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Svetislav Marković [1], Ljubica Milović [2], Aleksandar Marinković [3], Tatjana Lazović [3]

TRIBOLOGICAL ASPECT OF SELECTING FILLER METAL FOR REPAIR SURFACING OF GEARS BY HARDFACING

TRIBOLOŠKI ASPEKTI IZBORA DODATNOG MATERIJALA KOD POVRŠINSKE REPARACIJE ZUPČANIKA TVRDIM NAVARIVANJEM

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Author's address:
[1)] Technical College, Čačak, Serbia
[2)] University of Belgrade, Faculty of Technology and Metallurgy, Serbia
[3)] University of Belgrade, Faculty of Mechanical Engineering, Serbia

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Ključne reči
- reparacija
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- zupčanici

Abstract

Analysis of repaired gears made of case-hardening steel 20MnCr5 by hardfacing method is presented in this paper. Hardfacing repaired gears are tested on the closed power circuit device with variation of the torque value. During testing the wear intensity is measured and the gears' working life is predicted. Samples made of the same material as the gear are tested on tribometer of the "block-on-disc" type. The gears are repaired in two ways: (1) by hardfacing with filler metal, which is subsequently case-hardened and heat-treated and then mechanically machined, and (2) by hardfacing with filler metal of high hardness (≈ 60 HRC).

Izvod

U radu je predstavljena analiza zupčanika izrađenih od čelika za cementaciju 20MnCr5 koji je repariran tvrdim navarivanjem. Zupčanici reparirani tvrdim navarivanjem su ispitivani na uređaju sa zatvorenim strujnim kolom sa varijacijom veličine prenosnog momenta. Tokom ispitivanja, izmeren je intenzitet habanja i procenjen je radni vek zupčanika. Uzorci napravljeni od istog materijala kao zupčanik su ispitivani na tribometru tipa „blok-na-disku". Zupčanici su reparirani na dva načina: (1) putem tvrdog navarivanja dodatnim materijalom, koji je onda termohemijski i termički obrađen a zatim obrađen mašinski, a (2) putem tvrdog navarivanja sa dodatnim materijalom visoke tvrdoće (≈ 60 HRC).

INTRODUCTION

The damage of working surfaces or the fracture of a driving-gear tooth of the gear pair leads to an interruption of operation not only of the gear but of the machine driven by it as well. Due to the high cost of manufacture of new gears, especially those with the modules exceeding 5 mm, as well as the necessity for quick repair and bringing the structure back in service and, rather often, the impossibility of manufacturing new gears, the procedures for repair of damaged gear elements (gear hubs, bodies and teeth) are applied /1/.

The primary form of gear damage is by wearing. Wearing appears either as fatigue wearing (pitting) or as abrasive wearing. Basic mechanisms of wearing are:
- wearing induced by material fatigue,
- sliding-induced adhesion, and
- abrasion caused by the presence of harder particles in the region of wear.

The fracture of gear teeth can be induced by periodically-variable bending load and, not so frequent but significant because of its magnitude, static and dynamic overload. During exploitation, fatigue cracks appear in the root tooth as a result of increased stress concentration caused by small curve radius of the tooth leg and the damages caused by cutting tools occurring during the process of gear manufacture. At the beginning, they propagate in the direction normal to rounded tooth flank, continuing their propagation toward the depth and down the tooth. The fracture of the tooth in the root can also be caused by residual tensile stresses occurring during heat- and thermal chemical treatment of the tooth-space /2-4/.

Gear damages are causes by inaccuracy of data on loads affecting gears, as well as by deviation of true vs. calculated teeth hardness, caused by structural, technological and exploitation errors in design. These errors in calculation result in the phenomena of additional forces, stress concentration, unfavourable distributions of residual stresses and decrease of the values of material mechanical properties, eventually leading to the weakening of the critical cross-section of the tooth.

The aim of the testing is to determine the friction coefficients of used filler metals for hardfacing and the width of the wear-band of the surfaced layer as well, in order to determine the optimal filler metals for hardfacing.

MATERIAL

Test samples (blocks) and discs for testing on the tribometer using block-on-disc method [X] are made of case-hardened steel 20MnCr5 (DIN 17006), whose chemical composition is presented in Table 1.

Hardfacing is applied by method of manual arc welding and TIG hardfacing. The process filler metals (FM) of various dimensions, the chemical analysis and properties are given in Tables 2 and 3.

Table 1. Chemical composition of steel for samples (wt. %).
Tabela 1. Hemijski sastav čelika za ispitivanje uzoraka (tež. %)

C	Si	Mn	P_{max}	S_{max}	Cr	Ni	Mo
0.17–0.22	0.15–0.40	1.1–1.4	0.035	0.035	1.0–1.3	/	/

Table 2. Properties of applied filler metals.
Tabela 2. Osobine primenjenih dodatnih materijala

Item No.	Designation		Specimen design. accord. to DIN 8555 (AWS)	Manufact.	Procedure design. according to	∅ (mm)	*J* (A)
	DIN	AWS					
1.	E-6-UM-55G	/	EDUR 600	Jesenice	SMAW (111)	2.5	70
2.	/	/	Castolin 2	Castoline Eutectic	SMAW (111)	3.25	92
3.	MSG-6-GZ-60	/	DUR 600-IG	BÖHLER	GTAW (TIG) (141)	1.2	76
4.	E-6-60-UM	/	UTP 670	UTP	SMAW (111)	3.25	90
5.	E-4-UM-60-65-S	EFe5-B	Tooldur	Jesenice	SMAW (111)	2.5	80
6.	ECrMo1B26	E8018-B2	EVBCrMo	Jesenice	SMAW (111)	2.5	75
7.	ECrMo2B26	E9018-B3	EVB2CrMo	Jesenice	SMAW (111)	2.5	75
8.	/	/	Phönix 120 K/E 425 B/E7018-1	Tüssen	SMAW (111)	2.5	72
9.	E18.8.Mn6B2+	E307-15	Inox 18/8/6	Jesenice	SMAW (111)	2.5	70
10.	/	/	Castolin 680S	Castoline Eutectic	SMAW (111)	2.5	75

Table 3. Chemical composition (wt. %) and mechanical properties of pure surface weld.
Tabela 3. Hemijski sastav (tež. %) i mehaničke osobine čistog metala šava površine.

No	C	Si	Mn	Cr	Ni	Mo	Other	Hardness HV	HRC	R_m [MPa]	R_{p02} [MPa]
1.	0.5	2	–	9.5					54		
2.			+	+		+			57–62		
3.	0.45	3.0	0.4	9.5					55–60		
4.	0.4	0.85	0.8	9.7		0.6	1.5 V	max. 600			
5.	0.9			4.2		8.5	0.9 V, 1.1 W		50–54		
6.	0.08	0.45	0.80	1.1		0.5				570–670	470
7.	0.08	0.45	0.70	2.4		1.0				620–700	>520
8.											
9.	0.12		7.0	19.0	9.0					590–690	>350
10.										800–850	600–700

EXPERIMENTAL

Experimental analysis is conducted first on test samples, and then on real gears made of case-hardened steel. In order to choose the most suitable filler metals for hardfacing gear' working surfaces, model testing is conducted on the tribometer according to the "block-on-disc" method. The test samples (blocks) are shown in Fig. 1. The curvature radius of the block corresponds to the value calculated for the tooth-curve radius of the gear to be repaired, and is derived to be $\rho = 44$ mm. Nine samples (blocks) are prepared according to technological procedures presented in Table 4, and are tested on the tribometer. The following parameters are varied from the tribometer testing process of samples: filler metal type, manufacturing technology procedure (hardfacing before and after heat treatment), and heat treatment regimes.

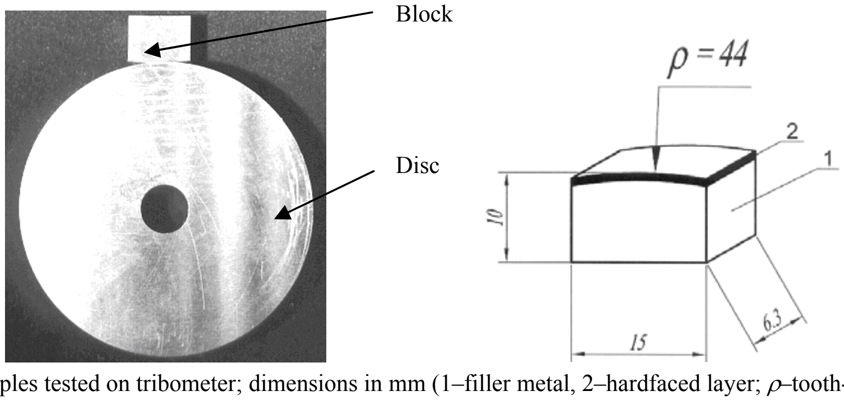

Figure 1. Samples tested on tribometer; dimensions in mm (1–filler metal, 2–hardfaced layer; ρ–tooth-curve radius).
Slika 1. Uzorci za ispitivanje na tribometru; dimenzije u mm (1–dodatni materijal, 2–tvrdo navareni sloj; ρ–radijus zaobljenja zupca)

Table 4. Technology preparation of 20MnCr5 samples for testing on tribometer.
Tabela 4. Tehnološka priprema uzoraka od 20MnCr5 za ispitivanje na tribometru

No.	Heat treatment before hardfacing	Hardfacing		Heat treatment after hardfacing	Hardness of working surface HRC
		Electrode	Surfacing procedure accord. to AWS		
1.	Preheating	Inox18/8/6+ EDur 600	SMAW (111)	Low-temperature tempering (LTT)	57.5
2.	Preheating	Castolin 2	SMAW (111)	LTT	58
3.	Preheating	DUR 600-IG	GTAW (TIG) (111)	LTT	56.5
4.	Preheating	UTP 670	SMAW (111)	LTT	55.5
5.	Preheating	Tooldur	SMAW (111)	LTT	56
6.	Preheating	EVBCrMo	SMAW (111)	Soft annealing + case-hardening + hardening + tempering (SCHT)	57
7.	Preheating	EVB2CrMo	SMAW (111)	SCHT	56
8.	Preheating	Phönix 120 K/E 425 B/E7018-1	SMAW (111)	SCHT	56.5
9.	CHT	/	No hardfacing	/	59

TRIBOLOGICAL TESTING OF MODELS

Experimental testing of the hardfaced gear teeth models on tribometer ALRU 20 is conducted under the following conditions. Lubrication made with HIPOL B SAE 90 oil is boundary; the 60 mm disc made of the same material as the tooth model is case-hardened and subsequently hardened and tempered to 55–58 HRC hardness; the sliding speed of the hardfaced block on disc is 2.78 m/s under the pressure force of 250 N.

Thus, throughout the 30-minute tests, the variation curves of the friction coefficient are obtained as shown in Fig. 2.

The mean values of the friction coefficient μ and wear band measured for all filler metals used in the experiment are presented in Table 5 and diagrams are shown in Fig. 3.

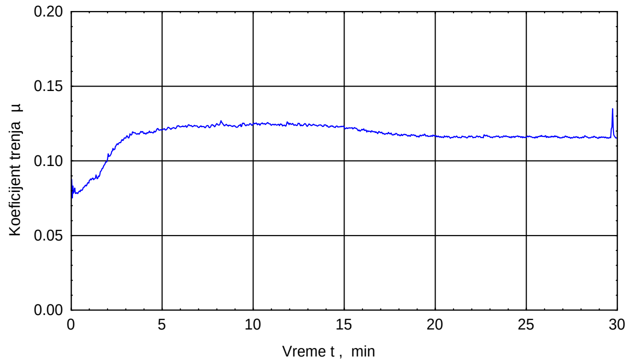

Figure 2. Variation of friction coefficient of the 20MnCr5 block, hardfaced using Castolin 2 electrode on 20MnCr5 disc.
Slika 2. Promena koeficijenta trenja bloka od 20MnCr5, tvrdo navaren sa Castolin 2 elektrodom na disku od 20MnCr5

Table 5. Friction coefficients μ and wear band for various filler metals.
Tabela 5. Koeficijenti trenja i trake habanja za razne tipove dodatnih materijala

Disc		Block			Friction coefficient μ	Wear-band width (mm)
Material	Hardness HRC	No.	Filler metal	Hardfacing procedure		
20MnCr5	58±3	1	Inox 18/8/6 + EDUR 600	SMAW (111)	0.064	0.960
		2	Castolin 2	SMAW (111)	0.115	1.028
		3	DUR 600-IG	GTAW (TIG) (141)	0.100	1.020
		4	UTP 670	SMAW (111)	0.090	0.955
		5	Tooldur	SMAW (111)	0.072	1.118
		6	EVBCrMo	SMAW (111)	0.110	1.130
		7	EVB2CrMo	SMAW (111)	0.106	1.198
		8	Phönix 120 K/E 425 B/E7018-1	SMAW (111)	0.108	1.200
		9	20MnCr5	/	0.077	0.751

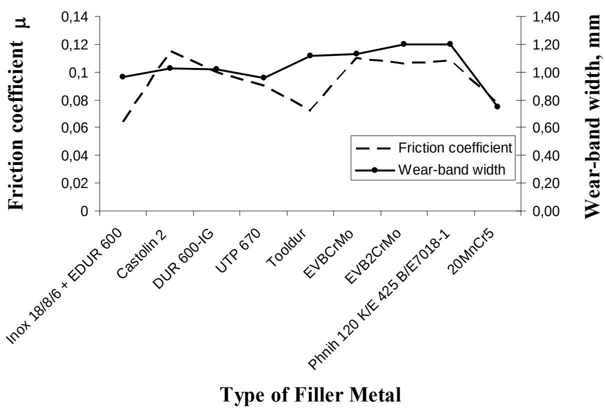

Figure 3. Comparative values of mean friction coefficient and wear-band width for various filler metals.
Slika 3. Uporedne vrednosti srednjeg koeficijenta trenja i širine traka habanja za razne dodatne materijale

TRIBOLOGICAL TESTING OF REPAIRED GEARS

The results of the determined friction coefficients for all tested materials have shown that the lowest values of both mean friction coefficient and wear-band width are obtained by hardfacing, where filler metals INOX 18/8/6 and EDUR 600 are combined. Based on the results of preliminary testing of the models, a few groups of gears are subjected to hardfacing with chosen filler metals. For a comparative analysis of applied various filler metals for hardfacing working surfaces of teeth, trial hardfacing of side-tooth surfaces of newly manufactured gears is conducted, Fig. 4. Gears are made of case-hardened steel 20MnCr5 as straight gears, with 6 mm modules and 43 teeth at 20° angle of the standard profile.

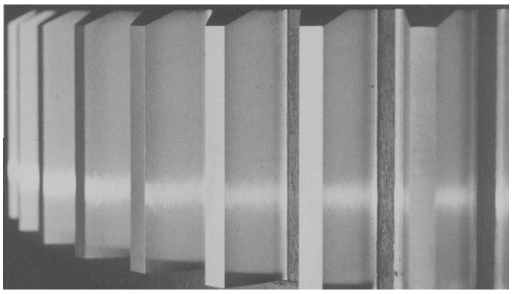

Figure 4. Hardfaced and finished gear geometry: circular pitch diameter ∅258 mm, correction factor $xm = 0$, root diameter ∅244.8 mm, working length of teeth 40 mm, pitch line 18.84 mm.
Slika 4. Tvrdo navaren i poliran zupčanik sa geometrijom: prečnik podeonog kruga ∅258 mm, korekcioni faktor $xm = 0$, prečnik korena zubaca ∅244,8 mm, radna dužina zubaca 40 mm, hod sprezanja 18,84 mm

Technology procedures for gear hardfacing are of two types. After manufacture, the first group of gears is case-hardened up to 1 ± 0.1 mm depth at 900°C in a protective atmosphere, hardened and tempered to surface hardness of 58 ± 3 HRC, prepared for hardfacing as shown in Fig. 5a, preheated, hardfaced manually by arc welding and TIG process with hard filler metals – either with soft interlayer or without one (INOX 18/8/6 + EDur 600, Castolin 2, DUR 600-IG and UTP 670), low-tempered and subjected to finishing by tooth-grinding. Also after manufacture, the second group of gears are prepared for hardfacing by removal of the working surfaces of tooth-flanks (Fig. 5a), preheated, surfaced manually by arc welding with soft filler metals (EVBCrMo and EVB2CrMo), soft-annealed, finished to dimensions with grinding supplement, case-hardened up to 1 ± 0.1 mm depth in a protective atmosphere, hardened and low-tempered up to 58 ± 3 surface hardness, and finished by grinding.

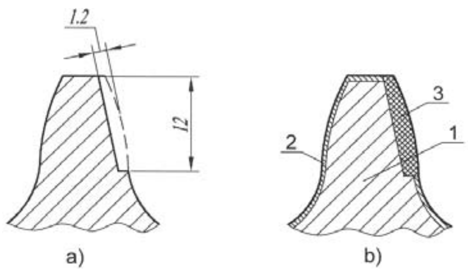

Figure 5. The preparation for hardfacing: (a) appearance of hardfaced teeth; (b) 1–base metal, 2–case-hardened layer, 3–hardfaced layer
Slika 5. Priprema za tvrdo navarivanje: (a) tvrdo navareni zubac; (b) 1–osnovni metal, 2–termohemijski otvrdnut sloj, 3–tvrdo navaren sloj

After the inspection of geometry and kinematic accuracy and non-destructive tests using magnetic flux, the gears repaired by hardfacing are exposed to exploitation tests of durability on a closed power circuit device (Fig. 6) of the following characteristics: electric motor: 15 kW, revolutions: 850 min^{-1}, torque-inducing device: reactive (by turning the housing of one gear box), maximal torque: 5000 Nm, measurement of torque: dynamometer and digital reader.

Tests are conducted with gradual variable load. They start with shaft-torque of 600 Nm per million cycles, to continue with 1200; 1800; 2400 and 3000 Nm per million cycles. Newly manufactured gears are designed to transfer the torque of 3000, with safety factor of 1.2. As no significant damages of repaired and newly manufactured gears are observed, the load is increased. Torques of 3600 Nm and then 4200 Nm per million cycles are induced. On tested gears, both repaired and newly manufactured, very little wear is observed, not leading to the loss of the working capacity. Based on this report, one can conclude that repaired gears are capable to transmit loads highly exceeding those which they were designed for.

CONCLUSIONS

In terms of previous research, activities in the field of the procedures for gear repair, the following is concluded regarding the selection of gear materials:

- Required mechanical properties, hardness at first, can be obtained by using proper hard-facing material and subsequent heat treatment processes.
- Improvement of all mechanical properties of repaired gears may be achieved by careful and well organised hardfacing preparation, selection of adequate filler metal and hardfacing regimes, strict observation of exploitation directives, and precisely defined and carefully conducted procedures of heat treatment before- and after hardfacing, as well.
- Based on experimental testing on the closed-load-circuit device and having in mind the chemical analysis of both base- and filler metals, it is concluded that tooth flanks, on the condition that hardfacing and finishing are properly done, have hardness and wear resistance almost the same as those of newly manufactured teeth. Thus, their exploitation life is not below the exploitation life of new gears.
- Economic effects of gear repair varies from 40% to 60% in terms of new gear manufacture, and it is higher for gears larger in size and of more complex shape.

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