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INVESTIGATION OF THE ABRASIVE WEAR RESISTANCE OF CARBURISED AND BORON-ENRICHED PROTECTIVE LAYERS EXPOSED TO DIFFERENT STRESSES

RAZISKAVA ODPORNOSTI NAOGLJIČENIH IN BORIRANIH SLOJEV PROTI ABRAZIVNI OBRABI ZARADI RAZLIČNE OBREMENITVE

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The possibility of using boron-enriched protective layers instead of conventional carburised layers is investigated. Experimental investigations have been carried out on worm presses for oil extraction. It was found that the operation of worm presses with boron-enriched layers, although having higher hardness values, display lower wear and tear resistance compared with those of carburised components. The conclusion is that the wear of protective layers exposed to abrasive action under conditions of changing pressure and abrasive action depends on the hardness of the surface layer, on the quality of the underlayer, and the level and type of contact pressure on the mechanical component.

Key words: protective layer, carbonizing, boron treatment, abrasion, wear resistance

Raziskana je uporaba boriranih namesto konvencionalno cementiranih slojev v polžastih stiskalnicah za ekstrakcijo olja. Ugotovljeno je, da deli z borirano površino, ki imajo večjo trdoto, imajo manjšo odpornost proti obrabi in luščenju kot deli s cementirano površino. Zaključek je, da je obraba površinskih slojev, ki so obremenjeni na abrazijo v pogojih menjajočega se pritiska in abrazivnega učinka, odvisna od trdote površinskega sloja, od kakovosti podsloja ter od vrste in velikosti pritiska na strojni del.

Ključne besede: varovalni sloj, cementacija, boriranje, abrazija, odpornost proti obrabi

1 INTRODUCTION

In numerous tribosystems the mechanical components are exposed to abrasive wear. A special group of such tribosystems are those in which metal particles removed by the abrasive action might influence the quality of the product, as f.i. worm presses for oil extraction from sunflower and rapeseed. Abrasive wear on these presses changes the geometry and the dimensional characteristics of worm segments and vessel-wall knives, leading to economic losses due to reduced manufacturing capacities and larger energy consumption (electric energy and hexane). Excessive wear can lead to stopping of the press operation due to the too large oil residue in the oil-cake and/or the too many metal particles in the extracted oil these may influence the oil quality, due to their oxidation effect.

The life time of worm-press components depends on the type and quality of the preparation of the oil seed and on the components protective layer. Records show that original imported components are produced with carbo-nitrided and hard welded layers and also frequently, as in the case of domestic solutions, with carburised layers on CrMn steel[1].

The main wear-resistance constituent in carburised layers with surface hardness values of 58-60 HRC is martensite, and eventually (depending on the base material and the procedure of heat treatment after carburising), a small quantity of carbide phase. The abrasive action of the oil seed is due to the presence of silica particles (SiO_2 hardness 1100-1200 HV) in the hulls[2,3].

As a boron treatment provides protective layers displaying greater hardness values (1300-2000 HV), and as the available domestic and foreign ref. no examples of its application under similar conditions have been found, an investigation was initiated to determine the abrasive conditions which occur in worm-press components during oil extracion.

2 EXPERIMENTAL PROCEDURE

2.1 Selection of typical presses

Croatian oil-production facilities mainly use sunflower seeds as a raw material (80-100% of available capacities). Prior to sunflower processing the seeds are decorticated, milled and conditioned.

The amount of hulls in the prepared oil-cake is of appr. 13%, the oil content is appr. 50%, and the temperature is in the range between 95-110 °C. The oil extraction is carried out by reducing the free volume

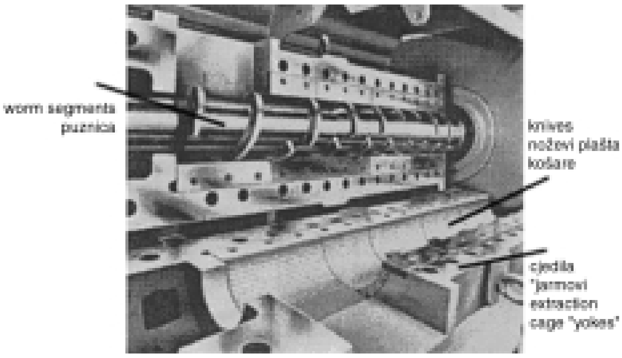

Figure 1: View of the open worm press
Slika 1: Odprta polžasta stiskalnica z razporeditvijo delovnih delov

between the worms and the wall knives mounted on the so-called yokes, from the inlet to the outlet of the press. A view of the opened press is shown in **Figure 1**.

For the experimental procedures two presses for oil extraction were selected: pre-pressing and final pressing devices.

The pre-pressing device (VPI type) with a working capacity of ≈40 tons/day of decorticated sunflower seed consists of four working fields with a total length of ≈1100 mm. The oil-cake on the outlet of the press contains ≈10% of oil which is diluted in the extraction processing with the application of hexane. The maximum operating pressure within the press reaches ≈250 bar in the third working field[4,5]. The rotation speed of the shaft is of 21 °/min.

The final-pressing RD type device with a working capacity of ≈35 tons/day of decorticated sunflower seed consists of seven working fields with a total length of ≈1960 mm. Pre-pressing is carried out in the first four working fields, while the last three fields are used for final pressing, so that the oil-cake on the outlet of the press has an oil content of 8 to 10%. The rotation speed of the shaft is of 35 °/min. The radial pressure within the press reaches the highest values in the third working field with ≈450 bar [6,7].

2.2 Experiment schedule

Wall knives were selected for the study of the protective layers. The reasons for the selection, apart from the price (average mass of knives is of appr. 500 g, while the worm-segment mass is 30-40 times larger, with an even greater difference in production costs), was that from the working field of the worm press (same pressure, and action of oil and abrasive) a larger number of sample knives with the protective layers can be tested, since depending in the press type, 40 to 60 knives are installed in one working field.

In addition to carburised layers of the steel Č.4320, which are used as reference samples, boron-enriched layers on the same base material were selected for the experiment.

The size of knives of the VPI press was of 275x18x10 mm and for the RD press of 278x25x10mm. The working area of one knife in contact with the oil seed is appr. the same for both presses: 2750 mm^2 for the VPI press and 2780 mm^2 for the RD press. Before applying the protective layers to the base material the samples and knives were ground to R_a = 0,80 μm.

The carburising of the samples and knives was carried out in a gaseous atmosphere at 930 °C for 10 hours followed by indirect quenching at 810 °C in oil and stress relieving at 170 °C. The surface hardness was of 59 HRC and the measured effective layer depth Edc (according to criterium HG = 550HV1) was of 1.8 mm. The microstructure carburised layer, consisted mainly of martensite and a small quantity of residual austenite, as shown in **Figure 2a**.

The boron treatment of the specimens and knives was carried out in Ekabor 3 powder at 900 °C for 5 hours. The cooling was performed in a box in air. The structure of the rand zone consists of a layer of Fe_2B with a hardness of approximately 1350 HVO.1 and an average thickness of ≈90 μm, **Figure 2b**.

2.3 Experimental results

Three boron-treated knives were installed prior to the sunflower-seed processing in each working field of the press for the pre-pressing procedure (VPI type) and for

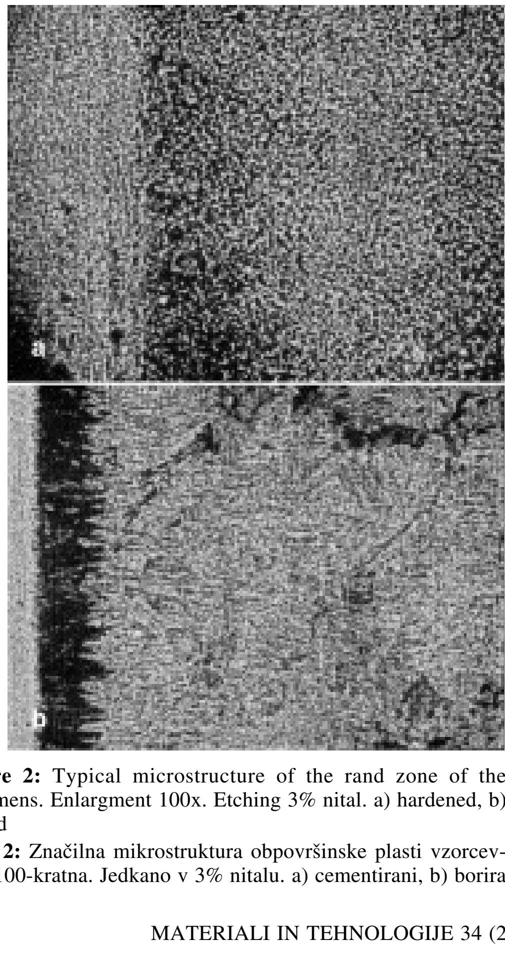

Figure 2: Typical microstructure of the rand zone of the knife specimens. Enlargment 100x. Etching 3% nital. a) hardened, b) boron treated
Slika 2: Značilna mikrostruktura obpovršinske plasti vzorcev-nožev. Pov. 100-kratna. Jedkano v 3% nitalu. a) cementirani, b) borirani

the final pressing (RD type). The knives were weighed (weight sensitivity 0.01 g) prior to installation and after the completion of the test.

In test period were ≈1650 tons and the RD press ≈1800 tons of decorticated sunflower seed were processed. The mass loss of the knives was divided by the total amount of processed sunflower, and the wear (I_t) is given in g/tons. The average wear for three knives in each working field is shown in **Table 1**.

Table 1: Average wear of hardened and boron-treated knives in press working fields
Tabela 1: Povprečna intenziteta obrabe cementiranih in boriranih nožev v različnih delovnih poljih stiskalnice

Working field	Wear intensity, I_t g/t x 10^4			
	RD press		VPI press	
	Protective layer			
	CEM	BOR	CEM	BOR
I.	19,54	15,49	3,51	2,80
II.	45,91	51,95	4,67	12,50
III.	48,83	93,77	8,48	18,11
IV.	29,82	49,41	7,01	16,34
V.	24,18	29,91	-	-
VI.	21,18	17,10	-	-
VII.	16,73	9,10	-	-

Because the wear of the knives increases in both presses from fields I to III and then reduces towards the outlet of the oil-cake, also the composition of the oil-cake was determined (oil and SiO_2 content) in the different working fields.

The oil-cake samples were removed after stopping the press and carbonizing of the plant matter. The oil content was determined according to the method of Soxhlet[8], while the SiO_2 content was determined using gravimetry[9]. The results of these investigations are shown in **Table 2**.

Table 2: Oil and SiO_2 content in the oil-cake in different working fields of the press
Tablica 2: Vsebnost olja in SiO_2 v mletju v različnih delovnih poljih stiskalnice

Working field	RD press		VPI press	
	Oil cake content			
	oil	SiO_2	oil	SiO_2
I.	50,64	0,74	47,28	0,71
II.	49,99	0,68	41,51	0,64
III.	38,85	0,32	32,44	0,37
IV.	24,08	0,24	22,50	0,25
V.	20,22	0,15	-	-
VI.	9,99	0,17	-	-
VII.	9,24	0,19	-	-

3 DISCUSSION

The analysis of the knives' wear indicates that most of the wear occurred in the third press working field (**Table 1**) with the highest radial pressure (450 b. in the RD and 250 b. in the VPI press). The SiO_2 content decreased from the first to the third working field in both presses (**Table 2**) most probably because of the washing with diluted oil (in these working fields the oil is always fluid, compared with the inlet fields where the oil-cake, prior to predeformation, becomes plastic and compact).

The working fields with the most intensive oil extraction during the pressure increase, as in the 2nd and 3rd fields of the VPI presses, and in the 4th field of the RD press, indicate that the wear of boron-treated knives is greater than that on carburised knives.

The analysis of the knives' working surfaces, **Figure 3**, shows a tendency for the carburised knives with to "pure abrasion" as a consequence of the great hardness of the abrasive SiO_2, compared to that of martensite (**Figure 3a**).

Boron-treated knives (**Figure 3b**) show a type of wear called "null abrasion" in places where the boron-treated layer still exists. Null abrasion is characterized by polished surfaces with a scattered peeling of the rand layer[10]. After the application of boron-treated layer, the base material of the knives, as well as the hardened surface, are exposed to pure abrasion wear, showing relatively parallel grooves of unequal width and thickness in the direction of the oil cake-working surface motion.

The probable cause of the lower wear resistance of the boron-treated knives compared to the carburised knives may be found in the microstructure of the

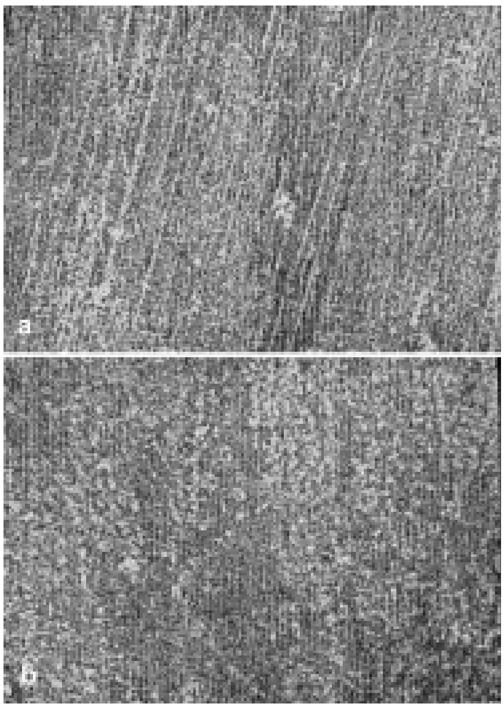

Figure 3: Characteristic signs of wear on knives after their application. Enlargement 200x. a) carbonized, b) boron treated
Slika 3: Značilni sledovi obrabe nožev po uporabi. Pov. 200-kratna. a) cementirani, b) borirani

material. Below the boron-enriched layer (**Figure 3b**) coarse pearlitic grains up to ≈0.5 mm can be observed.

This brittle, granular underlayer cannot support the elastic deformation and probably cracks after the boron-treatment. Therefore, the slightest bending stress on boron-enriched layer, which represents only a "local bridge" on the cracked foundation also causes cracking of this very same layer. This was the beginning of the further intensive knife wear, while the boron-enriched layers were removed by crushing and the pearlitic under-layer by the intensive abrasive action of the hard SiO_2 particles. In contrast, the martensite layer's hardness decreases from the rand zone towards the boundary of the effective depth of the carburising (550 HV1 on ≈1.8 mm). Wear marks lead to the conclusion that the relative motion of the oil-cake (depending on the number of revolutions of the worm shaft) does not affect the wear of the knives because otherwise consequences of the mechanism change from abrasive to abrasive heat wear[1,11] could have been observed.

4 CONCLUSION

A four- to six-times greater loss of knives' mass in the final RD press (max. pressure ≈450 b.) compared with the knives tested in the VPI press (max. pressure ≈250 b.), by of similar share of oil and abrasive in both presses, leads to the conclusion that pressure represents the main factor influencing the wear of worm-press components. The boron-enriched layers, although displaying greater hardness values, have a lower wear resistance compared to the carburised layers.

Experimental results also lead to the conclusion that the wear of protective layers exposed to abrasion under conditions of changable pressure and presence of abrasive does not depend exclusively on the hardness of the surface, but on the quality of the under-layer, and on the size and kind of abrasive contact pressure on the protective layer. The coarse-grained underlayer of pearlite underneath the boron-enriched layer is probably the main reason why boron-enriched protective layers are recommended for the manufacturing of worm press components.

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