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AN INVESTIGATION OF THE ECONOMICS OF USING WELDED LAYERS FOR SOME PARTS OF WORM PRESSES FOR THE EXTRACTION OF OIL FROM SUNFLOWER SEEDS

RAZISKAVE UPORABNOSTI NAVARJENIH PLASTI ZA DELE VIJAČNIH STISKALNIC ZA EKSTRAKCIJO OLJA SONČNIC

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The working parts of worm presses from different manufacturers were collected from oil mills in Croatia, Vojvodina and Bosnia and Herzegovina. The chemical composition, microstructure and hardness were determined, and the wear was examined for the original (imported) and the substituted (domestic) parts. The direct costs of tribological origin are larger for the substitute parts than for the original parts and they depend on the protective surface layer. The indirect tribological losses are a few tens of times greater than the direct tribological losses. The wear resistance of the welded layers was tested experimentally on extraction cage knives and the results are compared to carburised knives (the substitution solution) commonly used in oil mills. It was found that the wear resistance of the welded layers does not depend only on the surface hardness, but more so on the microhardness and the distribution of the carbide particles in the tough matrix. Based on recordings in oil mills and on the results of our investigation, we concluded that the use of welded layers instead of carburised layers could extend the lifecycle of the parts of the presses. In this way, the efficiency of the oil extraction could be increased and the economics of operating oil mills could be improved.

Key words: worm-presses, sunflower, welded layers, wear, economics

Zbrani so bili deli različnih proizvajalcev za stiskalnice za sončnično olje iz oljarn na Hrvaškem, v Vojvodini in v Bosni in Hercegovini. Analizirana je bila kemična sestava, izmerjena trdota, pregledana mikrostruktura in analizirana obraba izvirnih (uvoženih) in nadomestnih (domačih) delov. Neposredni stroški tribološkega izvora so za nadomestne dele večji kot za izvirne in so odvisni od površinske (varovalne) plasti. Indirektni tribološki stroški so nekaj desetkrat večji od direktnih. Obrabno obstojnost navarjenih slojev smo eksperimentalno preverili na nožih iz ekstrakcijske kletke, rezultate pa smo primerjali s cementiranimi noži (nadomestna rešitev), ki se večinoma uporabljajo v oljarnah. Ugotovili smo, da obrabna obstojnost navarjenih plasti ni odvisna samo od trdote površine, ampak bolj od mikrotrdote in od porazdelitve karbidnih zrn v žilavi matici. Na podlagi podatkov iz oljarn in rezultatov raziskave sklepamo, da lahko uporaba navarjenih plasti namesto cementiranih podaljša trajnostno dobo delov stiskalnic. Tako se poveča učinkovitost ekstrakcije olja in izboljša gospodarnost oljarn.

Ključne besede: vijačna stiskalnica, sončnično seme, navarjena plast, obraba, gospodarnost

1 INTRODUCTION

The working parts – worm segments and extraction cage knives – of worm presses for extracting oil are a striking example of a tribological system where wear is unavoidable. Operating with worn out worm segments increases the residual oil content in the cake. In oil mills with pre-pressing only, a too high residual oil content in the cake increases the consumption of hexane [1] and slows down the operation of the extraction plant, thereby decreasing its capacity. For oil mills with pre-pressing and final pressing the increased amount of oil residue in the cake increases the oil loss, could cause problems with correct storage and affects the quality of the cattle food prepared from the cake. Operating with worn out extraction cage knives also increases the number of tiny particles of metal in the extracted oil and as a result of this more frequent choking and damage to the filters during cleaning occurs [2]. The increasing amount of metal in the oil also decreases the installed capacity of the pressing plant.

Although in oil mills due attention is given to the removal of metal from the oil because of its pro-oxidative effect, the increasing severity of regulations regarding the ecological quality of food means it will require even more attention in the future.

In spite of the numerous technological factors influencing the efficiency of oil extraction [3], e.g., the technological ripeness of the seeds, adjustments to the hulling machine, the character of the hulling and the conditioning parameters, the total oil extraction (depending upon the hybrid it is in most cases about 45 % to 50 % of the oil in the sunflower) depends not only on the type of worm press and the adjustment of the working parts (worm-screw pitch and the distances between the knives along the working fields) but also on a correctly defined criterion for the end of their functional working time, i.e., on the allowed dimensional wear before failure or replacement (the so-called wear-reserve) [4].

The need for stronger regional connections was the reason for the systematization of earlier recorded results on the work of worm presses in two oil mills in Vojvodina ("Mladost" in Šid and "Dijamant" in Zrenjanin – English and Russian equipment), in one oil mill in Bosnia and Herzegovina ("Bimal" in Brčko – German equipment), and in two Croatian oil mills ("Zvijezda" in Zagreb and "T.U. Čepin" in Čepin – English and German equipment). The data from interviewing and polling on the quantities of sunflower seeds processed before the replacement of the worm presses' spare parts, either original imported or domestic substitutes, were collected. The data were used for the calculation of the cost of worm-press parts per ton of processed sunflower seeds. It was found that the costs of the working parts of presses per ton of processed sunflower ranged from about € 0.35/t for original parts to about € 0.45/t for domestic substituted knives, and from about € 0.45/t for original parts to about € 0.90/t for domestic substitution segments.

On the basis of the data it was decided to investigate the possibility of applying our solution of welded layers to extend the lifecycle of the parts of presses and also to investigate the influence of protective layers on the working efficiency of the pressing plant and the operation of the entire oil mill.

2 MATERIAL AND METHODS

The parts of the worm presses of different manufacturers were collected over several years for the purpose of establishing the protection procedures applied so far.

The readiness of the maintenance staff in the mentioned oil mills allowed us to collect imported parts (original and substitute) and the parts made in domestic factories as substitutes. The worm press is shown in **Figure 1**.

The characteristic wear traces on the surfaces of the used knives and worm segments are shown in **Figure 2**.

The abrasive ($SiO_2 \cdot H_2O$) [5,6] contained in the hulls of the sunflower seeds (the most common high-oil seeds produced in our region) is the main cause of the wear to worm-press components and the extraction cage knives. Its hardness (about 6 by Mohs, i.e., more than HV = 1000) directly affects the wear mechanism of the working surfaces of worm-press parts and for this reason, the type of applied protective layer affects the life time of these parts. It was found that the dominant wear mechanism was a selective abrasion, characterized by furrows in the direction of the relative movements of the meal – the working surface. Pores and small pits were observed at the places where the carbide particles were removed from the matrix and protrusions were observed where these hard particles, a constituent of the alloy microstructure, stuck out from the surrounding softer matrix. It was found that carbides on the welded layer Stellit 6 are the result of high-pressure pressing into a resisting Co matrix and so produce a creased matrix (**Figure 2c**).

The hardness distribution $HV1$ from the surface towards the core of the worn worm segments and the extraction cage knives was determined on parts protected by thermal-chemical processing, because they provided fairly homogenous depths of the layer on all the surfaces [7]. Unequal wear on the working surface parts was found and the following was established:

- The wear of the worm segments is the greatest on the frontal part of the top worm screw, less wear occurs on the top of the top worm screw and even less on the front side of the worm screw, while the body of the segment and the backside of the worm screw are only slightly worn out.
- The wear of the extraction cage knives is the greatest on the leading edge, somewhat less on the back edge, even less on the upper working surface and only slight on the lateral sides.

In the investigation of the wear resistance of different protective layers and with monitoring of the performance

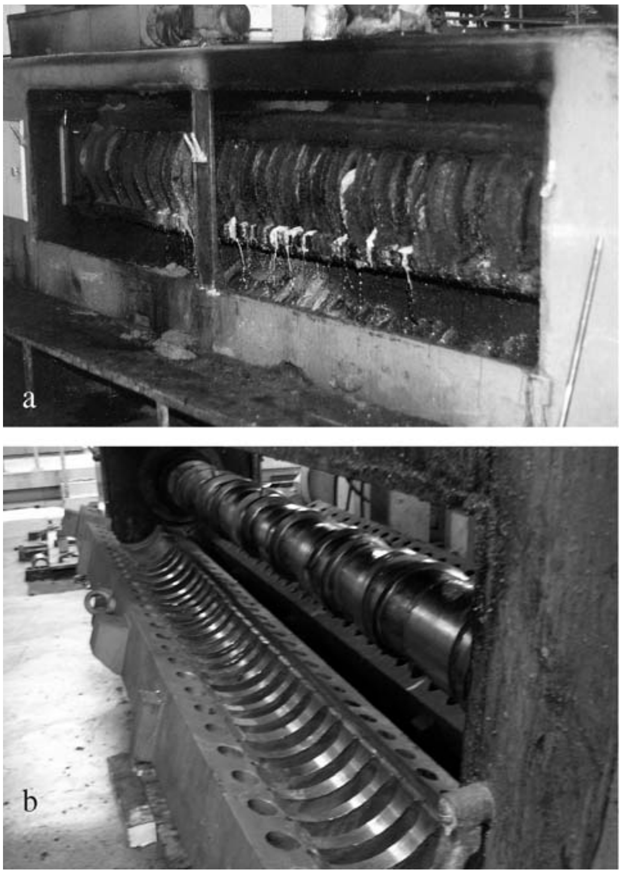

Figure 1: Worm press for oil extraction (a – in operation and b – opened with new cage knives)
Slika 1: Vijačna stiskalnica za ekstrakcijo olja (a – med delom, b – odprta z novimi noži kletke)

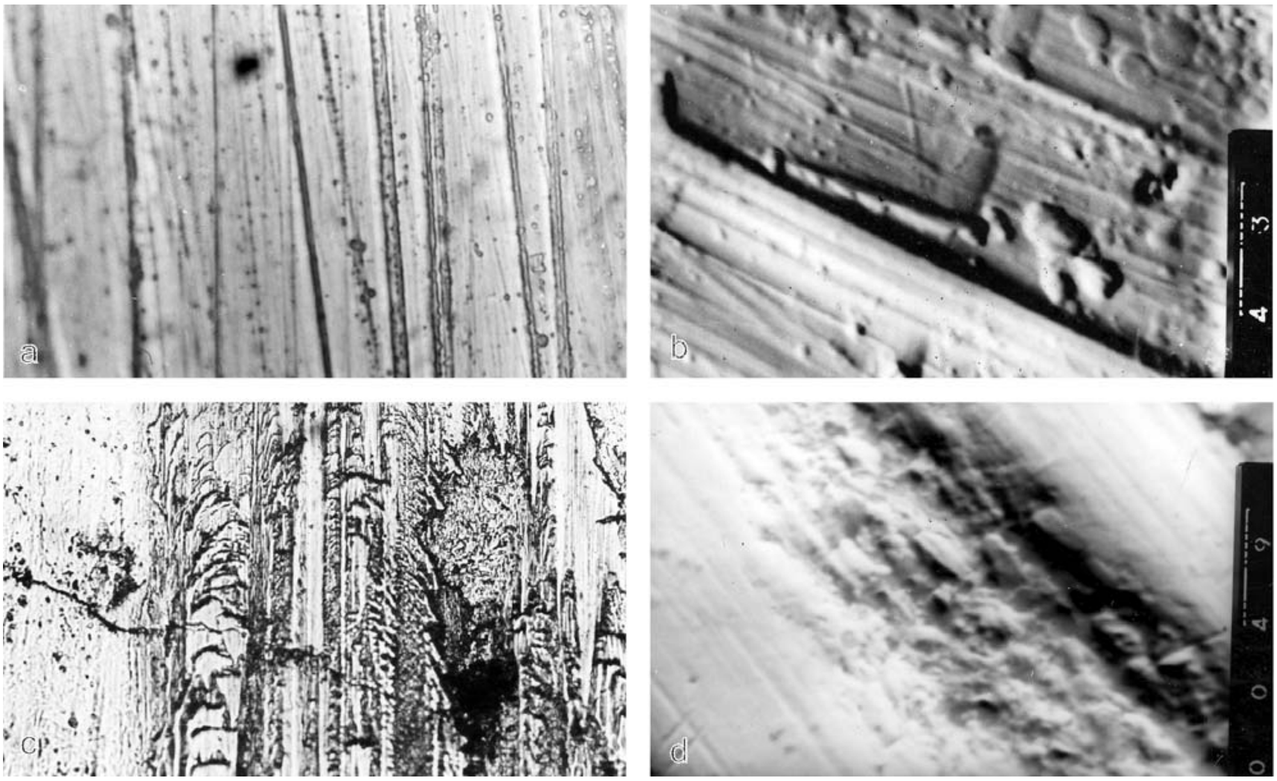

Figure 2: Characteristic wear traces of different protective layers on the parts of the presses: a – Carburised layer, optical microscope, mag. x200; b – Carbonitrided layer, SEM, mag. x700; c – Welded layer Stellite 6, optical microscope, mag. x200; d – High-grade steel for cold work, SEM (TOPO), mag. x700

Slika 2: Značilni sledovi obrabe na različnih varovalnih plasteh na delih stiskalnic; a – cementirana plast, optični mikroskop, pov. 200-kratna; b – karbonitrirana plast, SEM pov. 700-kratna; c – navarjena plast Stellit 6, optični mikroskop, pov. 200-kratna; d – orodno jeklo za delo v hladnem, SEM, pov. 700-kratna

during oil extraction, the uneven wear of the parts of the working surfaces, the uneven wear of the worm nut segments and of the extraction cage knives along the working surfaces from the meal intake to the cake discharge were established. The conclusions were as follows:

- The wear of the extraction cage knives is greater in the working fields where the oil extraction is most intensive.
- The wear of the worm segments is the strongest in the discharge working fields.

The differences can be related to the change of the radial and axial components of the pressure upon the meal by the working fields along the worm screw during its movement from the meal intake to the cake discharge [8].

3 PRE-EXPERIMENTAL INVESTIGATIONS OF THE PROTECTIVE LAYERS AND SELECTION OF THE OPTIMAL VARIANT

A lot of information about wear protection for the parts of oil presses during oil extraction is not available, as it known to the manufacturers of worm presses. Based on accessible references, the results of our on-site collection and the investigation of the original and spare parts the following conclusions were drawn:

- The original parts of the presses most often have a protective layer obtained by depositing additional material. Russian presses (one oil mill) had carbonitrited working surfaces, while the German presses (older solutions) had carburised surfaces.
- The thickness of the protective layer on the worm screw ranged from 4 mm to 5 mm, on the body of the worm assembly parts it was about 2 mm, and the same on the upper working surface of the extraction cage knives.
- The effective depth of the carbonitrided layers (according to the criterion *E*dc *HV*1 = 550) on both the worm assembly parts and the extraction cage knives of the Russian presses was about 1.8 mm, while the effective depth of the carburised layers was in the range from 0.6 mmto 1.8 mm.
- With domestic substitution solutions, in addition to the welded layers with similar depths to the original parts, two approaches were noted. The first was the carburising to an effective depth of 0.6 mm to 1.2 mm (depending on the part supplier) and the second was the surface quenching of tool steel for cold work (and subsequent tempering) with a quenched layer depth of 2 mm to 3 mm.

Table 1: Oil content in the meal and the average mass loss of the knives per working field for carburised knives
Tabela 1: Vsebnost olja v gneteni masi in povprečna izguba mase na delovno polje za cementirane plasti

Working fields	I	II	III	IV	V	VI	VII
Average mass loss, *m*/g	12.34	16.29	19.57	24.45	13.61	11.07	12.15
Oil portion in meal, *w*/%	49.61	47.43	41.26	30.05	21.64	16.03	12.39

The extraction cage knives were chosen for the investigation with regard to the fact that in every working field, depending on the press type, from fifty to sixty knives are built in. This gives us the possibility of installing experimental knives into oil presses in addition to the knives owned by the oil mill. In this way the same conditions of testing (e.g., the pressure, the quantity of abrasive and oil, the temperatures, the relative speeds of meal movement along the working-examination surface of sample knives etc.) were achieved for all the knives.

The tests of wear resistance on the working parts of the presses during oil extraction were carried out in the oil mill with presses for pre-pressing and final pressing (without oil flat cake extraction). These presses have seven working fields, defined by the size of the knives' gaps acting as the oil extraction. The opening width of these gaps is 0.75 mm in the first working field (at the entrance of the meal in the press) and decreases to 0.15 mm in the seventh working field, before the exit of the oil cake from the press.

Considering that the presses were newly designed (since being put into operation in 2002), the preliminary testing was carried out to define the working fields with the most exposed wear of the knives. For this purpose, 21 knives were randomly selected from a complete, new replacement set. A laboratory investigation showed that the complete set had a carburised layer with an effective depth of 1.2 mm, and a surface hardness of *HRC* 56 to 58. Selected knives were marked and weighed (with an accuracy of 0.01 g). The mass of one knife (dimensions 11 mm x 25 mm x 300 mm) was 620 g. During the replacement of worn original marked knives three experimental knives were built into each working field of the final pressing.

After 3500 tons of processed sunflower meal, all the knives were taken out for replacement. From the weight of the marked knives the loss of mass for each knife per working field was calculated (**Table 1**). Data on oil extraction from the meal per working field are also given in **Table 1** (the samples of meal were taken after the meal had been overdone in the press). The oil content in the meal was determined according to ISO 659 [9].

From the results of the weight loss it is clear that the wear is increased in working fields III and IV, and that the weight loss decreases in the output working fields. This is logical because in these fields the oil extraction was the most intensive, as shown by the oil residue in the meal.

4 RESULTS OF EXPERIMENTAL INVESTIGATIONS

As the welded layers were found to be most often applied in the most worn parts of the presses, three types of additional material for the welding of the surface layers were chosen for the experimental investigations of wear resistance in the contact with sunflower seeds as an abrasive medium in the routine operation of the worm presses. The carburised layer was chosen as a reference protective layer because this is used in most cases as a substitution solution for the worn original parts of the press.

The case of hardening steel 16MnCr5 (Č4320) was selected as the basic material for all the samples.

The same manufacturer supplied all three additional materials for the welded layers of knives, which varied in production costs and chemical composition (see **Table 2**).

Table 2: Prices and nominal chemical compositions of the additional materials
Tabela 2: Cene in nazivna kemična sestava dodajnih materialov

Ordinal number	Internal mark	Chemical composition, *w*/% [1)]	Price, kn/kg [1)]
1	A	0.6 % C, 7 % Cr, 0.4 % Mo	80.00
2	B	2 % C, 31 % Cr, 11 % W, rest Co	560.00
3	C	3 % C, 40 % Fe, rest W carbide	675.00
[1)] Approximate value			

The box carburising of previously ground samples (*Ra* = 0.8 µm) was performed for 10 h at 950 °C. The carburised knives were air cooled, quenched from υ_k = 850 °C and tempered at υ_p = 200 °C. When measuring the hardness profile *HV*1, the effective depth of the layer was found to be *E*dc = 1.2 mm, and the surface hardness was *HRC* 59.

The welded material was deposited (by REL) in two layers using a Ø 3.25 mm electrode. The knives were then machined with grinding to *R*a = 0.8 µm. The hardness of the welded knives was as follows: welded layer A *HRC* 60; welded layer B *HRC* 57; welded layer C *HRC* 62. The hardness *HV*1 measurements from the surface of the welded layer to the core of the knives showed that the thickness of the layer with a hardness above *HV*1 550 ranged from 1.9 mm to 2.3 mm.

Characteristic microstructures of the surface zones of the experimental protective layers are shown in **Figure 3**.

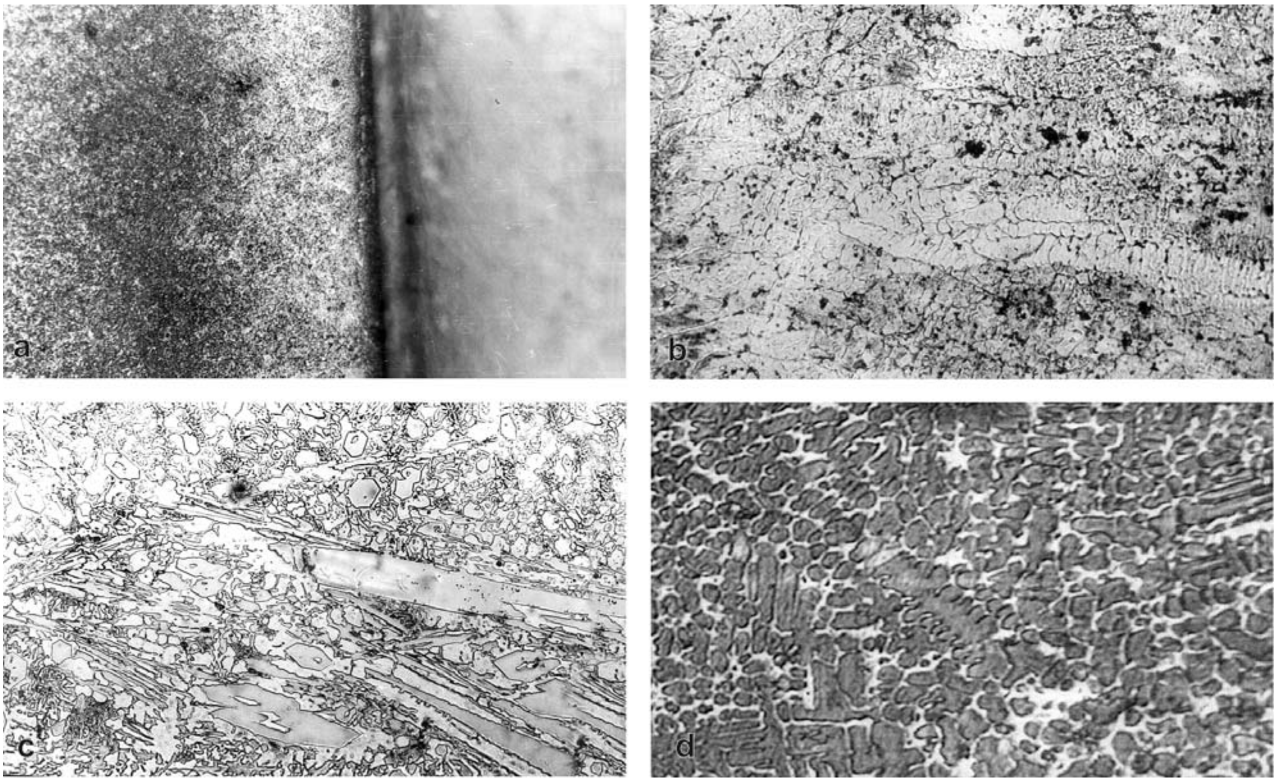

Figure 3: Characteristic microstructures of the surfaces of the experimental protective layers (mag. 200)) (a – carburised, etched by nital 3 %; b – welded layer A, etched electrolytically; c – welded layer B, Adler etching; d – welded layer C, Adler etching)

Slika 3: Značilne mikrostrukture ob površinskih eksperimentalnih varovalnih plasti (pov. 200-kratna) (a – cementirana plast, jedkano z nitalom, b – navarjena plast A, elektrolitsko jedkano; c – navarjena plast B, jedkanje Adler, d – navarjena plast C, jedkanje Adler

The microstructure of the carburised layers consisted of martensite, bainite and residual austenite. The microstructure of the welded layer A was similar, with dendrites in the direction of the heat flow. In the cobalt matrix of the welded layer B microstructure tungsten and chromium carbide particles were observed. Tungsten carbide particles were also present in the martensitic matrix of the welded layer C.

From each type of protective layer six knives for the extraction cage were machined with geometrical and dimensional characteristics defined in the technical documentation of the worm-press for final extraction. Three knives were built into the working fields III and IV, along with the carburised knives owned by the oil producers. These working fields were selected because previous examinations showed that they were the zones with the greatest wear.

Table 3: Average loss of weight for the knives in the working fields III and IV of the worm-press for final extraction

Tabela 3: Povprečna izguba mase v delovnih poljih III in IV vijačnih stiskalnic za končno ekstrakcijo

Working field	Average loss of knives mass, m_k/%			
	Protective layer			
	Carburized	Welded layer A	Welded layer B	Welded layer C
III	16.41	14.83	6.53	9.38
IV	18.58	17.90	8.75	12.11

The knives were removed from the press when the monitoring of the level of the fine particles of meal in the extracted oil required a periodic overhaul. The mass of the knives was controlled within 0.01 g, as before the installation. The measured loss of weight for the knives along the working fields, after processing about 40,00 t of partly decorticated sunflower, are given in **Table 3**.

5 DISCUSSION AND CONCLUSION

An experimental examination of the knives in the extraction cage showed that the knives with Cr and W carbide particles in the cobalt matrix (welded layer B) provide the highest wear resistance. The wear resistance of the knives with W carbide particles in the martensite matrix (welded layer C) is smaller, although for surface layers consisting of martensite (welded layer A) it was only slightly greater than for the carburised layers. These results have to be related to the determined dominant wear mechanism of the parts of the press. As hard "abrasive" ($SiO_2 \cdot nH_2O$), is found mostly in the sunflower hulls, its hardness is from *HV* 1000 to 1100, carbides with higher hardness (Cr and W carbides) provide the best wear resistance [10].

The complete examination of different protective layers applied to the parts of presses in oil mills was used to estimate the production costs of the parts as compared to the recorded quantities of the processed raw materials until the breakdown or replacement of the worn parts.

Possible savings by manufacturing and using worm-press parts with more wear-resistant protective layers can result in a decrease of the indirect tribological losses. The parts breakdown dimensional criterion also affects the selection of the protective layer type through a so-called "wear reserve", which should be higher than the maximum designed wear. For this reason, the constituents of the microstructure responsible for wear resistance (carbides or carbonitrides) should be harder than the abrasive contained in the oil seeds and as regularly distributed as possible in the matrix, which is as tough as possible, to prevent them from falling out in the dynamic stressing and wear in the worm-presses during oil extraction.

The mentioned possible savings are particularly large for the full operation of the oil mill. From the economic viewpoint for business efficiency this means:

- approximately 280 working days per year, including a month for overhaul and a month for collective holidays,
- operation of all the plants with a declared or roughly equivalent capacity: hulling, preparation, pressing, extraction and refinement without unplanned outages.

In conditions of processing of sunflower for commercial purposes during the receiving, warehousing and drying of the unavoidably mixed hybrids, the oil mills that also deal with subcontracting sowing areas for their own needs should pay attention to other parameters and not only to the oiliness of the "contracted" sunflower hybrids, as confirmed by the results of investigations conducted into hybrids selected in climatic conditions similar to those in Slavonia and Baranja [11,12]. From the tribological point of view, the technical and technological characteristics of the seeds can contribute to a change of the pressing plant's installed capacity utilization level and to direct and much higher indirect costs (losses due to breakdowns). Some improvements might be achieved with a multidisciplinary approach to the tribo-system of worm-presses. Such an approach requires an interconnection of the whole chain: selection and choice of the hybrid in terms of the corresponding (micro) regional preconditions, soil preparation for sowing, conditions of cultivation and harvest, warehousing, preparation for pressing, percolation, refinement, and the quality of oil, i.e., the crushed oil seed for stock-cattle feed preparation. The contribution of scientists could be made through a meaningful and organized research activity along with the systematic acquisition and interconnection of collected data.

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