

Metal powders are highly alloyed with silicon, boron and chromium and have a higher carbon content, materials NP 60 WC 20 and RD 571 contains a significant proportion of tungsten carbide.
An NPK-3 torch with a medium neutral flame and a welding speed of 3-4 $mm.s^{-1}$ was used for the application of metal powders. The rod was hardfaced with a medium neutral oxygen-acetylene flame with a welding speed of 2-3 $mm.s^{-1}$.
After hardfacing, the samples were cut into dimensions of 25x22.5 mm using an abrasive water jet to avoid thermal effects during cutting.
Hardness measurements were realized on a HPO 250 hardness tester using Vickers method, according to the STN EN ISO 6507 standard.
The relative abrasive wear resistance measurement on the sanding cloth was realized on 24 samples, 12 of them with a single-layer deposit and 12 of them with a two-layer deposit, and each type of deposit was on 4 samples. The deposits were made in the fixture on one base of the test cylinder for tribological tests, then machined to the standardized geometric shape, size and roughness of 0.4μm.
The deposits on the faces of the rollers were aligned on a surface grinder to Ra=0.4 μm using sufficient cooling so that no heat-affected area was generated on the samples.
The tribological test was performed on the device for testing the resistance to abrasive wear on the sanding cloth according to the ČSN 01 5084 standard.
The average mass losses were determined and the relative abrasive wear resistance was calculated from them using the weight of the samples before and after the test measurement on the PRECISA 205 A device with an accuracy of 10^{-4} g.
Metallography was done on twelve samples; six of them were single-layered and six were double-layered. Before the test, the samples were cut to smaller dimensions and inserted into a resin mold, then they were polished and etched. Samples created using metal hardfacing powders were etched using a solution created from H_20, HNO_3 and HF in a ratio of 3:2:1. A light microscope AXIO OBSERVER was used to monitor the structure of the deposits. On the basis of metallographic analysis, the microstructure of welds was evaluated using the standard STN EN ISO 17 639 – Destructive tests of welds of metallic materials. Macroscopic and microscopic analysis of welds.

RESULTS AND DISCUSSION

During the laboratory tests, the hardness, relative abrasive wear resistance and the microstructure of the welds were evaluated.
As mentioned above, knowing the properties of individual deposits allows us to choose the appropriate material and technology that will ensure the resistance of the deposits applied on the surface of the part.
In the laboratory, we therefore further investigated the resistance of one- and two-layer deposits by determining the relative resistance of the hardfacing materials.

Hardness values for all three hardfacing materials divided for 1-layer and 2-layer deposits are presented in Fig. 1.
The average value of the hardness of the single-layer deposit of NP 62 powder was 1095 HV30, the average value of the double-layer deposit was 1105 HV30, which represents a 0.91% increase in hardness.
The average value of the hardness of the single-layer weld from NP 60 WC 20 was 1176 HV30, the double-layer 1143 HV30, which is a decrease in hardness by 2.8%.
Filled stick for flame hardfacing in single-layer deposit reached an average hardness value of 681 HV30, double-layer reached a value of 865 HV30, which is a 27% increase in hardness.

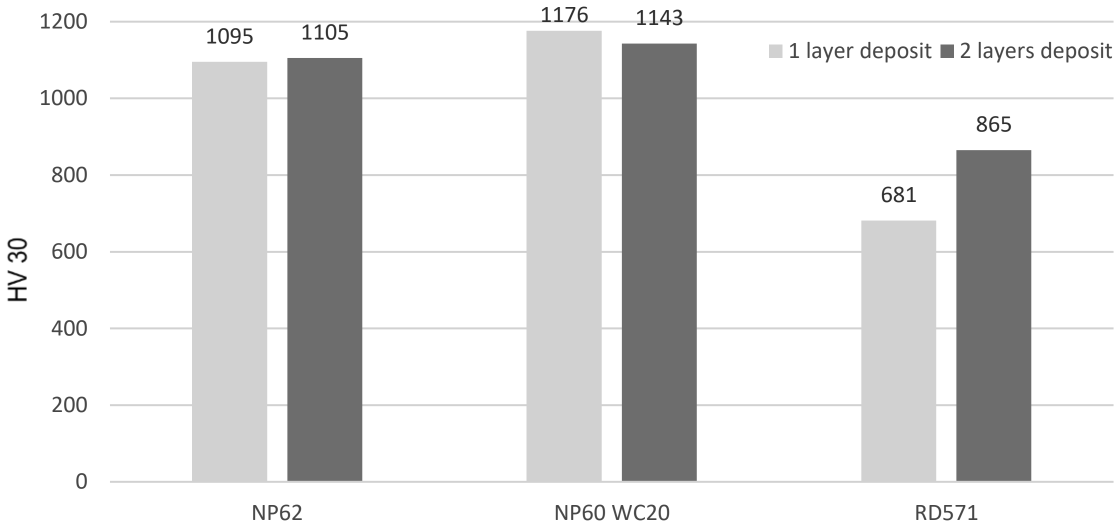


Fig. 1 Hardness of single-layer and double-layer deposits

The average mass loss and the relative wear resistance of the deposits are presented in Tab. 2.
Based on these data, relative abrasive wear resistances for the harfacing deposits are presented in the graph in Fig. 2.

Tab. 2 Average mass loss and relative abrasive material resistance

Material	Relative mass loss, g		Relative abrasive resistance, -	
	1 layer	2 layers	1 layer	2 layers
NP 62	0.9	5.5	4.0	5.0
NP 60 WC 20	0.6	5.0	3.9	5.0
RD 371	0.1	0.8	0.3	-

The relative resistance to abrasive wear on the sanding cloth for a single-layer deposit made of NP 62 was Ψ_{abr} = 1.55, and the double-layer one reached the value Ψ_{abr} = 1.688, which represents an increase of 8.9%.
The relative resistance to abrasive wear on the sanding cloth for the single-layer deposit of NP 60 WC 20 reached Ψ_{abr} = 4.4, for the double-layer it reached almost the same value Ψ_{abr} = 4.38, basically the same values.
The best result in relative resistance was achieved by the filled rod, the value of relative resistance was Ψ_{abr} = 11.57 for the single-layer deposit, Ψ_{abr} = 15.74 for the two-layer deposit, which represents an increase of 36.04%.
Nickel-based hardfacing powders has a limited ability to improve relative abrasive wear resistance, while the tungsten carbides appears to be a very effective wear propagation barrier, improving the abrasive wear resistance significantly.

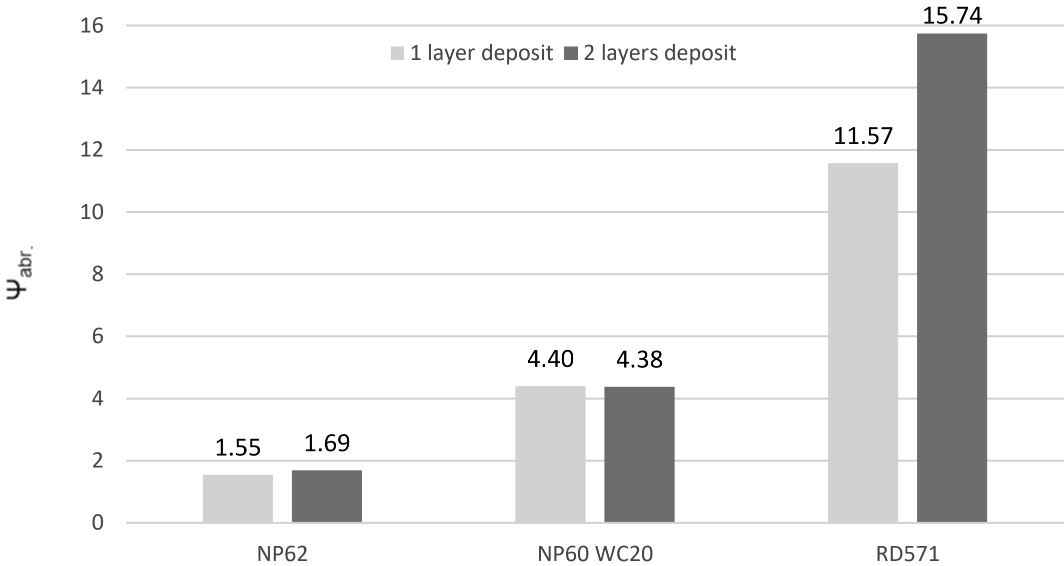


Fig. 2 Relative abrasive wear resistance of deposits

In the case of the first hardfacing material, single-layer and double-layer deposits have approximately the same chemical composition, the hardness of the coatings was also the same, but the relative wear resistance of the two-layer coating increased by only 8.9%. The microstructure of a single-layer weld is identical to the microstructure of a two-layer weld, see Fig. 3.

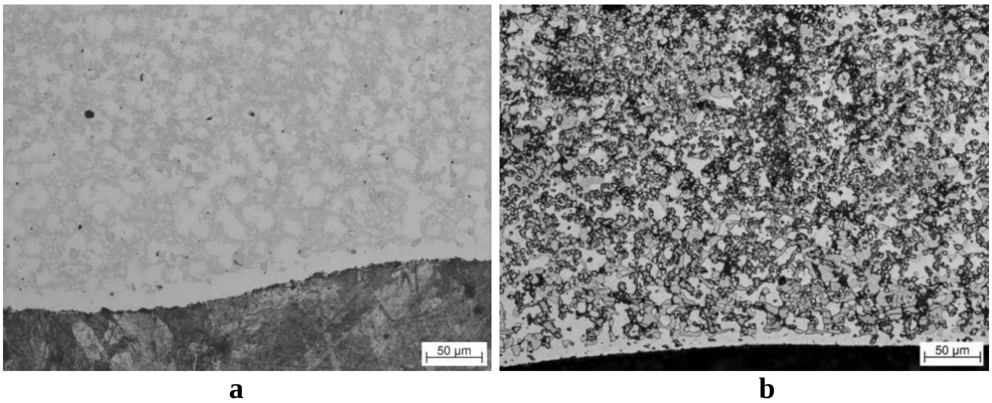


Fig. 3 Microstructure of single-layer (a) and double-layer (b) deposits of NP 62

For the second hardfacing material NP 60 WC 20, single-layer and double-layer welds have approximately the same chemical composition, the hardness of the two-layer deposit has slightly decreased, and the relative wear resistance of the one- and two-layer deposits has reached the same value.

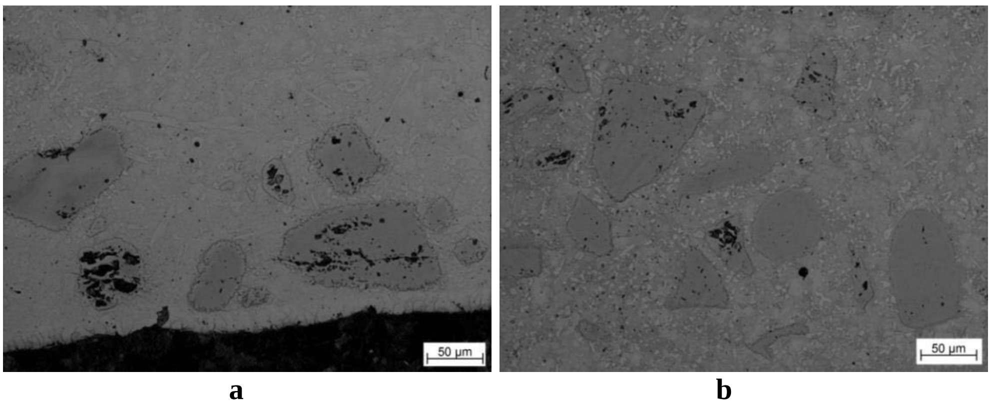
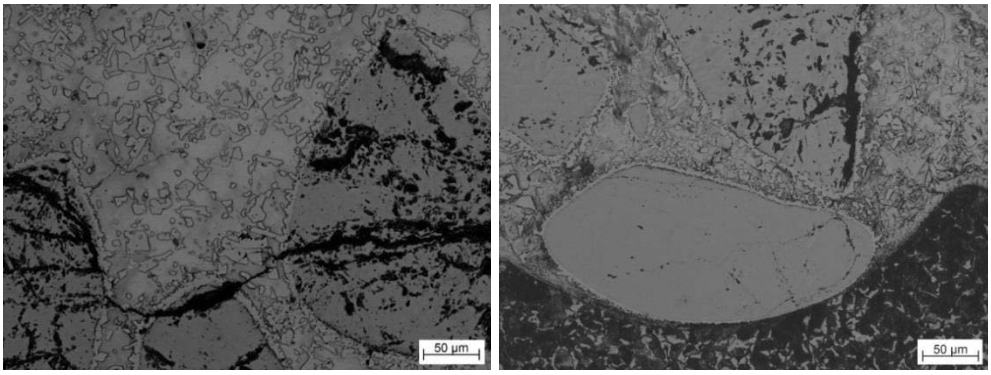


Fig. 4 Microstructure of single-layer (a) and double-layer (b) deposits of NP 60 WC 20

In the single-layer deposit of NP 60 WC 20, we can again observe (see Fig. 4) small excluded phases together with tungsten carbide particles of size 60-80 μm. The microstructure of the NP 60 WC 20 two-layer deposit remained the same. In the microstructures, we can observe the uniform distribution of tungsten carbides and also the fact that the carbide particles do not have fused edges, which probably results in an interruption of the grooving by abrasive grains and increased resistance to wear.



a **b**

Fig. 5 Microstructure of single-layer (a) and double-layer (b) deposits of RD 571

In the case of the third hardfacing material RD 571, it can be seen that the individual single- and double-layer deposits have almost the same chemical composition.
Compared to the two previous hardfacing materials, it reached the lowest hardness, but it can be caused by the measurement missing the carbide grains. Despite the measured lowest hardness value, the relative resistance of one and two-layer deposits was very high. It even increased by 36% for the double-layer deposit.
The microstructure of the single-layer deposit was formed by relatively large unfused tungsten carbide grains, which are embedded in the basic dendritic matrix (Fig. 5). Tungsten carbide grains reach a size of 200 to 300 μm.
According to the results of the research of *Chotěborský et al. (2009)* dedicated to the issue of the size of carbide grains for the wear of deposits, it is clear that with the increase in the size of the carbide grains stored in the basic matrix of the deposit, the resistance of the material against abrasive wear also increases.
Individual excluded phases have a small size, the NP 62 powder coating approaches nanostructured materials. It has a granular character, while the morphology is formed by austenite, as the nickel content is at the level of 65% of the total content of elements.
Tungsten carbide grains formed in RD 571 deposits are several times larger compared to NP 60 WC 20 carbide grains. The increased wear resistance was due to the uniform distribution of W_2C. These kept their size and square shape during the hardfacing process.
Until now, there is no consensus on the most advantageous type of structure in terms of resistance to abrasive wear. Some authors consider the austenitic-carbide structure to be the most advantageous, others the martensitic-carbide structure (*Chotěborský, 2019; Blaškovič, et al., 1990*)

CONCLUSIONS

The deposit of NP 62 in both single-layer and double-layer form shows approximately the same structure, which is due to the fact that the hardfacing layer – substrate binding is characterized as a diffusion and there is probably no significant mixing. In the second layer, a finer structure of globular formations can be seen.
NP 60 WC 20 the microstructure in single-layer and double-layer deposit remains the same, there is practically no mixing of the first and second layers, and no mixing with the base material in the case of the first layer, because the hardfacing material is joined by the diffusion. From the results obtained from these two materials, it can be concluded that the material NP60 WC20 could be more resistant to wear in the same operational conditions.

In the case of powder coating materials, it is a diffuse application, there is no large mixing of the coating powder with the base material, nor is there a large mixing between the one- and two-layer coating.
While it is not valid for the third hardfacing material RD 571, from the results obtained from these materials, the conclusion can be drawn that the material RD 571 should be the most wear-resistant under the same operating conditions.

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Corresponding author:
doc. Ing. Martin Kotus, PhD., Institute of Design and Engineering Technology, Faculty of Engineering, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, Nitra, 949 76, Slovak Republic, phone: +421 37 641 5689, e-mail: martin.kotus@uniag.sk