

Reparatory and Manufacturing Hard-Facing of Working Parts Made of Stainless Steels in Confectionary Industry

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ABSTRACT

In this paper, for the sake of improving the reparatory hard-facing technology is especially analyzed reparatory hard-facing of tools for manufacturing compressed products in confectionary industry. Those products are being made of a mixture consisting of several powdery components, which is compressed under high pressure. In that way the connection between particles is realized, thus achieving certain hardness and strength of the confectionary product. The considered tool is made of high-alloyed stainless steel. The tool contains 30 identical working places. Besides the production process wear, on those tools, from time to time, appear mechanical damage on some of the products' shape punches, as cracks at the edges, where the products' final shapes are formed. Those damages are small, size wise, but they cause strong effect on the products' final shape. The aggravating circumstance is that the shape punch is extremely loaded in pressure, thus after the reparatory hard-facing, the additional heat treatment is necessary. Mechanical properties in the heat affected zone (HAZ) are being leveled by annealing and what also partially reduces the residual internal stresses.

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1. INTRODUCTION

The first part of the paper analyzes the damage of the shape punches and explores the possibility of their repair hardfacing. It also describes predominant types of wear - abrasive, adhesive and fatigue wear. The second part of the paper deals with repair hardfacing procedures. After the filler materials and the repair procedures had been chosen and technological hardfacing parameters defined, hardfacing was performed

first on the models and then on the real parts. The models were used for metallographic analysis, microstructure measurements and tribological investigations. The real hardfaced parts were mounted on the tool holder and used in the production process where they were exposed to real operating conditions, after which, the wear scar width was measured. In the final part of the paper, commentary on the obtained results was given. Figure 1 shows a new shape punch before it is placed in service.



Fig. 1. A new shape punch.

2. DAMAGE OF THE SHAPE PUNCHES

2.1 Damage caused by tribological processes

Tribological processes are main causes (50-80%) of surface damage to working parts of machines and devices, and the costs of dealing with this damage can be very high [1-3]. In order to reduce the costs it necessary to apply modern tribological knowledge regarding construction and operation, and to consider economical use of materials, rational use of energy sources, efficient maintenance, as well as measures to increase the life and reliability of the products. Hardfacing is primarily used to restore parts worn during service and to rebuild damaged or new faulty parts, but it is also increasingly applied to new components, which are hardfaced with hard alloys. In some cases, hardfacing can even replace heat treatment. Due to its wide application, hardfacing has an important place among the so-called advanced technologies. Major working parts of machines, assemblies and devices are usually made from expensive alloys so the fact that they can be repaired not only reduces downtime, but it also provides savings by reducing costs of expensive base materials and final machining process. Hardfacing is cost-effective if the repair hardfacing costs do not exceeded the price of a new part. This particularly applies to large size parts and mass production. Nevertheless, repair hardfacing of unique machines and devices has to be performed regardless of the costs [4-11].

Confectionery tools are subject to mechanisms of abrasive, adhesive and fatigue wear. Abrasive wear is caused by the constant contact between a great amount of hard candy mass and the working surfaces of the tool during the production process (approximately 300 kg/h). Abrasive wear is much more intensive when sub-cooled sugar mass is used because sugar crystals formed in the process of peripheral sugar crystallization act as abrasives. Adhesive wear occurs when movable and fixed

parts of the tools come into contact under the effect of pressure needed to deform the product. The pressure increases when the sugar mass is sub-cooled. Fatigue wear occurs as a result of frequent changes in the loading direction when movable and fixed parts come into contact during forward and backward movement of the tool. Worn shape punches are shown in Fig. 2.



Fig. 2. Worn shape punches.

2.2 Damage caused by mechanical influences

In addition to tribological damage, mechanical damage is also quite often in rotary tools containing several shape punches. The most frequent mechanical damage is brittle fracture of the return spring of the shape punch. If a broken piece falls into the working area of the tool, it gets hit by the sharp edges of the shape punch. Since the piece of the spring is much harder than the candy mass, it damages sharp edges or even causes the shape punch to fracture. Damage in the edges of the shape punch is usually small, only a few millimetres in size, but it has a bad effect on the quality of work and the quality of the product. The shape punch fracture is a serious damage that causes a major downtime and requires trained staff to repair it. In that case, the tool is dismantled and the broken shape punch is restored or replaced with a new one.

Since the main cause of fracture is the low quality of springs, there have been many investigations and activities aimed towards solution of this problem. However, brittle fracture remains a cause of damage. Figure 3 shows damage caused by broken pieces of the spring.



Fig. 3. Damage caused by broken pieces of the spring.

Mechanical damage can be caused by foreign objects entering raw materials or the machine during the technological production process, although there are some measures (magnetic separators and sifters) used to prevent these things from happening. Foreign objects can be either metal or non-metal. In most cases, accidental damage causes interruptions in the production process, which calls for quick responses and timely interventions. Whenever it is possible, the fastest solution to these problems is to apply an adequate repair technology at the place where the damage occurred, and then manual grinding of the hardfaced part (Fig. 4). Such procedures are cost-effective and often very quick, and they significantly reduce the downtime.



Fig. 4. Manual grinding of the hardfaced shape punch.

3. SELECTION OF PROCEDURES, FILLER MATERIALS AND HARDFACING PARAMETERS

3.1 Base and filler materials

Tools in food and confectionery industry are usually made of quenched and tempered martensitic stainless steels. They contain 0.15-1.0% C and 12-17% Cr, which enables formation of martensitic structure from the austenite region, even at slow cooling. The chemical composition of the steel Č4172 (JUS) – X20Cr13 (EN 10027) and applications of the base material (BM) are given in Table 1 [12].

Table 2 gives basic information on type of the heat treatment and the most important mechanical properties.

Due to practical reasons, since the damage was small, the shape punches were hardfaced using the filler material of the same chemical composition, made from old removed shape punches. They were soft annealed and then ground into strip pieces with the cross-section of 0.5×1 mm.

Table 1. Base material properties (BM).

Labelling		Chemical composition, %			Notice
Steel Labelling by JUS	Manufacturer's code	C	Si	Cr	
Č4172	"Prokron 3"	0.20	1.0	13	Tools in food industry, cutlery, surgical instruments, wood processing knives, bearing rollers, pressing dies etc.

Table 2. Heat treatment and the most important mechanical properties [12].

Steel code	Forging, Temperature, °C	Soft annealing		Hardening			Tempering Temperature, °C
		Temperature, °C	Hardness, HB	Temperature, °C	Cooling aid	Hardness, HRC	
Č4172	1150-750	750-800	220	980-1030	Oil/Air	44-53	650-750

Table 3. Main properties and chemical composition of the filler materials [12].

Code	Chemical composition, %						Hardness
	C	Si	Mn	Cr	V	Mo	
Č4172	0.20	1.0	1.5	13	-	-	400 HV
Č4850	1.50	0.30	0.30	12.0	0.90	0.80	55 HRC

The second filler materials was also obtained from removed tools used in manufacturing of compressed hard candy (made of steel Č4850 (JUS) – X155CrVMo12-1 (EN 10027)). In addition to these two, there were two more powder filler materials used (Castolin BRONZOCHROM 10185 - hardness 400 HV and Castolin EUTALLOY 10494 - hardness 35 HV) (Tab. 3). Main properties of these filler materials are given in the manufacturers' catalogues [12].

3.2 Choosing repair technology

Taking into consideration the weight of the parts, relatively small damage, availability of adequate filler materials and the possibility to use own equipment, two hardfacing procedures were chosen:

1. TIG hardfacing (basic method), and
2. Gas hardfacing using powder (additional/alternative method).

Both of the two methods involved two filler materials, and in each procedure two real parts and a sample for tribological tests were hardfaced. As explained, the filler materials for TIG procedure were prepared by grinding soft annealed shape punches with the cross-section of approximately 0.5×1 mm. The second procedure involved two filler powders of

different hardness made by world renowned manufacturers [12,13].

Damaged edges of two shape punches were hardfaced in two passes with the lowest power possible in order to avoid hardening and flaws at the sharp edges (at the beginning or at the end of the hardfaced layers). The height of one-pass hardfaced layer was about 1-1.5 mm, while the width ranged from 2-2.8 mm. The damaged edge was placed in a slanting position and then hardfaced from top down using the leftward technique. This way, the penetration was decreased and the height of the hardfaced layer was increased. The filler material codes and hardfacing parameters are given in Table 4.

One of the two hardfaced shape punches was tested under the real operating conditions, while the other one was cut transversely to the hardfaced layer and used for metallographic investigations and hardness measurements.

The third shape punch was hardfaced and cut out into a block used for tribological investigations (Fig. 5c). Hardfacing was carried out in two layers as show in Fig. 5b. The height of one layer was 1.2-1.5 mm and the width was 3-4 mm (Fig. 5a). The TIG-hard facing parameters for tribological investigations are given in Table 5.

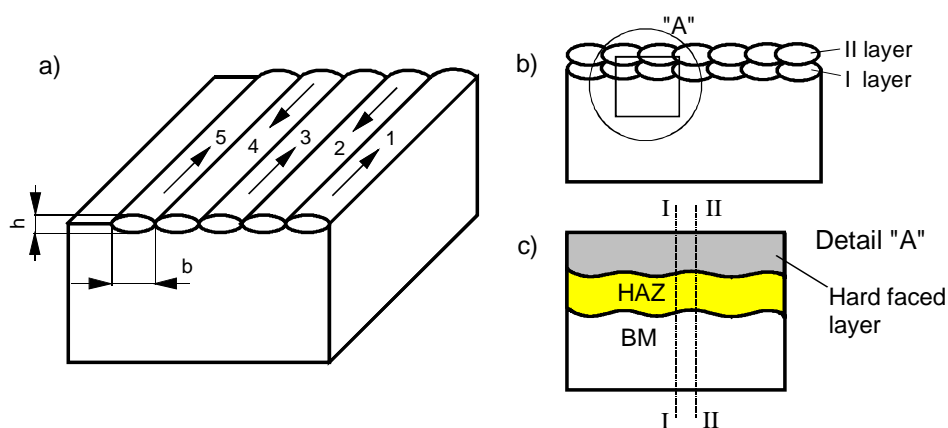


Fig. 5. The order of hardfaced layer deposition: a- 1 layer, b- 2 layers, c- metallographic sample (block).

Table 4. Technological parameters for hardfacing of real parts using TIG procedure [13].

Thickness, mm	FM code	FM cross-section, mm	I, A	U, V	Number of passes	Number of pieces
12	Č4172	0.5×1.0	15-20	10	2	2
12	Č4850	0.5×1.0	15-20	10	2	2

Table 5. Technological parameters for hardfacing of models using TIG procedure.

Thickness, mm	FM code	FM cross-section,	I, A	U, V	Number of	Number
12	Č4172	1.0 x 1.0	50-60	12	2	1
12	Č4850	1.0 x 1.0	50-60	12	2	1

Table 6. Technological parameters for the gas hardfacing of real parts using powder filler materials [12,14].

Thickness, mm	FM code	Hardness, HRC	Chemical composition	Working temperature, °C	Welding procedure
12	Castolin EUTALLOY BRONZOCROM 10185	36-42	Ni-B-Si powder	1100	Oxy-acetylene
12	Castolin EUTELLOY 10494	35-40	Ni-Cr-Fe-Be-Si powder	1100	Oxy-acetylene

Due to increased hardness, the blocks for model testing were erosion cut by a wire electrode (using low power and water bath), and then ground to the depth of 0.5 mm from the cut surface, with abundant cooling using the adequate cooling aid. This was done in order to reduce the influence of heat on the process of sample preparation.

Powder gas hardfacing was performed using two different powder filler materials whose main properties and technological parameters are given in the catalogues [12]. The number of hardfaced samples and the technological process of sample preparation is the same as with TIG hardfacing. Technological parameters for the gas hardfacing using powder filler materials are given in Table 6.

4. EXPERIMENTAL INVESTIGATIONS ON MODELS AND SHAPE PUNCHES

4.1 Metallographic analysis and hardness measurements on real parts

Metallographic investigations and hardness measurements were performed on models obtained by hardfacing and cutting real parts (shape punches) normally to the hardfaced cutting edge (Fig. 6).

**Fig. 6.** Direction of microhardness measurements on a hardfaced edge of a shape punch.

4.1a Metallographic investigations and hardness measurements - Sample I

Macro appearance of the TIG- hardfaced shape punch is shown in Fig. 7. The depth of penetration was about 0.8 mm, while the height of the hardfaced layer was approximately 2.5 mm. There were neither cracks nor flaws on the cross-section, which means that the bonding between the hard faced layer and the base material was firm.

**Fig. 7.** Hardfaced shape punch – Sample I (BM-Č4172, FM-Č4172)

The base material microstructure was estimated as small-grained interphase quenched and tempered structure. The hardfaced layer has martensitic structure with needle-shaped carbides at metal grain boundaries. The transient zone is hardly visible and is dominated by interphase structure with little residual martensite. The HAZ is about 5 mm wide, not especially prominent, and it has interphase quenched and tempered structure. The hardness distribution diagram shows that hardness decreases in the HAZ, which means that tempering and not hardening occurred. This is highly favourable because it reduces the possibility of cracking. Hardening in the HAZ would affect the desired mechanical properties of the repaired shape punch. Hardness distribution and microstructures of the hardfaced layer zones are given in Figs. 8-1 and 8-2 [15-18].

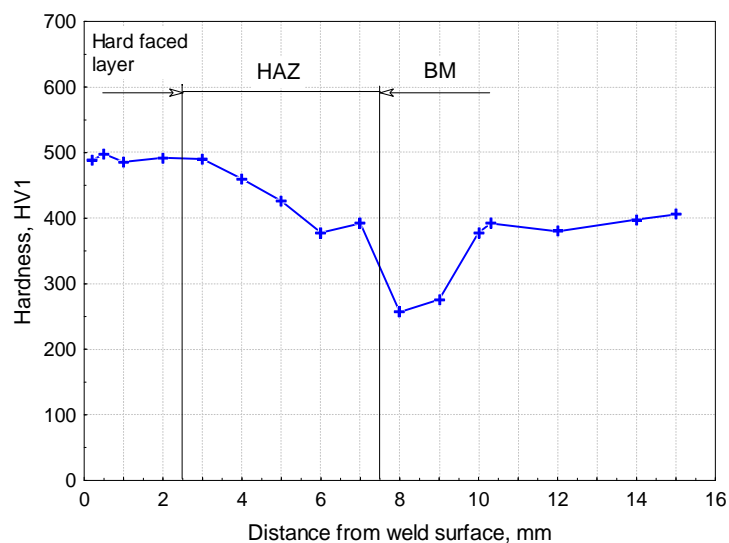
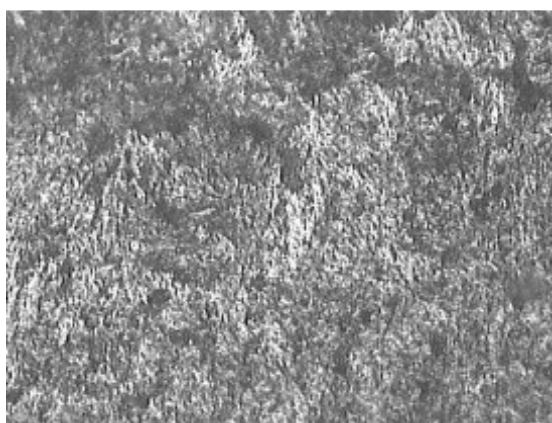
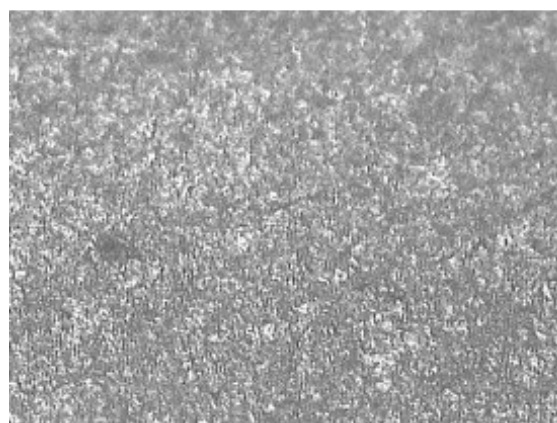


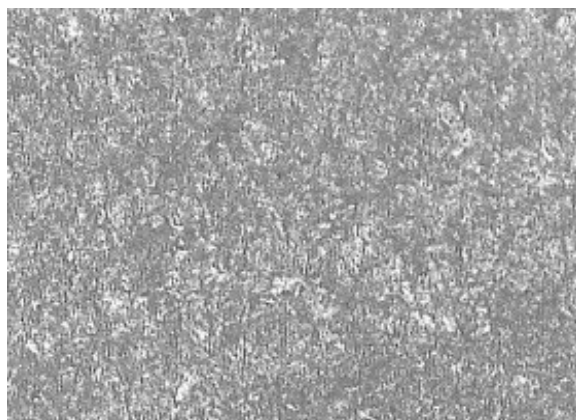
Fig. 8-1. Distribution in the cross-section of the hardfaced layer - Sample I (BM-Č4172, FM-Č4172).



The hardfaced layer – martensitic structure with needle-like carbides at metal grain boundaries (200×)



HAZ – interphase quenched and tempered structure (200×)



BM – homogenous small-grained interphase quenched and tempered structure (200×)

Fig. 8-2. Microstructures of typical hardfaced layer zones – Sample I.

4.1b Metallographic investigations and hardness measurements - Sample II

Macro appearance of the shape punch hardfaced using TIG procedure is shown in Fig. 9. The depth of penetration was about 0.8 mm while the height of the hardfaced layer was approximately 2.2 mm.



Fig. 9. Hardfaced shape punch - Sample II (BM-Č4172, FM-Č4850).

There were neither cracks nor flaws on the cross-section, which means that the bonding between the hard faced layer and the base material was firm.

The base material microstructure was estimated as small-grained interphase quenched and tempered structure. The hardfaced layer has martensitic structure with needle-shaped carbides at metal grain boundaries with a lot of residual austenite. The transient zone is easily visible and dominated by interphase structure with little martensite. The HAZ is about 5 mm wide, it is not especially prominent and it has interphase quenched and tempered structure. The hardness distribution diagram shows that hardness increases in the HAZ, which is explained by hardening of the base material particularly in the transient zone. Hardness distribution and microstructures of the hardfaced layer zones are given in Figs. 10-1 and 10-2.

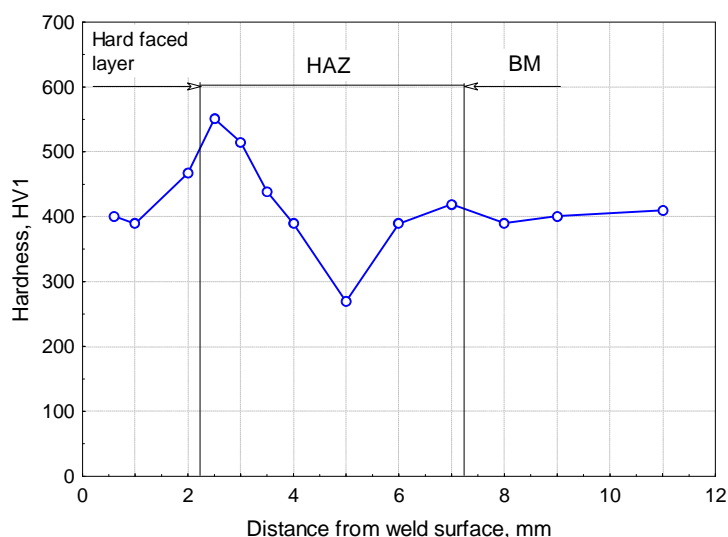


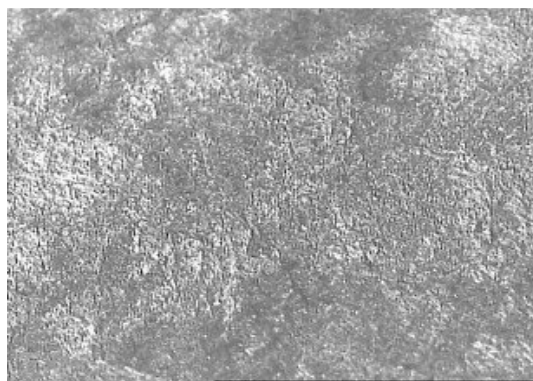
Fig. 10-1. Distribution of microhardness in the hardfaced layer - Sample II (BM-Č4172, FM-Č4850)



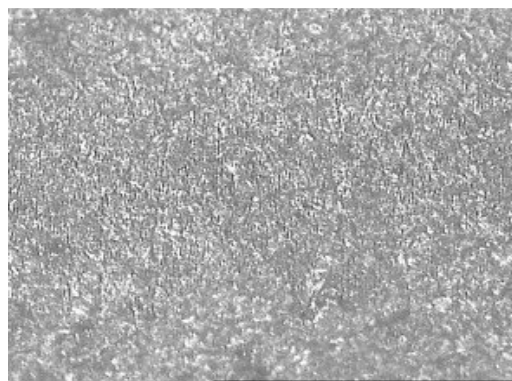
Hardfaced layer - martensitic structure with needle-shaped carbides at grain boundaries with residual austenite (200×)



Hardfaced layer/HAZ - interphase quenched and tempered structure with residual martensite (200×)



HAZ - interphase quenched and tempered structure (200×)



BM - homogenous small grained interphase quenched and tempered structure (200×)

Fig. 10-2. Microstructures of typical hardfaced layer zones.

4.1c Metallographic investigations and hardness measurements - Sample III

Macro appearance of the shape punch hardfaced using gas-powder hardfacing is shown in Fig. 11. The height of the hardfaced layer was approximately 1.3 mm.



Fig. 11. Macrostructure of the hardfaced layer obtained by gas hardfacing (BM-Č4172, FM-powder Castolin EUTALLOY BRONZOCROM 10185).

There were neither cracks nor flaws on the cross-section, which means that the bonding

between the hard faced layer and the base material (BM) was firm.

The base material microstructure was estimated as small-grained homogenous interphase quenched and tempered structure. The hardfaced layer has austenitic structure with small-grained needle-shaped martensitic structure at austenite grain boundaries. The transient zone is visible because the base and filler materials have not mixed. The HAZ is not particularly wide, but the metal grains of interphase quenched and tempered structures have clearly increased in size. The hardness distribution diagram shows that hardness increases in the HAZ, which is explained by hardening of the base material. The increase in hardness is not significant, therefore it will not have a considerable effect on the output properties of the hardfaced layer. Hardness distribution and microstructures of the hardfaced layer zones are given in Figs. 12-1 and 12-2.

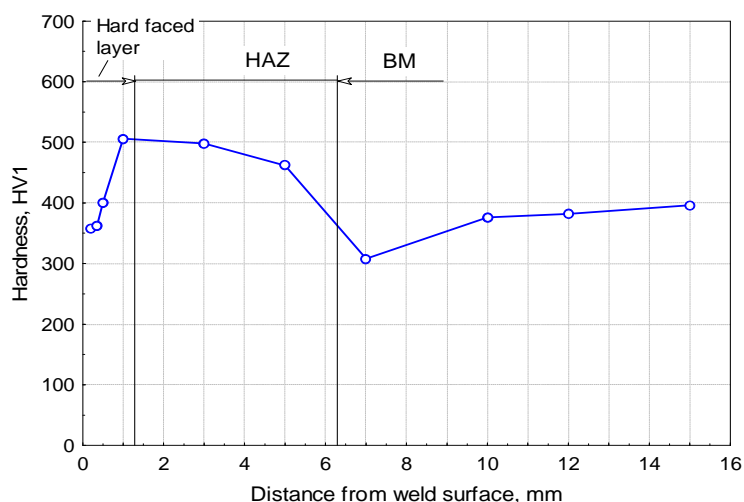
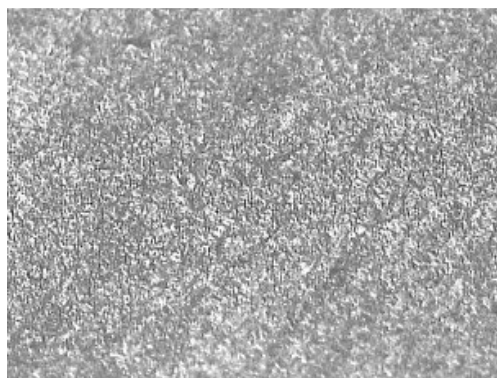


Fig. 12-1. Distribution of microhardness in the cross-section of the hardfaced layer - Sample III (BM-Č4172, FM-powder Castolin EUTALLOY BRONZOCROM 10185).



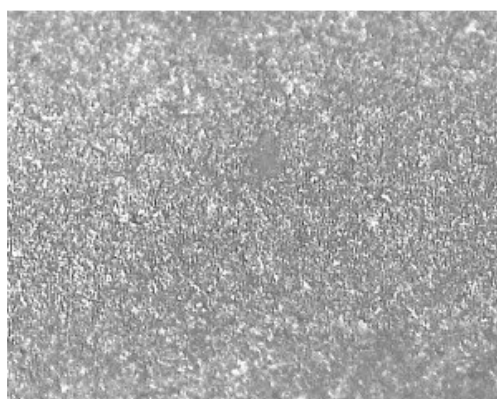
Hardfaced layer – austenitic structure with small-grained needle-like martensitic structure at grain boundaries (200×)



Hardfaced layer/HAZ –coarse-grained interphase quenched and tempered structure with residual martensite (200×)



HAZ – interphase quenched and tempered structure (200×)



BM – homogenous small-grained interphase quenched and tempered structure (200×)

Fig. 12-2. Microstructures of typical hardfaced layer zones.

4.1d Metallographic investigations and hardness measurements - Sample IV

Macro appearance of the shape punch hardfaced using gas-powder hardfacing is shown in Figure 13. The height of the hardfaced layer was approximately 2.25 mm.



Fig. 13. Macrostructure of the hardfaced layer obtained using gas hardfacing procedure (BM-Č4172, FM-powder Castolin EUTELLOY 10494).

There were neither cracks nor flaws on the cross-section, which means that the bonding between the hard faced layer and the base material was firm enough to ensure good

properties of the hardfaced layer, i.e. of the hardfaced part.

The base material microstructure was estimated as small-grained homogenous interphase quenched and tempered structure. The hardfaced layer has austenitic structure with small-grained needle-shaped martensitic structure distributed at austenite grain boundaries in a net-like pattern. The transient zone is easily visible because the base and filler materials have not mixed. The HAZ is about 5 mm wide, but it is not very prominent although it has been treated with aqua regia [16]. The hardness distribution diagram shows that hardness increases in the HAZ, which is explained by hardening and change in the structure of the base material due to the input heat. The increase in hardness is not significant so it will not have a considerable effect on the properties of the hardfaced part. Distributions of hardness and microstructure of hardfaced layer zones are given in Figs. 14-1 and 14-2.

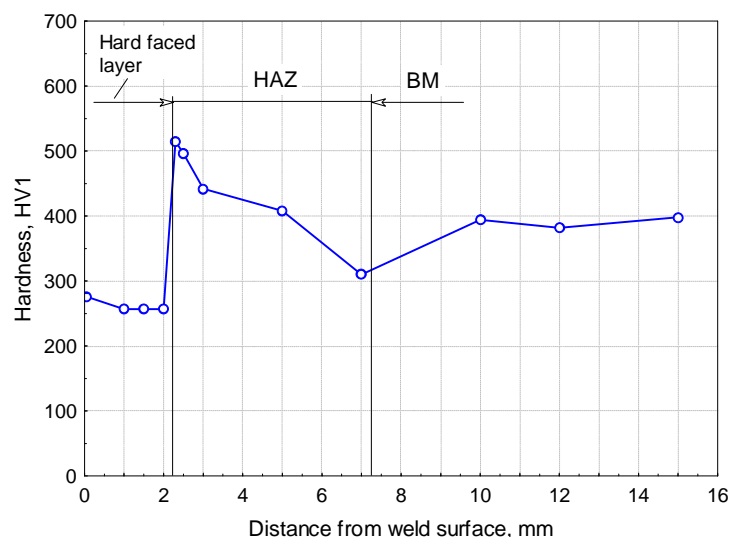
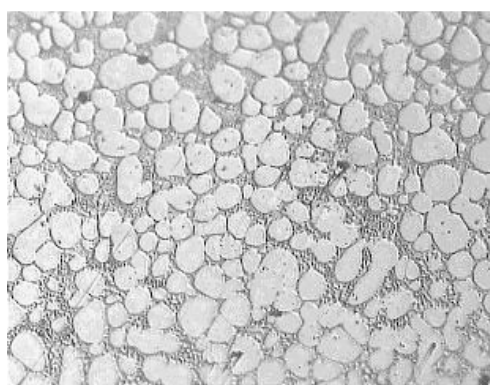
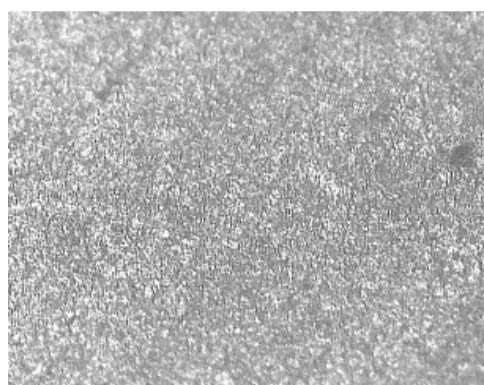


Fig. 14-1. Distribution of microhardness in the cross-section of the hardfaced layer - Sample IV (BM-Č4172, FM-powder Castolin EUTELLOY 10494).



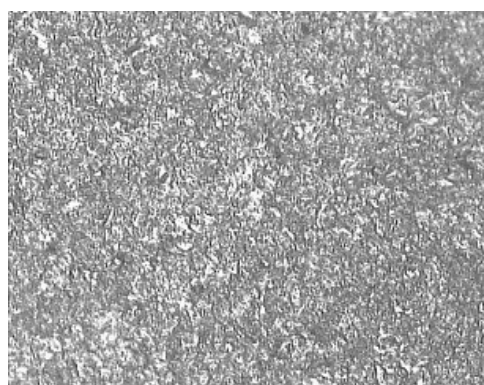
Hardfaced layer – austenitic structure with small-grained needle-like martensitic structure at grain boundaries (200×)



Hardfaced layer/HAZ –coarse-grained interphase quenched and tempered structure with residual martensite (200×)



HAZ – interphase quenched and tempered structure (200×)



BM – homogenous small-grained interphase quenched and tempered structure (200×)

Fig. 14-2. Microstructure of typical hardfaced layer zones.

4.2 Tribological tests

Tribological investigations were carried out for a block-on-disk contact, on a tribometer TPD-93 (Fig. 15) installed at the Faculty of Mechanical Engineering in Kragujevac. The aim of these

investigations was to evaluate the resistance to wear of the base materials and deposited layers [4-5,15-18]. Prismatic samples (four from the hardfaced layer and one from the base material) were prepared for tribological tests ($6.5 \times 15 \times 10$ mm). During the tests, the line block-on-disk

contact was realized. The outer variables of the tested samples were contact forces, sliding speed and the lubricant. Motor oil Nisotec SE15-40 was used for the tests.

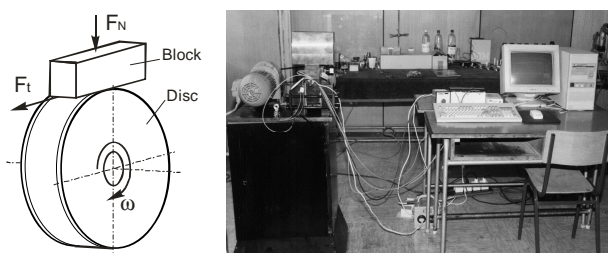


Fig. 15. Tribometer TPD - 93 and other measuring equipment for tribological testing.

Prior to investigations, topography of the disc and block surfaces was measured on the computer measuring system Talysarf 6. Then, the contact was realized. The normal force of $F_N = 50$ N and the sliding speed of $v_{kl} = 0.5$ m/s were adopted. After the contact of 60 minutes, the wear scare width was measured. This way the tribological characteristics of the blocks were determined. The wear scar width was measured using a universal microscope UIM-21, with magnification of 50 times. The samples were marked as shown in Table 7. Firstly, the friction coefficient was measured for all the samples. After each test, the samples were ground again in order to enable the same conditions throughout the experiment. Then, the wear scar width was measured and the roughness profile was established [4,5,11,15-18]. The wear scar width was measured using a universal microscope UIM-21, while the roughness was measured and the wear scar profile determined on Talysarf 6.

Figure 16a gives a summary graph (histogram) of the mean values of the friction coefficient and

Fig. 16b displays a histogram of the mean values of wear scar width for tribological couples.

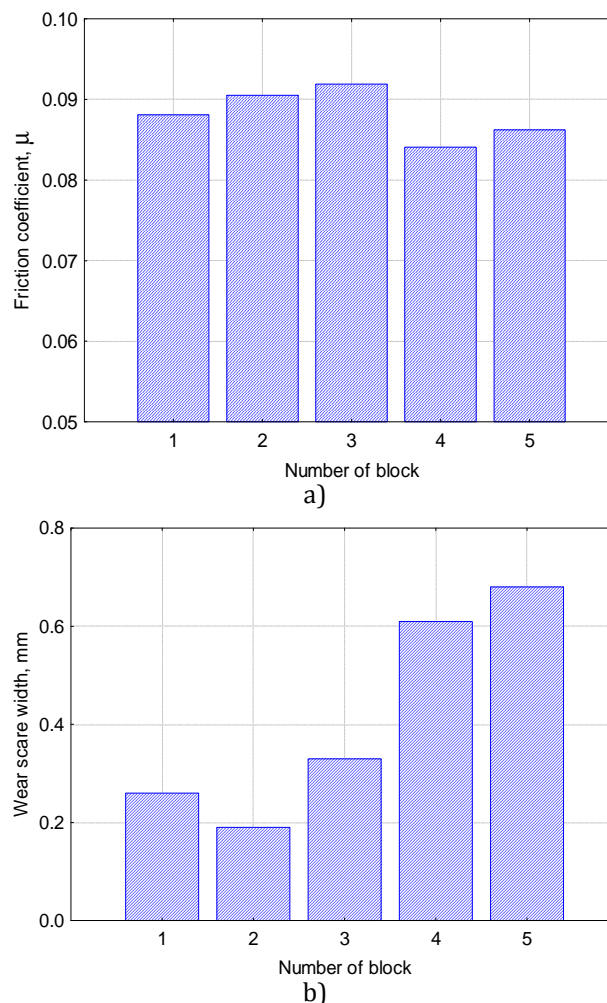


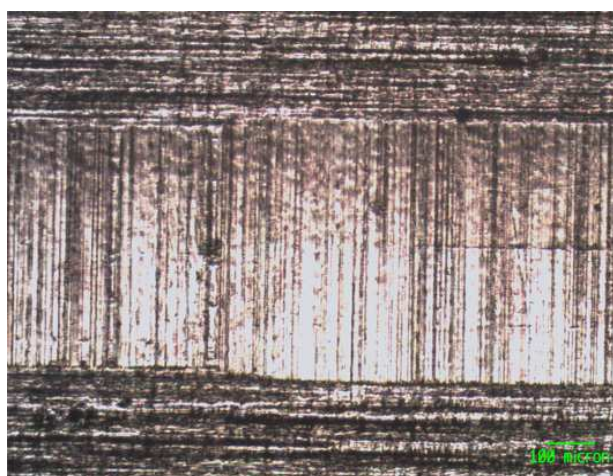
Fig. 16. Histogram of distributions of the mean values of the friction coefficient and (a) and wear scar width (b).

Resistance to wear of the hard faced layer is estimated based on the wear scar width bsr and the friction coefficient μ .

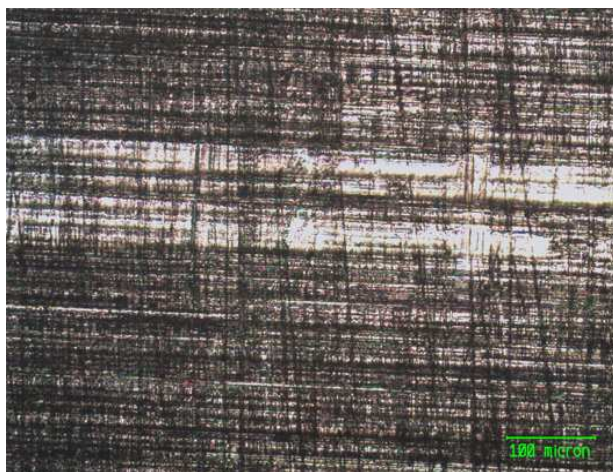
Table 7. Technology of the block preparation [4, 5].

Block number	Substrate material	Hardfaced (filler) material	Number of layers	Height of the hardfaced layer, mm	Appearance of blocks and discs
1.	Č4172	Č4172	2	2.5-3.0	
2.	Č4172	Č4850	2	2.5-3.0	
3.	Č4172	Castolin Bronzocrom 10185	1	1.5-2.0	
4.	Č4172	Castolin 10494	1	1.5-2.0	
5.	Č4172	-	-	-	

Figure 16a shows that all the materials have approximately the same mean value of the friction coefficients ranging from $\mu = 0.08409$ (block 4) to $\mu = 0.09192$ (block 3). As seen in Fig. 16b, the block 2 (FM-Č4850) has the smallest mean wear scar width $b_{sr} = 0.1865$ mm, while the block 4, whose friction coefficient is the lowest, has the largest wear scar width $b_{sr} = 0.614$ mm. It is noticed that the base material has the lowest friction coefficient but the largest wear scar width $b_{sr} = 0.68$ mm, which indicates the possibility of production hardfacing of new parts. Figure 17 shows wear scar images for the blocks 2 and 5.



a) Block 2



b) Block 5

Fig. 17. Microscopic view of the wear scar on the blocks tested using the lubricant Nisotec SE 15-40 during the contact of 60 min (50 \times).

Based on these findings it can be concluded that all hardfaced samples have given better results than the base material, which is in favour opinion held by many authors that both repair and production hardfacing have many

advantages [4-11, 15-18]. The parts studied here have relatively small masses, but their mechanical and tribological damage can cause serious downtime in the production process and a considerable increase in costs.

4.3 Hardfacing of real parts

Technological parameters for hardfacing of real parts are given in Table 4. Damaged cutting edges of the shape punch are hardfaced in two passes and then manually ground to fit the needed geometry (Fig. 18). After that, they were mounted on the candy manufacturing tool (Fig. 19) and the interrupted production process was continued.



Fig. 18. Hardfaced shape punches.



Fig. 19. Candy manufacturing tool.

In order to insure a genuine comparison of the service life, there was no new shape punches mounted together with the repaired ones. Whilst in service, geometry and wear scar width of the shape punches were periodically checked. After the repaired shape punches had been used for nine months, wear scar width was measured again. The results of these measurements are shown in Fig. 20.

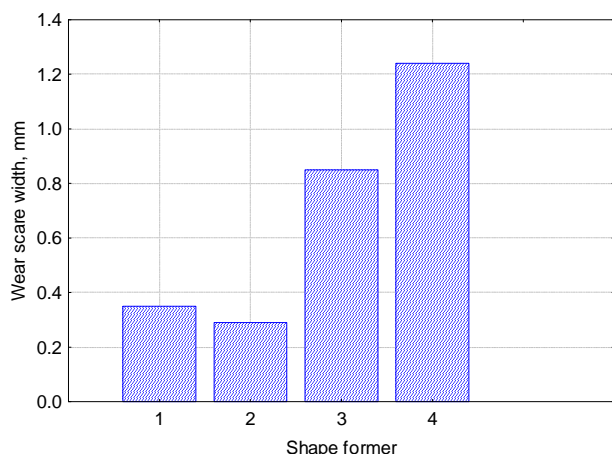


Fig. 20. Distribution of the mean value of the wear scar width for real parts.

In all four cases, the hardfaced shape punches not only proved to be more resistant but some of them also had a few times longer service life compared to the new ones. This increase in resistance is the result of a more favourable microstructure of the hard faced zones and a better bonding between the hardfaced layer and the base material.

5. CONCLUSION

Theoretical and experimental investigations carried out in this paper are a part of a wider project whose aims are to create a unique hardfacing methodology applicable to different parts of machines and devices, improve the existing technology and enable the right choice and quality checking of available filler materials and to reduce the downtime and machine failure.

Repair hardfacing of the shape punches have proven to be successful, efficient and cost effective. This is a fast and effective way to repair tribologically and mechanically damaged shape punches at the equipment operation place. Satisfactory results have been achieved without any heat treatment after hardfacing, although the base material is very prone to hardening.

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