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The Influence of Hardening Related Deformations on Selection of Abrasion Inhibition Process

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Wear mass loss on samples was compared at depth of hardened layers of induction quenched C 60, carburized 16MnCr5, hard faced with C-Cr-Mn and C-Cr-W-Co electrode deposited layers as well as thermal flame sprayed deposits of C-Cr-Mo layer. Measurements of surface hardness, changes of sample surface hardness towards the core and metallographic examination of the structure were carried out using SMT 1-2070 wear and tear testing device, consisting of a disc and a bracket, in a chamber filled with oil containing SiO_2. Wear mass loss on samples in the shape of disc in depth of the hardened layer was measured. Counter body in the form of pedal was made out of material GG 20. It was established that wear mass loss changed the least with the hard faced C-Cr-W-Co layer, after that with thermal flame sprayed deposits and hard faced C-Cr-Mn layers. Then some surface hardened and at last cemented layers, which displayed greatest wear mass loss. Correspondingly, conclusion was drawn that there was need for additional caution when selecting an adequate wear protection process for those machine parts that, due to macro deformation, require surface abrasion as final machining operation.

Keywords: wear, makro deformation, surface hardening, protective layer, surface strength

0 INTRODUCTION

Tribology is considered as one interdisciplinary science because there is interdisciplinary knowledge applied from the areas of physics, chemistry, mechanics, projecting, material science, lubrication technology, as well as ergonomics, business economy, management, industrial methods etc. [1] to [4]. An overview of standards and organizations in field of the tribology is done in paper [1].

In addition to having hard surface layers, wear-prone machine parts are also required to be of high geometrical precision. Due to varying structure and hardness values across the layer, there is a danger that final surface machining may result in lower wear resistance than expected. Possibility of occurrence of macro deformations is particularly present after hardening (heat treatment and welding) of slender, elongated parts (axes and some tools) whose length is significantly bigger than their width or height [5] to [7].

Surface hardening of quenched and tempered steel, carburizing of cemented steel, hard facing and gas spraying (sputtering) can all respectively result in similar thickness of protective layers and desirable surface hardness. Depending on respective production processes and their duration, manufactured parts do however differ in their cost, but also in macro-deformation by buckling. This experiment aims at a better understanding of the influence of structural changes and of hardness distribution on wear resistance between surface border layers and respective part cores.

1 EXPERIMENTAL PART OF WORK

1.1 Test Materials and Layers

The following materials were selected for making of samples:
- for surface hardening steel C 60 [8], quenched tempered steel that allows surface quenching to equal depth of hardened-layer as with cementing,
- for carburizing 16MnCr5 [8], a very commonly used cemented steel,
- for hard facing C-Cr-Mn electrodes [9] of declared facing surface hardness 350 - 450 HB, base material 42CrMo4 + QT (steel into quenched condition [7]),

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- for hard facing C-Cr-W-Co electrodes [10] of declared facing surface hardness ≈ 42 HRC, base material 42CrMo4 + QT, and
- for thermal flame spraying: wire Al-Ni as substrate, wire C-Cr-Mo for final coating, with declared surface hardness of 40 - 50 HRC, base material 42CrMo4 + QT.

Chemical analysis was performed and it was established that steels fulfill required chemical composition. Norm declared [8] and results of chemical analysis of the base material are shown in Table 1. Table 2 shows declared composition and surface hardness of additional materials for hard facing and spraying.

Table 1. *Norm declared and measured chemical composition of base material of tested samples*

Designation	Chemical composition , %							
	C	Si	Mn	S	P	Cr	Ni	Mo
C60	0.61	0.35	0.74	0.031	0.023	0.32	0.12	-
Prescript for C60 EN 10027-1	0.57 0.65	max. 0.40	0.60 0.90	max. 0.035	max. 0.035	max. 0.40	max. 0.40	max. 0.10
16MnCr5	0.18	0.33	1.12	0.026	0.024	1.05	0.13	-
Prescript for EN 10027-1 16MnCr5	0.14 0.19	max. 0.40	1.00 1.30	max. 0.035	max. 0.035	0.80 1.10	-	-
42CrMo4	0.41	0.35	0.79	0.021	0.028	1.12	0.21	
Prescript for 42CrMo4 EN 10027-1	0.38 0.45	max. 0.40	0.60 0.90	max. 0.030	max. 0.030	0.90 1.20	0.15	0.30

Table 2. *Declared properties of spraying materials*

Category	Declared	
	Chemical element portion	Surface hardness
Wire Nikl- alumirid, ≈	20 % Al 80 % Ni	38 - 40 HRC
Wire C- Cr -Mo, ≈	0.38 % C; 0.03 % S; 0.03 % P; 0.75 % Si; 0.38 % Mn; 13.5 % Cr; 13.5 % Mo	40 - 50 HRC
Electrode C-Cr-Mn, ≈	0.25 % C; 1.3 % Cr; 1.7% Mn	350 - 450 HB
Electrode C-Cr-W-Co, ≈	1.2 % C; 28 % Cr; 4.5 % W; rest Co	42 HRC

Surface quenching of C60 steel samples was performed using induction heating to a temperature of ≈850 °C, oil-cooled. Their average recording value of measured surface hardness was 42 HRC, effective layer thickness ≈2 mm, bainites - martensite structure, Fig. 1.b.

Carburizing of 16MnCr5 steel samples was performed for 12 hours in a gaseous atmosphere at a temperature of 930 °C. Oil at 830 °C/30 min was used for direct hardening, followed by air-tempering at 200 °C/30 min. Surface hardness was ≈58 HRC at effective layer depth ≈ 1.8 mm, mainly martensite structure, Fig. 1.c.

For electrode facing with selected added materials (electrode diameter Ø 3.25 mm), 16MnCr5 base material was used for samples that were pre-tooled to an under size of $d = 4$ mm. The C-Cr-Mn facing to have dendritic structure, Fig. 1.d; surface hardness ≈40 HRC. The C-Cr-W-Co facing layer structure consisted of Cr- and less of W - carbides embedded in a Co-matrix, Fig. 1.e.; surface hardness ≈39 HRC.

Hard facing of samples was carried out by thermal flame treatment with the wire Ø 3.2 mm, melting point ≈1100 °C. Finely grain structure of the sprayed layer is shown in Fig. 1.f; surface hardness ≈ 40 HRC.

1.2 Machining of Test Pieces

The experiment required twelve test pieces of each protective layer type – three samples for four respective test series. Every of the four series differed by an external diameter alteration of 0.4 mm: Series I: d = 50 mm; Series II: d = 50.4 mm; Series III: d = 50.8 mm, Series IV: d = 51.2 mm. External diameters of facing test pieces were smaller by 3 mm for each series because of their consequent facing thickness ≈2.5 mm. After application of protective layer by hard facing and spraying, all test pieces were machined to a diameter d = 50 mm.

2 TEST RESULTS

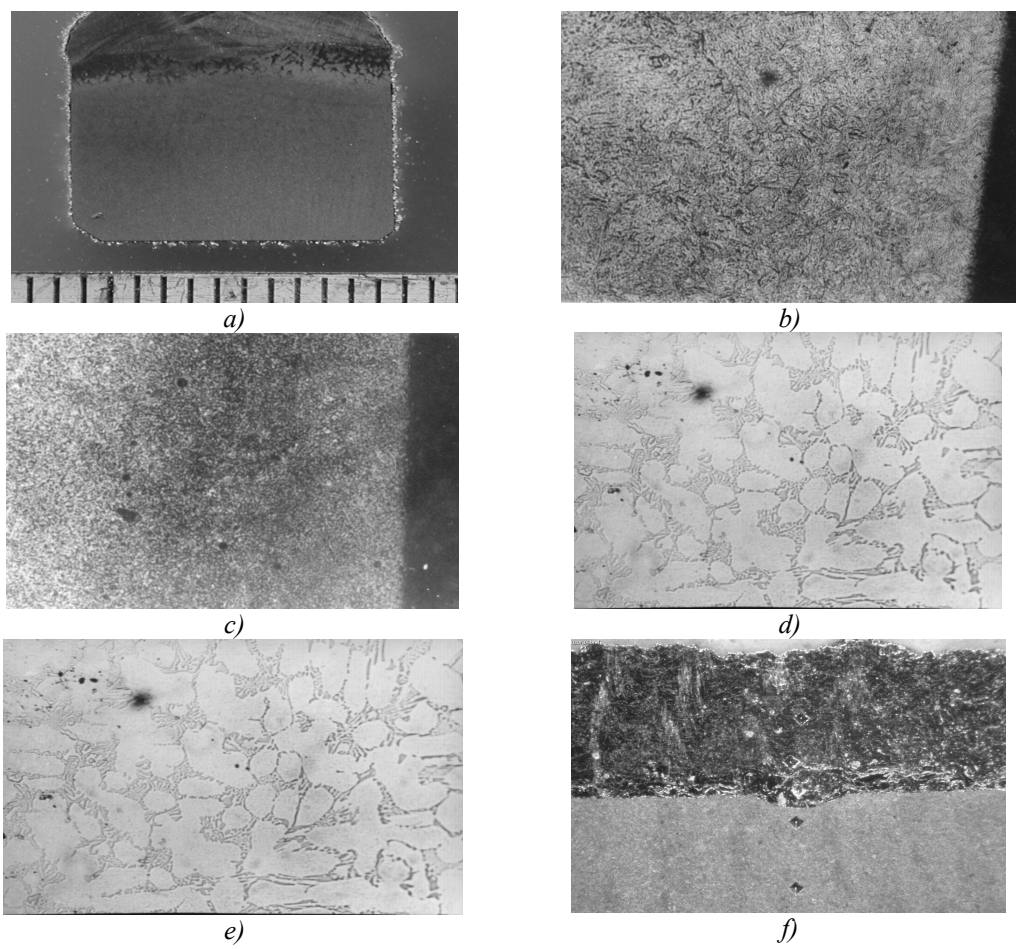
2.1 Microstructure of Test Pieces

Out of test pieces metallographic samples were produced for the control of structure. In Fig. 1, we have characteristic structures of test pieces.

2.2 Wear Resistance Testing

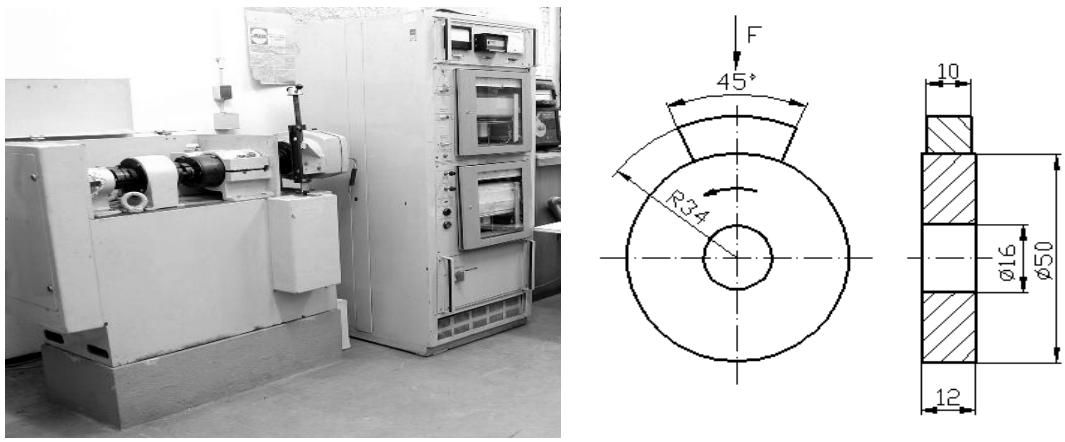
Fig. 2.a shows the wear testing device 2070 SMT-1. Fig. 2.b illustrates respective positions of the specimen and counter-body as well as their dimensions. The bracket-shaped counter-body matches GG 20 (hardness ≈200 HB) in its material composition.

Wear examination was performed in a chamber, in slip conditions for the disc/bracket - pair. Oil of a viscosity 47 to 55 m^2s^{-1} and 0.5 % SiO_2 added was used as intermediate fluid, grain size 0.35 to 0.2 mm. Regarding size of the contact surface a bracket load of 2000 N was selected, resulting in contact pressure ≈10 N/mm^2 between bracket and ring. Disc RPM was set at 500 min^{-1}. The control interval for the loss of disc mass was at every 50000-disc revolutions, followed by a change of oil and abrasive for fresh ones. The total of disc revolutions was 200000. Mass loss control of the test piece was carried out on the scales with accuracy of 0.01 g. Resulting mass loss (Δm) for every series of samples (average values for three discs) is presented in a diagram, Fig. 3.



a) *b)* *c)* *d)* *e)* *f)*

Fig. 1. *Characteristic structures on the cross section of the test pieces. Magnification 100X*
a) macro view of the cross section ; b) induction quenched C60
c) carburized 16MnCr5; d) hard facing C-Cr-Mn electrode
e) hard facing C-Cr-W-Co electrode; f) spray deposited C-Cr-Mo



a) *b)*

Fig. 2. *Wear testing device, type 2070 SMT-1*
a) – device view; b) – testing scheme and specimen dimensions disc/bracket

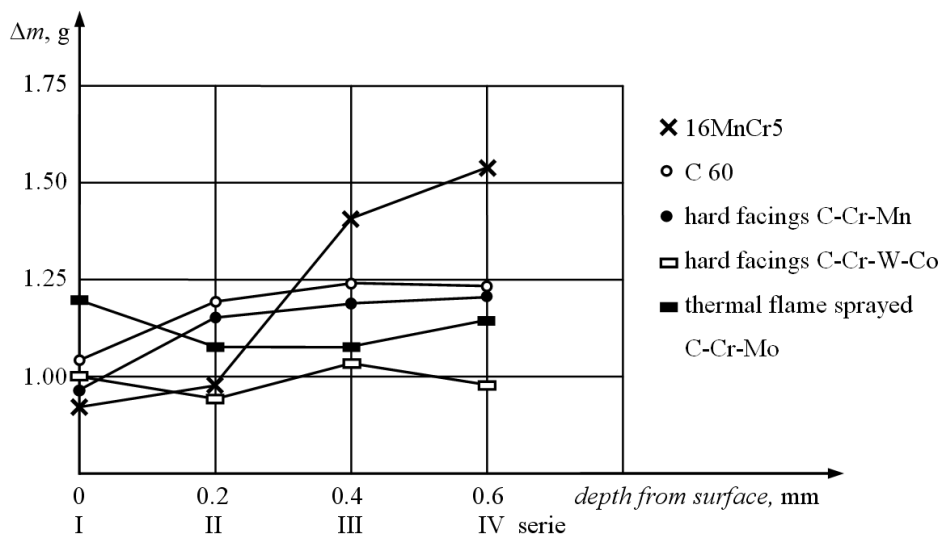


Fig. 3. *Average mass loss across test piece layer*

3 RESULT ANALYSIS

Experiment results for induction quenched C60 and carburized 16MnCr5 demonstrated that a cemented surface layer has significantly lower mass loss. This ratio shifts in favor of C 60 of in the depth span of 0.2 to 0.4 mm from the surface. However, between 0.4 and 0.6 mm, wear of the carburized layer has almost doubled, while that of the induction-quenched specimen remained almost insignificant. Material mass loss of the carburized 16MnCr5 steel increased almost thrice, in comparison with the mass loss up to depth of 0.2 mm from the border. Under the same experiment conditions induction quenched C 60 exhibits only up to 25 % wear increase in relation to surface layer.

Hard faced layers have a similar mass loss as the carburized layers at the depth of 0.2 mm from surface. However, it should be noted that they do not display in-depth increase mass loss, i.e. with increase of distance from the surface border. The smallest mass loss was observed with C-Cr-W-Co deposited layer. However at 0.2 mm depth from the surface mass loss of the hard faced layer reduce and does not change significantly at 0.4 and 0.6 mm distance from the surface.

4 CONCLUSION

The drop in wear resistance of a layer after tempering can partly be contributed to the chemical composition of the surface layer of machined material [11], i.e. its superficial and in-depth harden ability. Hardness drops towards the material core with decreased content of carbon underneath the carburized layer.

With hard faced layers, the same as with the sprayed layers, mass loss does not increase significantly with the depth of the layer. The smallest wear was measured on C-Cr-W-Co hard faced layer. Probably it is the consequence of positive impact of Co matrix with distributed Cr and W carbides. Hard of the welded C-Cr-Mn faced and sprayed layers of C-Cr-Mo do not differ considerably with the depth of the layer.

Experiment results question the benefit of adding 0.2 mm or more for final machining in the case of those carburized parts, which may suffer macro-deformation due to complicated shape of the work piece. The option of layer facing appears acceptable from a perspective of wear resistance. In its further analysis however, that choice must include economical considerations related to the cost of added material, of the particular facing technology and the cost of final surface machining.

Consecutive experiments should concentrate on testing of shear and cutting behavior and offer a detailed comparison of sprayings with respect to preceding base material surface preparation and related bond quality. A variation of welded and spraying parameters (i.e. wire supply speed, feed rate during spraying etc.) will illustrate their relation to layer properties and behavior.

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