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TRIBOLOGIC PROPERTIES OF SELECTED MATERIALS

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K e y w o r d s: pin on disk test, adhesive wear, wear resistance.

A b s t r a c t

The contribution brings evaluation of selected materials regarding wear resistance in conditions of chosen experiment. Systemic approach to the task in question is emphasised. The results of basic material are compared to results of material of weld deposits. The results of tribologic experiment enable prediction of certain characteristics of friction pairs in conditions of particular friction node. The following materials had been chosen for the particular experiment:

– steel 12 050 (C45) in state after heat treat,
– steel 12 050 (C45) in state after hardening.

Selected materials are compared to weld deposits C 508 and C-64 after being welded on and heat treated. The tribologic experiment was carried out on device TE 97/A, which ranks in category of "pin – disk" test devices. The resistance of selected materials was evaluated ragarding size of weight loss and regarding energy.

In the experiment conditions it was observed that combinations of material C 508 + C 64 indicated the best results for both categories of test samples. For this combination of material, not the state of heat treatment but good friction characteristics was determining

WŁAŚCIWOŚCI TRYBOLOGICZNE WYBRANYCH MATERIAŁÓW

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S ł o w a k l u c z o w e: eksperyment: czop – tarcza, zużycie adhezyjne, odporność na zużycie.

A b s t r a k t

Przedstawiono ocenę wybranych materiałów w aspekcie ich odporności na zużycie w warunkach eksperymentu laboratoryjnego. Problem rozwiązywano systemowo. Wyniki dla materiału podstawowego porównano z wynikami uzyskanymi dla warstw napawanych. Uzyskane w eksperymencie trybologicznym wyniki pozwalają na predykcję właściwości par trących konkretnego węzła.

Do eksperymentu wybrano:
– stal 12 050 (C45) w stanie po uszlachetnieniu,
– stal 12 050 (C45) w stanie po hartowaniu.

Właściwości wybranych materiałów porównywano z właściwościami napoin utworzonych z materiałów C 505 i C 64 w stanie po napawaniu i obróbce cieplnej. Właściwy eksperyment trybologiczny realizowano, korzystając z urządzenia TE 97A, należącego do kategorii maszyn badawczych w układzie czop – tarcza. Odporność materiałów na zużycie oceniano na podstawie ubytków ich masy oraz zużycia energii.

Eksperyment wykazał, że w obydwu kategoriach próbek najlepsze wyniki osiąga się w kombinacji z materiałami C 509 + C 64, w których decydujący nie był ich stan obróbki cieplnej, lecz prawdopodobnie ich dobre właściwości cierne.

Introduction

Friction as an important physical effect required a lot of theoretic and experimental work to be understood. Many theories have evolved, explaining the effect in a more or less complex way. Systemic approach is necessary for the complex solution of friction and related attrition in both theoretic and experimental sphere. Regarding tribologic properties of materials, it is the right choice of material or material pair, geometric shape, roughness, etc. which is important. Regading tribometry, it is a question of the test device, choosing own test methods as well as the right shape and size of the test samples. Choosing appropriate approach to solving the problem of adhesive friction and related wear is also very important.

Specific working conditions of agricultural machinery effect its working life. This is sometimes relatively short as a result of heterogenous forms of breaking the components and components' surface. Relative short working life of machinery's and devices' components in agricultural production is caused by (KUČERA 1991):
– excessive wear,
– variability of the work regime,
– aggressive environment.

For the purpose of handling durability it is necessary to recognize basic causalities and relations, which determine deffects and decrease operating reliability.

For the specification of the reliability as a complex attribute of the system, analysis of operating conditions is the ultimate factor. Operating reliability of a machine is directly connected to problems arising in tribologic node of the machinery. It is place where functional parts of the node interact with each other with simultaneous affection of other factors.

Tribologic node:
– pin or shaft,
– sleeve bearing, shaft seal etc.,

– grease medium,
– environment,

ranks among frequent nods in agricultural machinery and is very important for the transmission of the torque or power from engine to functional parts of adapters. The solution of a particular tribologic node requires systemic approach (BALLA 1979).

The problem is even more complicated in case of a need of supplying the worn surface. As it is tribologic node with weld deposit that is concerned, the knowledge of materials' properties, effect of alloying elements and effect of the welding technique on weld depostits' properties, is of the utmost importance (BLAŠKOVIČ, ČOMAJ 2006).

Adhesive wear is complicated process of damaging surface layers of friction pairs̀ material during interaction of bearing surfaces̀ undulations.

The pattern of the deformation depends on the penetration depth of irregularities into the other part's surface as well as on the radius of the particular penetrating irregularity. In case of elastic deformation, surface layers̀ faults are of high-cycle contact fatique pattern. In case of plastic deformation, the surface attrition is determined by low-cycle contact fatique.

The contribution deals with possibility of prediction of friction pairs̀ behaviour based on results of tribologic experiment. In this contribution we would like to mention several aspects of systemic approach to selection of material, preparation of samples and methods of testing in relation to agricultural machinery.

Within the experimental work, material used for production of components of "shaft, pin" type have undergone analysis. Selected materials were compared to each other as well as to weld deposits recommended by producers for refitting the worn surfaces.

Material and methods

We paid great attention to selection of appropriate material. We assessed components of shaft or pin – type of various agricultural devices (tractor, harvester, straw-cutter, mobile machines, etc.), with worn functional parts of cylindrical shape (KUČERA 1992).

We found out that 22 types of steel is used for production of group of 186 components:

3 types of steel class 11 (11 500, 11 523, 11 600)
4 types of steel class 12 (12 020, 12 050, 12 060, 12 061)
2 types of steel class 13 (13 240, 13 242)
8 types of steel class 14 (14 140, 14 220, 14 221, 14 223, 14 230, 14 231, 14 240, 14 331)

4 types of steel class 15 (15 130, 15 142, 15 230, 15 240)

1 type of steel class 16 (16 231)

More results arising from the observed group:

– 16.7% of components were manufactured from untreated steel

– 11.8% of components were treated, with exposion areas inductive hardened

– 38.2% of components were manufactured from treated steel

– 30.1% of components were cemented and hardened on exposion functional parts

Treatment itself or in combination with another type of heat processing was used for 52.7% of components.

From the group of materials mentioned above, the selected types of steel were chosen for purposes of the experimental wear resistance test:

– steel 11 500 (EN, E 295) as representative of steel type used in natural state

– steel 12 050 (EN, C45) as representative of steel type used after heat treated and inductive hardened

– steel 14 220 (EN, 16MnCr5) as representative of steel type used for components with cemented and hardened surfaces.

For the purpose of the particular experiment material C 45 was selected as representative of steel types used for manufacturing of components of "shaft-type" with treated and hardened surface.

This material was compared to weld deposits of additional material C 508, recommended by manufacturer for hard surfacing of worn surfaces of shafts without heat treatment. The samples were hard surfaced on material C 45 of tubular shape using welding technique in shielding gas MIG/MAG, by unifilar and two-wire process.

Selection of test methods and test devices

For the selection of test methods, test devices and evaluation of results, definition of wear according to STN 01 5050 was followed:

Wear (attrition, deterioration) is undesirable change in surface or size of solid entity, that is caused either by interaction of functional surfaces or interaction of functional surface and medium, which starts the wear. Wear is demonstrated as removing or transfering elements of surface by mechanical motivation.

Regarding this definition we decided for:

– adhesive wear test without greasing

Tests were executed on test device of type TE 97/A – Fig.1, which ranks among "pin-disk" devices with flat contact of friction nod elements. The test device is suitable for comparation tests of selected materials. The fundamental of the test is that test samples of pin shape are imprinted to facing surfaces of rotating disk using hydraulic cylinder and constant force. Pins have been manufactured from material C 45 plus another weld deposits mentioned above. The counter part was made of material 12 020 (C 15 E).

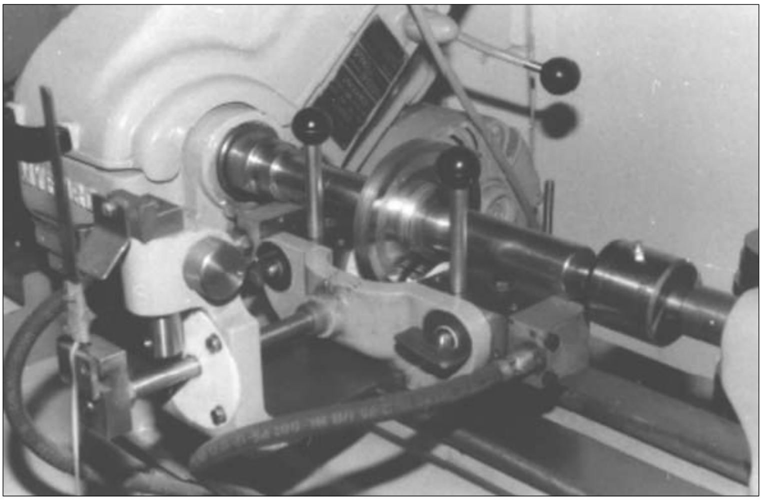

Fig. 1. View of active part of device TE 97/A

Test parameters

Test parameters were selected from test parameters of adhesive wear test without greasing used in tribologic laboratory in order to enable the best possible comparison of tribologic properties of supplied samples.

Parameters of the test are as follows:

– pressure in hydraulic circuit	1.47 MPa
– compressive force on the pin	74.3 N
– surface speed of the test radius	3.2 $m.s^{-1}$
– exposition time	15, 30, 45, 75 s
– material of the counter part	steel 12 020
– dimensions of the sample	8 x 50 mm

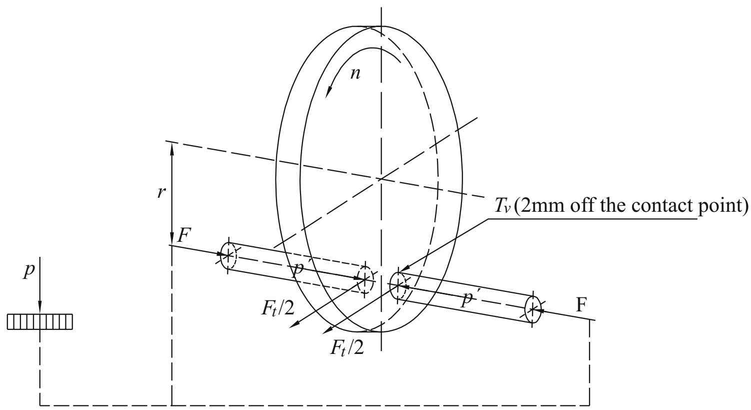

Fig. 2. Illustrates principled scheme of device TE 97/A

Preparation of samples

Hard surfacing was executed on experimental welding machine ENZ-100 in shielding gas CO_2. The samples for adhesive wear resistance test were welded on bar of 105 mm in diameter made of material C 45 by rotating welding technique. For every sample 20 to 25 mm were welded on. The welding-on parameters are listed in Table 1. After cooling, the samples were lathed into ring shape, which was then divided in 15 parts. Another latheing prepared the active part of the sample (Fig. 3c), which was imbeded into counter part and pasted by aldurit. The thickness of the weld deposit on the facial surface after completion was 2 mm. Four pairs of test samples were prepared from each weld deposit. After heat treatment, the elements were modified according to (Fig. 3d) and lathed to final measure 8 mm in diameter.

Table 1

Parameters of hard surfacing of samples for wear test without greasing

Additive material			Speed of feeding [m min^{-1}]		Intensity of hard surface flow [A]	Arc voltage [V]	Rotation speed of spindle [min^{-1}]	Weld deposit gradient [mm min^{-1}]	CO_2 consumption [l min^{-1}]
OD	SD	ØOD/ØSD [mm]	OD	SD					
C508	–	1.2 / 0	4.7	–	165	20	2.5	5	12
C508	C64	1.2 / 0.93	3.4	2.4	115	20	1.7	5	12
2xC508	–	2x 1.2/ 0	2.0	–	145	20	2.2	5	12

OD – arc wire, SD – cold wire

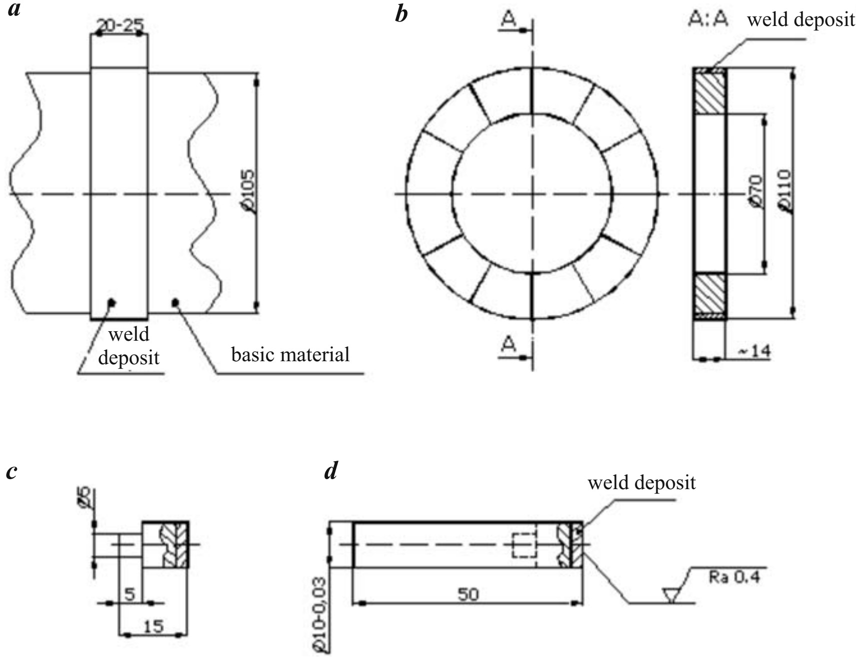

Fig. 3. Preparation of test element: a) weld deposit on basic material, b) partition of the ring into 12 parts, c) active part of the sample, d) test element before the final treatment

Despite being difficult, the way of samples preparation mentioned above guaranteed, that the active part of the samples, especially in case of weld deposits, will correspond with real surfaces as far as behaviour is concerned.

Figure 3 shows our approach to testing the wear of sliding nod using chosen material pairs in conditions which simulate part of real nod's surface. Cross comparison of different materials of samples was possible thanks to material of the counter part being the same in each sequence of the test. Conditions of the test followed the methodology elaborated by prestigious test stations. After consultations with workers from these stations we decided to evaluate the energy demandingness of the wear process. This method appeared convenient especially for comparison of wear resistance of basic material with properties of weld deposits (BLAŠKOVIČ 1990).

The same procedure was used for preparation of elements made of basic material C 45, as comparative material.

Characteristics of test elements, the status of their heat treat and temper is shown in table 2. Figure 4 ilustrates shape and dimensions of the disk for adhesive wear test without greasing.

Table 2

Samples characteristics for wear test without greasing

Sample no.	Basic material	Additive material	Heat treatment	Surface hardness (HV)
1	12 050 (C 45)	C 508	Hardening 850°C/water,tempering 170°C/1h./air	554
2	12 050 (C 45)	C 508+C64	Hardening 850°C/water, tempering 170°C/1h./air	598
3	12 050 (C 45)	2 x C 508	Hardening 850°C/water, tempering 170°C/1h./air	527
4	12 050 (C 45)	–	Hardening 850°C/water, tempering 170°C/1h./air	606
5	12 050 (C 45)	C 508	–	368
6	12 050 (C 45)	C 508+C64	–	368
7	12 050 (C 45)	2 x C 508	–	ą296
8	12 050 (C 45)	–	Hardening 850°C/water, tempering 650°C/1h./air	256

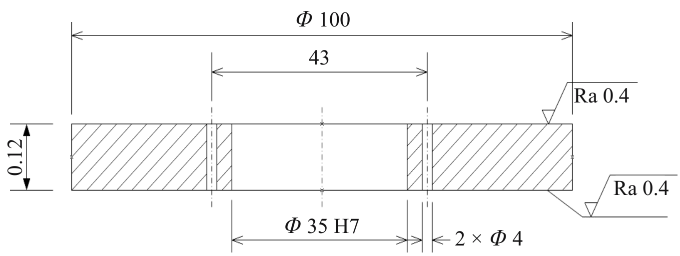

Fig. 4. Shape and dimensions of the disk for wear test without greasing

During the test, changes in friction force are scanned and recorded. The friction force was scanned and recorded by tensometric scanner. The record of the course of friction force enables evaluation of:

- Maximum friction force,
- Mean value of the friction force,
- Frictional labor,
- Friction factor.

The wear of the samples was detected by direct observation before and after the test. After proper degreasing and drying, samples were weighted on analytic scales MEOPTA. The result of the wear test on device TE 97/A is diagram showing the relation between extent of wear and time of test.

We used coefficient of tribologic capacity K^* as criteria for evaluation of the result of the wear test withou greasing on device TE 97/A. K^* expresses quantity of friction labor needed for detachment of unit quantity of material.

The hardness was measured on the front of the samples i.e. at the point of interaction of the sample with testing disk. Hardness tester MEOPTA – VICKERS with load of spire F = 295,3 N was used for measuring.

Evaluation of results

In case of tests without greasing, we detected the quantity of friction labor – from the course of friction force at given time – and its contribution to weight loss – coefficient K_{VZ}, (K^*).

Coefficient K^* is referred to as coefficient of tribologic capacity of weld deposits (materials).

Comparing the rate of wear and friction labor to material etalon we get K_N coefficient, which is reffered to as coefficient of relative tribologic capacity of weld deposit (material). Besides these criteria, our test type enables defining:

– ratio of friction coefficient to weight loss,
– coefficient K^* to weight loss,
– coefficient K_N to weight loss.

Criteria K_N accepts physical nature of detachment of surface particles during friction.

Interpretation of results of adhesive wear test without greasing

The objective of adhesive wear test without greasing on device TE 97/A was to assess:

– weight loss of basic materials and weld deposits,
– coefficient of tribologic capacity of weld deposits,
– ratios of friction coefficient to values of weight loss,
– transfer of material for selected pairs, nature of transfered elements and its chemical composition.

We observed weight loss relating to time on device TE 97/A (Fig. 1).

Results were obtained by weighing the samples before and after the test.

$$\Delta m = m_o - m_1, \text{ g} \tag{1}$$

We detected the wear rate at exposition time of 15, 30, 45, 75 seconds. The results are listed in table 3.

Table 3

Results of adhesive wear test without greasing on device TE97/A

Sample no.	Material	Heat treatment	Wear W_0, mg after test time [s]			
			15	30	45	75
1	C 508	Hardening	1.4	4.65	5.5	6.95
2	C 508 + C 64	Hardening	1.65	4.5	8.45	5.2
3	2 x C 508	Hardening	1.35	3.35	4.75	5.3
4	12 050	Hardening	1.25	1.85	1.85	8
5	C 508	–	2.3	2.85	5	7.3
6	C 508 + C 64	–	0.05	0.2	1.45	4.95
7	2 x C 508	–	1.1	5.45	2.8	8
8	12 050(C 45)	Heat treated	2	1.1	1.8	6.6

Graphic presentation of the results of the adhesive wear test without greasing on device TE 97/A is shown in Figure 5 and 6.

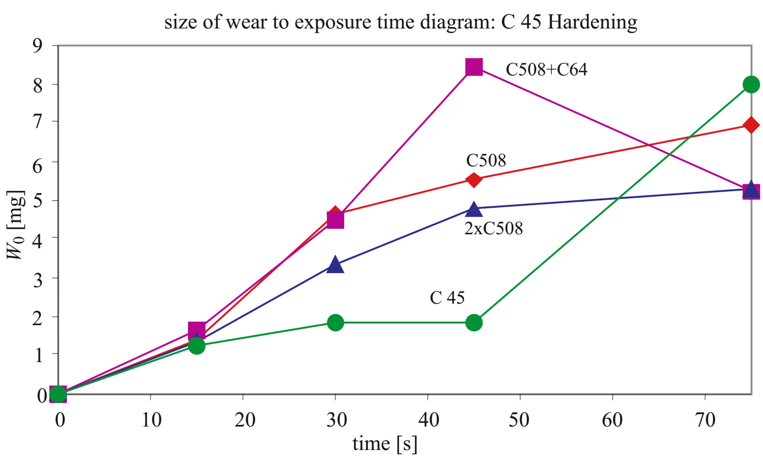

Fig. 5. Size (W_0, mg) to exposure time diagram for selected group of test material C45 in state after hardening

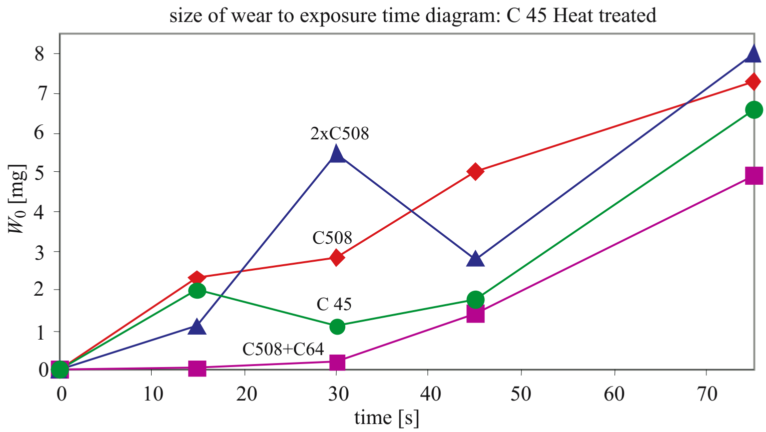

Fig. 6. Size (W_0, mg) to exposure time diagram for selected group of test material C45 in state after heat treated

To simplify the evaluation of results, two groups of samples were formed. The first group involves hardened samples. That means, that basic material was hardened and weld deposits for this material were heat treated – inductive hardened – too. The second group involves treated material. Only basic material was treated. Weld deposits for this material were not heat treated after being made.

Based on results listed in table 3 and shown in Figure 5 and 6, we may point out, that sample no. 2 with weld deposit marked C508 + C64 indicated minimum wear from the first group of samples, i.e. for treated steel. Sample no. 3, i.e. 2xC508, indicated very similar values. Sample no. 4, i.e. basic material, indicated the highest value of wear rate.

In case of the second group of samples, treated samples, weld deposit labelled C508+C64 indicated minimum loss. But as contrasted to treated steel, the major weight loss was not indicated for basic material, but for weld deposit marked 2xC508.

We may state, that samples with weld deposits made with combination of additional materials C508+C64 are the best of the whole group, while it is not the hardness that plays the decisive role, but probably good frictional attributes of the combination of additional materials. It must be stressed out, that during surfacing with technology MAG the degree of mixing of weld metal with basic material is 20 to 30%. The degree of mixing declines as cold wire is added. That means, the weld deposit has approximately the same properties as additive material, therefore it shows satisfying results in the area of adhesive wear.

Evaluation of tribologic capacity

In laboratory conditions, weight loss of weld deposits W_0 was observed on devices, which enable observing the course of friction force F_T during loading by constant force F_N at given time t. Time t is proportional to friction path L.

Based on the fact introduced above we may describe friction labor A, N.m. as follows:

$$A = \int_0^t F_T \cdot t \cdot dt \tag{2}$$

When relating the friction labor to unit weight (volume) of worn weld metal, we get relation:

$$K^* = \frac{A}{W_0}, \text{ Nm kg}^{-1} \tag{3}$$

K^* value is referred to as coefficient of tribologic capacity of weld depoits and expresses the quantity of friction labor needed for detachment of unit quantity of weld material.

If we relate values of the wear W_0 and friction labor A to etalon material, then it may be stated:

$$K_N = \frac{K_s^*}{K_e^*} = \frac{\frac{A_s}{W_{0s}}}{\frac{A_e}{W_{0e}}} = \frac{A_s}{A_e} \cdot \frac{W_{0e}}{W_{0s}} \tag{4}$$

A_s – friction labor of the sample, J,
A_e – friction labor of etalon, J,
W_{0s} – wear of sample, g,
W_{0e} – wear of etalon, g,

K_N is referred to as coefficient of relative tribologic capacity of weld deposit.

Table 3 displays results of the hardness testing at body front of samples and as well calculated values of coefficient of tribologic capacity of weld depoits K^* and coefficient of relative tribologic capacity of weld deposits K_N.

Table 4

Chart of hardness as measured, K^* and K_N

Sample no.	Material	Heat treatment	Hardness HV	K^* (Nm kg^{-1})·10^8	K_N –
1	C 508	Hardening	554 – 620	2.382	1.536
2	C 508 + C 64	Hardening	598 – 626	3.841	2.478
3	2 x C 508	Hardening	527 – 586	3.062	1.976
4	12 050	Hardening	606 – 644	2.446	1.578
5	C 508	–	368 – 400	2.348	1.514
6	C 508 + C 64	–	368 – 398	3.339	2.153
7	2 x C 508	–	269 – 297	1.754	1.131
8	12 050 (C 45)	Heat treated	256 – 262	3.141	2.026
etalon	12 020(C 15 E)	–	160 – 180	1.55	1

K_N criteria accepts physical basis of detachment of particles from the surface during friction process and enables assessment of weld deposits for tribologic use.

To assess the suitability of weld deposits using coefficients of tribologic capacity we operated with two material groups again.

The first group involves samples made of steel C 45 hardened (samples 1-4) and samples with weld deposits after hardening. Within evaluations according to coefficient of tribologic capacity of weld deposits K^*, the highest values were achieved for weld deposits made with combination of additive material C508+C64. Based on K^* value we point out, that weld deposits of the combination of materials mentioned above achieve the highest adhesive wear resistance in given conditions. Slightly lower values achieved sample no. 3 with additive material 2xC508. The lowest values achieved sample no. 1 with additive material C508. It is necessary to notice that single additive material marked C508 attains lower order values than C508 in combination. Practically, it is therefore much more convenient to use this additional material in combination, either with cold wire C64 or for welding with two-wire 2xC508.

In case of the second group of materials (samples 5-8) (only basic material was treated), within evaluations according to coefficient of tribologic capacity of weld deposits K^*, the highest values were achieved for weld deposits made by combination of additive material C508+C64. At this point it is possible to observe, that the basic material C 45 achieved very similar values. The order of other materials was: material C508 and 2xC508. Samples of weld deposit made with additive material marked 2xC508 attained low K^* values. Practically, this presents the lowest adhesive wear resistance in given conditions.

The evaluation of weld deposits using K_N coefficient, following the relation (4), accepts physical nature of detachment of particles related to etalon.

Conclusion

The objective of this contribution was not to present results of friction and wear test, but to mention possible solutions of the problem. Some results are presented "in alieno loco" and can be found in literature listed below. From the observation that was carried out during many experiments we find it necessary to mention the importance of systemic approach in each sequence of given experiment. This regards:

- selection of material,
- difficulty of experiment,
- availability of test devices,
- evaluation methods of results,
- application of results, etc.

Today, it is necessary to extend this problem to area of non-stationary processes and to utilize attainable methods for mathematic simulation of specific processes.

This article developed within the context of designing the research target:

– VEGA 148/03 110: Design of experimental testing methods and parameters simulation and characteristics of sliding nodes for agricultural machines.

– VEGA 1/0712/08: The analysis of random loading process on tribologic properties of selected materials.

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