Journal of the Balkan Tribological Association *Vol. 22, No 1A-I, 605–618* (*2016*)

REPARATORY HARD FACING OF WORKING PARTS MADE OF MARTENSITIC STAINLESS STEEL IN CONFECTIONARY INDUSTRY

D. ARSIĆ*, V. LAZIĆ, S. ALEKSANDROVIĆ, M. BABIĆ,
D. MILOSAVLJEVIĆ, M. ĐORĐEVIĆ, N. RATKOVIĆ

Faculty of Engineering, University of Kragujevac, 34000 Kragujevac, Serbia
E-mail: *dusan.arsic@fink.rs*

ABSTRACT

In order to improve the reparatory hard facing technology in this paper is especially analysed 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 realised, thus achieving certain hardness and strength of the confectionary product. The considered tool is made of high-alloyed martensitic stainless steel. The tool contains 35 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 reduce the residual internal stresses.

Keywords: hard facing, filler material, confectionery industry, wear, hardness, microstructure, shape punch.

AIMS AND BACKGROUND

Here has been analysed the damage of the shape punches, described predominant types of wear, and it was also explored the possibility of their hard facing. Specially attention has been devoted to choice of repair procedures in hard facing. After the filler materials and the repair procedures had been chosen and techno-

* For correspondence.

logical hard facing parameters defined, hard facing was performed both on the models and on the real parts. The models were used for metallographic analysis, microstructure measurements and tribological investigations. The real hard faced parts were mounted on the tool holder and used in the production process where they were exposed to real operating conditions, and then the wear scar width was measured.

Hard facing of working parts has been subject of numerous investigations[1–7]. Lazic et al.[1] analyse the causes of damage of mallet for hammer. Mallets of the forging hammers are exposed to thermal fatigue due to the cyclic temperature changes and impact loads. Besides that the price of new part is high. With regards on that, authors of paper proposed the hard facing as method for reparation of damaged part. Type of filler material, hard facing parameters and hard facing technology were proposed. Repaired part showed remarkable exploitational characteristics. Causes of damage of certain parts of the civil engineering mechanisation and technology for hard facing of damaged parts are discussed in Refs 2–4. The aim of these researches is to study the possibilities for extending of service life. The mechanism of the impact abrasive wear of parts that wear the most, was analysed. The cutting edges of damaged parts were regenerated by hard facing, and then they were sharpened by grinding to the similar shape and size as the new working parts. After that, to the working machine rotors were mounted alternatively new and repaired cutters and their wear was monitored under the same working conditions. It was established that the endurance of the hard faced cutters is better than the nonhard faced ones, which can be explained by the more favourable microstructure of the hard faced layer, which better corresponds to the given working conditions. Besides repairing the parts damaged in normal conditions, hard facing is also used for parts damaged due to failures, as well as for new, flawed cast pieces. All these facts indicate that hard facing is an important advanced technologies. In Ref. 5 for the sake of improving the reparatory hard facing technology is especially analysed reparatory hard facing of tools for manufacturing compressed products in confectionary industry. 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. The reparatory hard facing, which was chosen in paper, should eliminate all of that damages and to extend the service life of repaired part. In some references[6,7] the main objective of study was to evaluate the wear behaviour for pure abrasion and for combined wear of iron-based alloys. Iron-based hard facing alloys are widely used to protect machinery equipment exposed either to pure abrasion or to a combination of abrasion and impact. The results of investigation of impact abrasion wear tests were discussed as well (combined impact and abrasion wear). The evaluation of wear behaviour was supported by micro- and macrostructural investigations and by hardness tests.

DAMAGE OF THE SHAPE PUNCHES

Hard facing is primarily used to restore parts worn during exploitation and to rebuild either damaged or new unsatisfactory parts. Due to its wide application, hard facing has an important place among the so-called advanced technologies. The main causes of surface damages to working parts of machines and devices are tribological processes (50–80%), and those damages may be very expensive[8–14]. In order to reduce the costs it is necessary to apply tribological knowledge, concerning construction and operation, and to consider economical use of materials, efficient maintenance, rational use of energy sources, as well as measures to increase the life and reliability of the products. Hard facing is cost-effective if the costs is below price of a new part. Nevertheless, repairs of unique machines and devices has to be performed, regardless of the costs[13,14].

Tools used in confectionery industry are subject to the various types of wear, among which the predominant part has 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 crystallisation 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.

When the sugar mass is sub-cooled the pressure increases. 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 punch is shown in Fig. 1.

Besides tribological damage, quite often causes of damage in rotary tools, containing several shape punches, are mechanical damages. A brittle fracture of the return spring of the shape punch is the most frequent mechanical damage. If a broken piece of metal falls into the working area of the tool, it may be hit by the sharp edges of the shape punch, and, since the piece of the spring is much harder than the candy mass, it may damage sharp edges or even cause the fracture of shape punch. Damage in the edges of the shape punch is usually small, only a few millimetres in size, but it has a bad effect on both the quality of work and the quality of the product. The shape punch fracture causes a major downtime and requires trained staff to repair it[4].

Fig. 1. Damaged shape punch

Mechanical damage can also be caused by foreign metal or non-metal objects, during entering of raw materials, or by the technological production process, although there are some measures, such as magnetic separators and sifters, which could be used to prevent these damages. The most efficient solution of these problems is to apply an adequate repair technology at the place where the damage occurred. Such procedures are cost-effective and they may reduce the downtime significantly[1–5,13,14].

SELECTION OF PROCEDURES, FILLER MATERIALS AND HARD FACING PARAMETERS

BASE AND FILLER MATERIALS

Tools in food and confectionery industry are usually made of quenched and tempered martensitic stainless steels. They contain 0.15–1.5% 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 Č4580 (SRPS) – X155CrVMo12-1 (EN 10027) and applications of the base material (BM) are given in Table 1 (Refs 4, 15) while Table 2 gives basic information on type of the heat treatment and the most important mechanical properties.

Table 1. Base material properties (BM)

Steel labelling		Chemical composition (%)				Notice
Code by SRPS	Manufacturer code	C	V	Cr	other	
Č4850	OCV 12VM	1.55	1.0	12	0.9 Mo	tools in food industry, cutlery, surgical instruments, bearing rollers, pressing dies.

Table 2. Heat treatment and the most important mechanical properties

Steel code	Forging temperature (ºC)	Soft annealing		Hardening			Tempering temperature (ºC)
		temperature (ºC)	hardness (HB)	temperature (ºC)	cooling aid	hardness (HRC)	
Č4850	1050–850	840–880	250	1000–1040	Oil/Air	62–64	150–550

Table 3. Main properties and chemical composition of the filler materials[4]

Code	Chemical composition (%)						Hardness
	C	Si	Mn	Cr	V	Mo	
Č4850	1.55	0.30	0.30	12.0	0.90	0.80	55 HRC
Č4172	0.20	1.0	1.5	13	–	–	400 HV

Due to practical reasons, since the damage was small, the shape punches were hard faced using the filler material (Table 3) 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.

The second filler material was also obtained from removed tools used in manufacturing of compressed hard candy (made of steel Č4172 (SRPS) – X20Cr13 (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). Main properties of these filler materials are given in the manufacturers catalogues[15].

SELECTION OF THE HARD FACING 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 hard facing procedures were chosen:

1. TIG hard facing (basic method);
2. Gas hard facing 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 hard faced. 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[15,16].

Damaged edges of two shape punches were hard faced 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 hard faced layers). The height of one-pass hard faced 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 hard faced from top down using the leftward technique. This way, the penetration was decreased and the height of the hard faced layer was increased. The filler material codes and hard facing parameters are given in Table 4 (Ref. 4).

One of the two hard faced shape punches was tested under the real operating conditions, while the other one was cut transversely to the hard faced layer

Table 4. Technological parameters for hard facing of real parts using TIG procedure

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

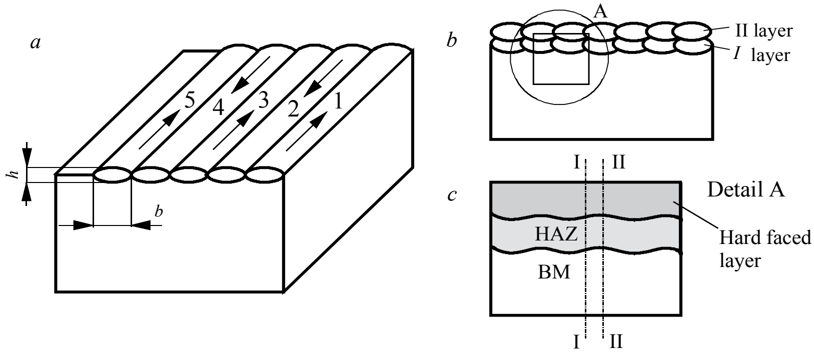

Fig. 2. Order of hard faced layer deposition: *a* – 1 layer, *b* – 2 layers, *c* – metallographic sample (block) (Ref. 4)

and used for metallographic investigations and hardness measurements. The third shape punch was hard faced and cut out into a block used for tribological investigations (Fig. 2*c*). Hard facing was carried out in two layers as shown in Fig. 2*b*. The height of one layer was 1.2–1.5 mm and the width was 3–4 mm (Fig. 2*a*). The TIG-hard facing parameters hard facing of the models and tribological investigations are given in Table 5.

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 hard facing was performed using two different powder filler materials whose main properties and technological parameters are given in the catalogues[14]. The num-

Table 5. Technological parameters for hard facing of models using TIG procedure

Thickness (mm)	FM code	FM cross section (mm)	*I* (A)	*U* (V)	Number of passes	Number of pieces
12	Č4850	1.0×1.0	50–60	12	2	1
12	Č4172	1.0×1.0	50–60	12	2	1

Table 6. Parameters for the gas hard facing of real parts using powder filler materials

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

ber of hard faced samples and the technological process of sample preparation is the same as with TIG hard facing. Technological parameters for the gas hard facing using powder filler materials are given in Table 6 (Refs 4, 15).

EXPERIMENTAL INVESTIGATIONS ON MODELS AND SHAPE PUNCHES

METALLOGRAPHIC ANALYSIS AND HARDNESS MEASUREMENTS ON REAL PARTS

Metallographic investigations and hardness measurements were performed on models obtained by hard facing and cutting real parts (shape punches) normally to the hard faced cutting edge.

Metallographic investigations and hardness measurements – Sample I. Macro appearance of the TIG-hard faced shape punch is shown in Fig. 3. The depth of penetration was about 0.8 mm, while the height of the hard faced 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. The base material microstructure was estimated as small-grained interphase quenched and tempered structure. The hard faced layer has martensitic structure with needle-shaped carbides at metal grain boundaries. The transient zone is hardly visible and is dominated by interphase

Fig. 3. Hard faced shape punch – Sample I (BM-Č4850, FM-Č4172)

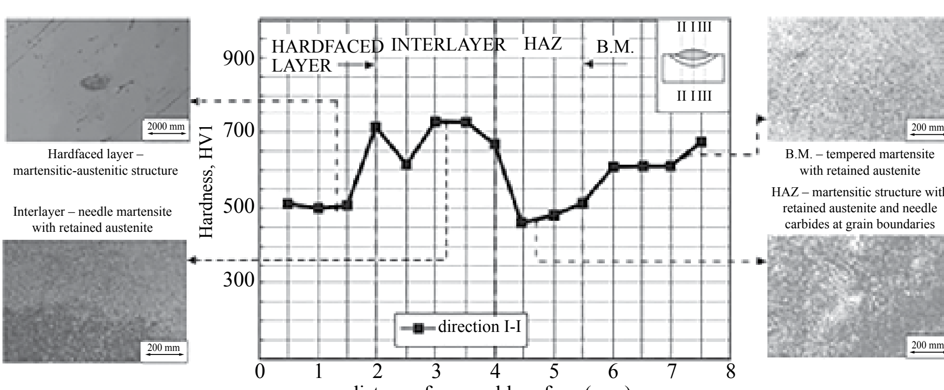

Fig 4. Distribution of hardness and microstructure of characteristic zones – Sample I

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 tool. Hardness distribution and microstructures of the characteristic zones are given in Fig. 4.

Metallographic investigations and hardness measurements – Sample II. Macro appearance of the shape punch hard faced using TIG procedure is shown in Fig. 5. The depth of penetration was about 0.8 mm while the height of the hard faced layer was approximately 2.2 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. The base material microstructure was estimated as small-grained interphase quenched and tempered structure. The hard faced 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 hard faced layer zones are given in Fig. 6.

Fig. 5. Hard faced shape punch – Sample II (BM-Č4850, FM-Č4850)

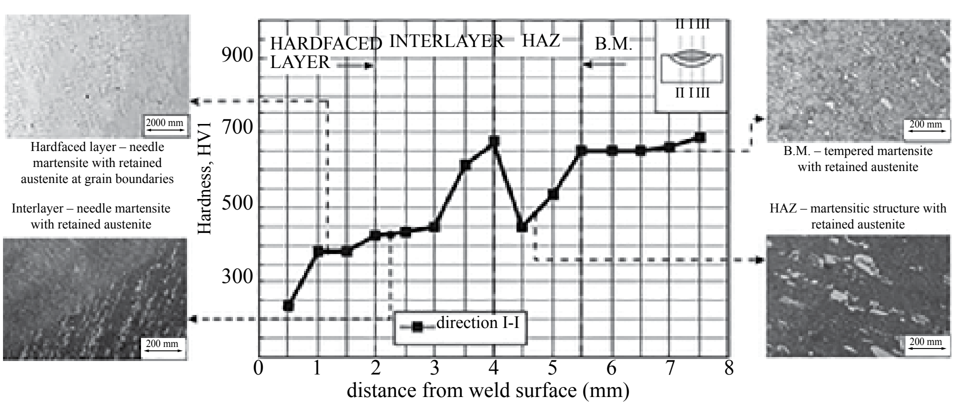

Fig. 6. Distribution of hardness and microstructure of characteristic zones – Sample II

Metallographic investigations and hardness measurements – Sample III. Macro appearance of the shape punch repaired using gas-powder hard facing is shown in Fig. 7. The height of the hard faced layer was approximately 1.3 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 (BM) was firm. The base material microstructure was estimated as small-grained homogenous interphase quenched and tempered structure. The hard faced 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 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 hard faced layer. Hardness distribution and microstructures of the hard faced layer zones are given in Fig. 8.

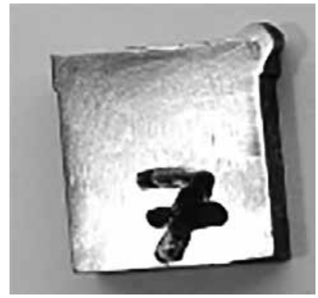

Fig. 7. Hard faced shape punch – Sample III (BM-Č4850, FM-Castolin EUTALLOY BRONZOCROM 10185)

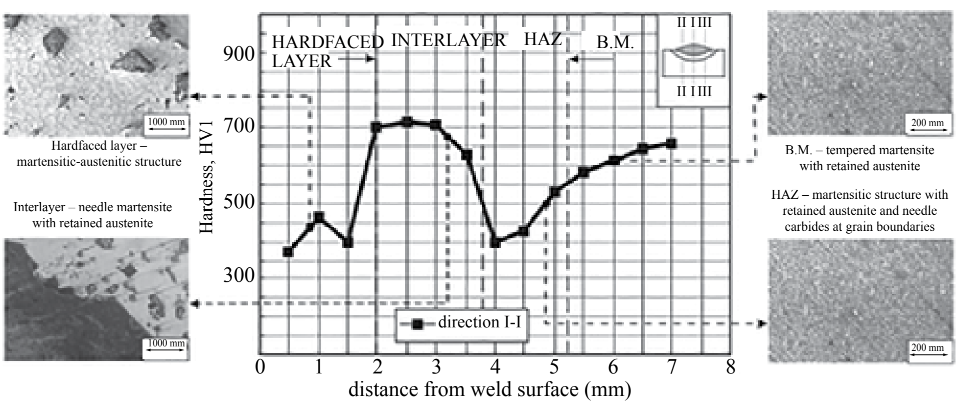

Fig 8. Distribution of hardness and microstructure of characteristic zones – Sample III

Metallographic investigations and hardness measurements – Sample IV. Macro appearance of the shape punch hard faced using gas-powder hard facing is shown in Fig. 9. The height of the hard faced layer was approximately 2.25 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 enough

Fig. 9. Hard faced shape punch – Sample IV (BM-Č4172, FM- Castolin EUTELLOY 10494)

to ensure good properties of the hard faced layer, i.e. of the hard faced part. The base material microstructure was estimated as small-grained homogenous interphase quenched and tempered structure. The hard faced 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[4,9,10]. 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 hard faced part. Distributions of hardness and microstructure of hard faced layer zones are given in Fig. 10.

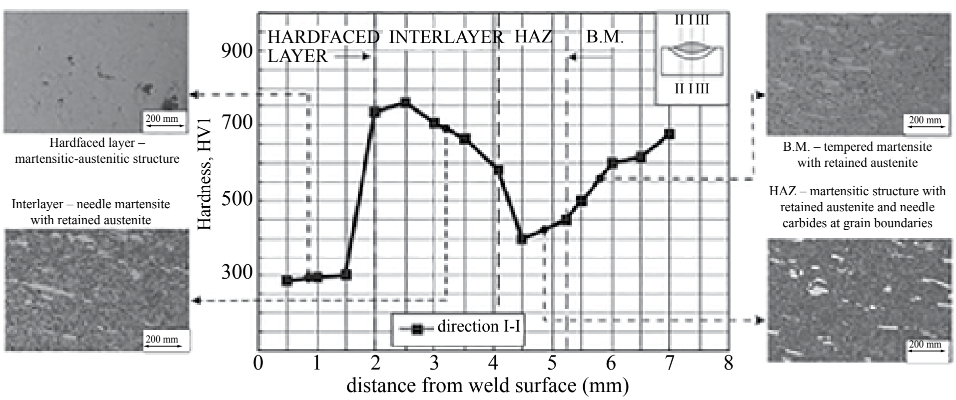

Fig. 10. Distribution of hardness and microstructure of characteristic zones – Sample IV

Tribological tests. Tribological investigations were carried out for a block-on-disk contact, on a tribometer TPD-93 (Fig. 11) 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[1–7,14,16]. Prismatic samples (four from the hard faced layer and one from the base material) were prepared for tribological tests (6.5×15×10 mm). During the tests, the line block-on-disk contact was realised. 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.

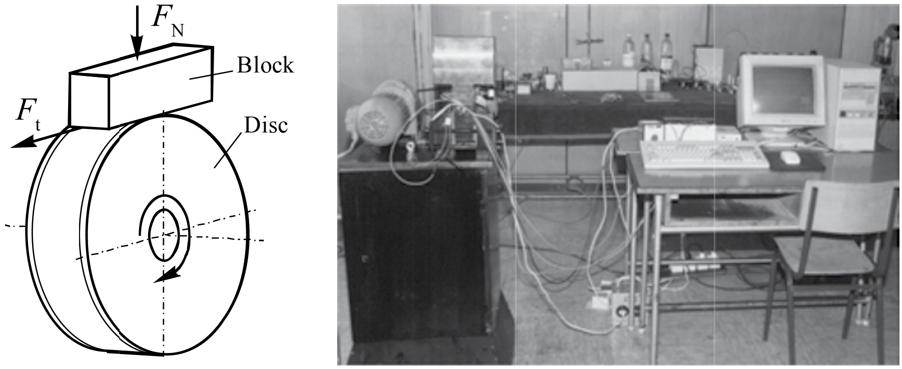

Fig. 11. Tribometer TPD–93 and other measuring equipment for tribological testing[4]

Prior to investigations, topography of the disc and block surfaces was measured on the computer measuring system Talysarf 6. Then, the contact was realised. The normal force of F_N = 50 N and the sliding speed of v_{sl} = 0.5 m/s were adopted. After the contact of 60 min, the wear scare width was measured. This way the tribological characteristics of the blocks were determined. 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[8–10,14]. The wear scar width was measured using a universal microscope UIM-21, with magnification of 50 times while the roughness was measured and the wear scar profile determined on Talysarf 6. Figure 12*a* gives a summary graph (histogram) of the mean values of the friction coefficient and Fig. 12*b* displays a histogram of the mean values of wear scar width for tribological couples. Also, Fig. 12*a* shows

Table 7. Technology of the block preparation[4,10,11]

Block No	Substrate material	Hard faced material	Number of layers	Height of the hard faced layer (mm)	Appearance of blocks and discs
1.	Č4850	Č4172	2	2.5–3.0	
2.	Č4850	Č4850	2	2.5–3.0	
3.	Č4850	Castolin EUTALLOY BRONZOCROM 10185	1	1.5–2.0	
4.	Č4850	Castolin EUTALLOY 10494	1	1.5–2.0	

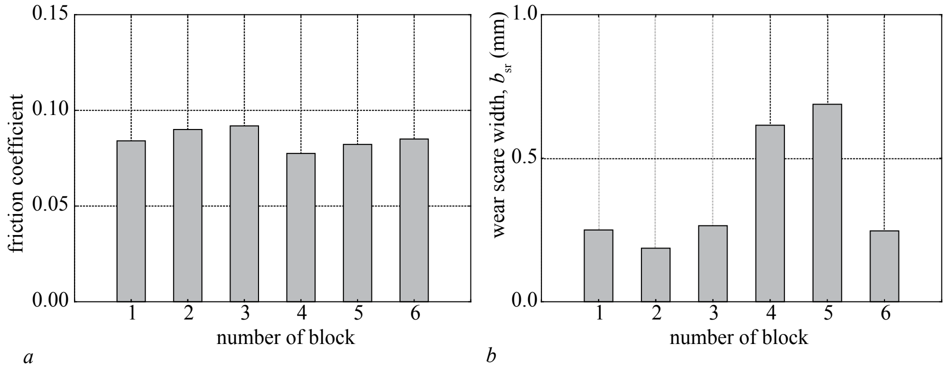

Fig. 12. Diagrams of mean values of the friction coefficient (*a*) and wear scar width (*b*)

that all the materials have approximately the same mean value of the friction coefficients ranging from μ = 0.08409 (block 4) to μ = 0.09192 (block 3). As seen in Fig. 12*b*, 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 hard facing of new parts.

Hard facing of real parts. Technological parameters for hard facing of real parts are given in Table 4. Damaged cutting edges of the shape punch are hard faced in two passes and then manually ground to fit the needed geometry. After that, they were mounted on the candy manufacturing tool and the interrupted production process was continued. In order to ensure a genuine comparison of the

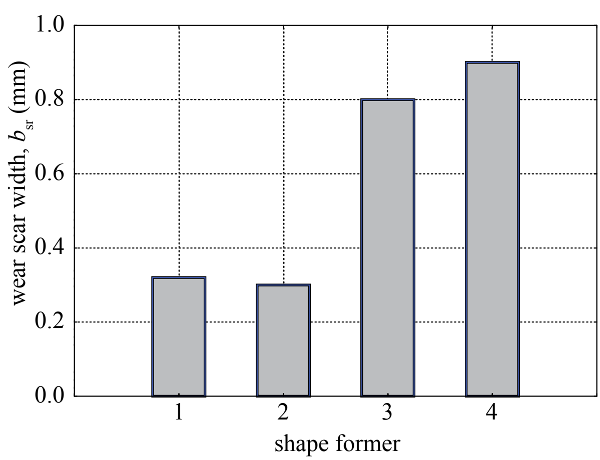

Fig. 13. Histogram of distributions of the mean values of wear scar width

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. 13.

In all four cases, the hard faced 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 hard faced layer and the base material.

CONCLUSIONS

The experimental results have shown that the hard faced layer has better mechanical properties than the base material. That is mostly correlated to the wear resistance and to results obtained by examination of wear scare width. The smallest wear scar width had specimens hard faced with steels Č4172 and Č4850 (blocks 1 and 2) Also, the friction coefficients of tested specimens were below 0.1, which means that tribological influence on damages of hard faced layer is reduced.

Beside, hard facing reduces the downtime of the necessary for reparation of shape punches.

Hard facing of the shape punches have proven to be successful, efficient and cost effective.

Achievements of this paper were creation of unique hard facing methodology, applicable to different parts of machines and devices, improvement of the existing technology, guidance to make right choice and quality checking of available filler materials and to reduce the downtime and machine failure.

ACKNOWLEDGEMENTS

This research was partially supported by the Ministry of Education and Science of Republic of Serbia through Grants: TR35021, TR34002 and TR35024. The authors are very grateful for this funding.

REFERENCES

1. V. LAZIĆ, A. SEDMAK, S. ALEKSANDROVIĆ, D. MILOSAVLJEVIĆ, R. ČUKIĆ, V. GRABULOV: Reparation of Damaged Mallet for Hammer Forging by Hard Facing and Weld Cladding. Tehnical Gazete, **16** (4), 107 (2009).
2. D. ARSIĆ, V. LAZIĆ, I. SAMARDŽIĆ, R. NIKOLIĆ, S. ALEKSANDROVIĆ, M. DJORDJEVIĆ, B. HADZIMA: Impact of the Hard Facing Technology and the Filler Metal on Tribological Characteristics of the Hard Faced Forging Dies. Technical Gazette, **22** (5), 1353 (2015).

3. D. ARSIĆ, V. LAZIĆ, A. SEDMAK, R. NIKOLIĆ, S. ALEKSANDROVIĆ, M. DJORDJEVIĆ, R. BAKIĆ: Selection of the Optimal Hard Facing (HF) Technology of Damaged Forging Dies Based on Cooling Time $t_{8/5}$. Metallurgy, **55** (1), 103 (2016).
4. M. HAWRYLUK, M. MARCINIAK, G. MISIUN: Possibilities of Investigating Abrasive Wear in Conditions Close to Those Prevailing in Industrial Forging Processes. Maintenance and Reliability, **16** (4), 600 (2014).
5. B. NEDELJKOVIĆ, M. BABIĆ, M. MUTAVDŽIĆ, N. RATKOVIĆ, S. ALEKSANDROVIĆ, R. NIKOLIĆ, V. LAZIĆ: Reparatory Hard Facing of the Rotational Device Knives for Terrain Leveling. J Balk Tribol Assoc, **16** (1), 46 (2010).
6. M. MUTAVDŽIĆ, R. ČUKIĆ, M. JOVANOVIĆ, D. MILOSAVLJEVIĆ, V. LAZIĆ: Model Investigations of the Filler Materials for Regeneration of the Damaged Parts of the Construction Mechanisation. Tribology in Industry, **30** (3&4), 3 (2008).
7. S. RAKIĆ, V. LAZIĆ, S. ALEKSANDROVIĆ, S. MITROVIĆ, R. NIKOLIĆ, D. MILOSAVLJEVIĆ, R. ČUKIĆ: Reparatory and Manufacturing Hard Facing of Working Parts Made of Stainless Steels in Confectionary Industry. Tribology in Industry, **34** (3), 138 (2012).
8. V. LAZIĆ, A. SEDMAK, D. MILOSAVLJEVIĆ, I. NIKOLIĆ, S. ALEKSANDROVIĆ, R. NIKOLIĆ, M. MUTAVDŽIĆ: The Working Life Theoretical and Experimental Estimates for Machine Parts Hard Faced Using Austenite-Manganese Electrodes. Materials and Technology, **46** (5), 547 (2012).
9. S. MARKOVIĆ, LJ. MILOVIĆ, A. MARINKOVIĆ, T. LAZOVIĆ: Tribological Aspect of Selecting Filler Metal for Repair Surfacing of Gears by Hard facing. Structural Integrity and Life, **11**, 127 (2011).
10. M. KIRCHGAßNER, E. BADISCH, F. FRANEK: Behaviour of Iron-based Hard Facing Alloys under Abrasion and Impact. Wear, **265,** 772 (2008).
11. V. LAZIĆ, D. ARSIĆ, R. NIKOLIĆ, M. MUTAVDŽIĆ, J. MEŠKO: Reparation by Hard Facing of the Damaged Secondary Stone Crushers. Manufacturing Technology, **16** (2), 375 (2016).
12. J. LIN, M. AAPLUND: Comparison Study of Heavy Haul Locomotive Wheels' Running Surfaces Wearing. Maintenance and Reliability, **16** (2), 276 (2014).
13. V. LAZIĆ, R. ČUKIĆ, S. ALEKSANDROVIĆ, D. MILOSAVLJEVIĆ, D. ARSIĆ, B. NEDELJKOVIĆ, M. DJORDJEVIĆ: Techno-economic Justification of Reparatory Hard Facing of Various Working Parts of Mechanical Systems. Tribology in Industry, **36** (3), 287 (2014).
14. R. WASSERMAN: How to Save Millions by Reparatory Welding in Machine Maintenance. Castolin Eutectic Institute for Advancement of Reparatory Welding Technique and Welding Technique in Machine Maintenance, Bor, 2003 (in Serbian).
15. V. LAZIĆ, A. SEDMAK, R. NIKOLIĆ, M. MUTAVDŽIĆ, S. ALEKSANDROVIĆ, B. KRSTIĆ, D. MILOSAVLJEVIĆ: Selection of the Most Appropriate Welding Technology for Hard Facing of Bucket Teeth. Materials and Technology, **49** (1), 165 (2015).
16. Catalogues and Prospects: Thyssen Marathon Edelstahl – Vosendorf, Železarna Jesenice-Fiprom, Bohler-Kapfenberg, Messer Griesheim-Frankfurt am Main, Esab-Göteborg, Lincoln Electric, USA, Castolin Eutectic Group.
17. M. DUMOVIĆ: Choice and Application of Alloys for Hard Facing. Welding and Welded Structures, **42** (3), 233 (1997) (in Serbian).

Received 7 July 2014
Revised 19 February 2015