BALKANTRIB'O5
5th INTERNATIONAL CONFERENCE ON TRIBOLOGY
JUNE.15-18. 2005
Kragujevac, Serbia and Montenegro

COMPARATIVE INDICATORS OF THE TRIBOLOGICAL CHARACTERISTICS OF THE REGENERATED GEARS REPARATORILY HARDFACED BY VARIOUS PROCEDURES

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Abstract

Aiming at the experimental determination of the length of the exploitation life of the regenerated gears, the endurability of the sides of the teeth of the three groups of gears was investigated: the newly made gears, the reparatory hardfaced by the "soft", additional material (EVB2CrMo) and the gears hardfaced by "hard" DM (UTP 670). The investigations were carried out on the device with the closed power circuit and they showed that the regenerated gears had the exploitation life which was rather close to the newly made gears. Besides, the considerable economic savings is obtained by the regeneration. In this study, the results of the investigations of microstructure, hardness and microhardness are given.

Key Words

1. INTRODUCTION

In order to fully observe the influence of the chosen procedure of hardfacing onto the length of service (effective usage) of the regenerated gears, we performed the reparatory hardfacing in two principally different ways. One group of gears was hardfaced in manual electro arc welding (MMA), with the additional "hard "material UTP 670, and the other group with the additional "soft" material EVB2CrMo, and it was cemented and heat treated, by which the hardness of the working surfaces of the gears was brought onto the required level.

When choosing the additional materials, we paid attention to the fact that, for the successfully regenerated gears, besides the kinematic and geometrical accuracy, the hardness of the working surfaces of gears, resistance of hardfaced layers to wearing and breaking, as well as the strength of the relation between the basic material and hardfaced layer are of the extreme importance.

2. PREPARATION OF SAMPLES FOR INVESTIGATION

Cylindrical gears with straight teeth were used as samples for investigation (Figure 1), with the following characteristics: the material of processing Č4321, module m= 6 mm, the number of teeth z=43, the angle of the basic profile $\alpha=20^0$, the sloping angle of tooth $\beta=0^0$, the correction of profile xm=0, the surface hardness 58±3 HRC.

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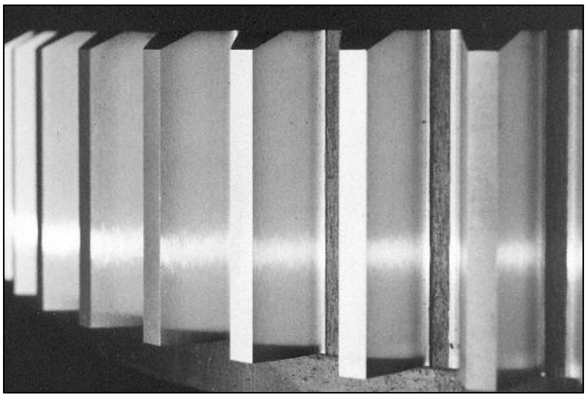

Figure 1: *A newly made gear*

Regarding the choice of procedures of the reparatory hardfacing, and the choice of the additional materials, the previous practical experiences and the research results had the crucial role. The markings of the additional used materials, their dimensions (diameter), D and the current strength (J) of the hardfacing are given in Table 1.

Table 1. Characteristics of the additional materials used

Ord. No.	Marking according to		Marking DM according to DIN 8555 (according to AWS)	Producer	Marking of procedure according to	D (mm)	J (A)
	DIN	AWS					
1.	E-6-60-UM	/	UTP 670	UTP (Germany)	SMAW (111)	3,25	90
2.	ECrMo2B26	E9018-B3	EVB2CrMo	Jesenice (Slovenia)	SMAW (111)	2,5	75

Chemical composition and the more important characteristics of the marked additional materials are shown in Table 2.

Table 2. Chemical compositions and mechanical characteristics of the additional materials used

Ord. No.	Chemical composition and hardness of the pure metal of facing										
	C	Si	Mn	Cr	Ni	Mo	Others	Hardness		R_m	R_{p02}
	%							HV	HRC	[MPa]	
1.	0,4	0,85	0,8	9,7		0,6	1,5% V	>600			
2.	0,08	0,45	0,70	2,4		1,0				620-700	>520

The technological process of the regeneration of the gears hardfaced by the additional material UTP 670 consists of the following procedures:

- removing of the cemented layer from the active working surfaces of the teeth by grinding on the grinding machine (in practice, it corresponds to the removal of the damaged layer of the side of tooth) onto the depth of $1,2^{+0,2}$ mm and 12 mm per hight of the tooth,
- preheating of the gear onto the temperature T=230^{0}C and keeping at the existing temperature in duration t=2^h,
- drying of electrodes at the temperature T=350^{0}C in the duration t=4^h,
- MMA hardfacing of the prepared surfaces by additional material UTP 670 (with coated electrodes ϕ3,25 mm, I=90 A),
- returning of the hardfaced gears into the furnace and slow cooling with the furnace,

- grinding of the hardfaced gears on the gears grinding machine “Niles”.

In case of the regeneration of gears by hardfacing by the “soft” additional material EVB2CrMo, the technological procedure of regeneration is considerably different from the previously described one. It consisits of the following operations:

- soft annealing. The operation of the soft annealing is necessary in order to reduce the surface hardness of the working surfaces of gears and to enable the preparation by milling. Annealing was done in the vacuum by heating at the temperature $T=680^0C$, at the speed of $10^0C/min$. Then, the gears were kept at that temperature for four hours, and after that they were cooled at the speed of $2^0C/min$,
- removing of the cemented layer from the active working surfaces of gears by milling on the universal milling machine (in practice it corresponds to the removing of the damaged layer of the side of the tooth) at the depth of $1{,}2^{+0{,}2}$ mm and 12 mm per hight of the tooth,
- preheating of the gears at the temperature $T=230^0C$ and keeping them at that temperature in the duration of $t=2^h$,
- drying of electrodes at the temperature $T=350^0C$ in the duration of $t=4^h$,
- MMA hardfacing of the prepared surfaces with additional material EVB2CrMo (with coated electrodes ϕ2,5 mm),
- high releasing in the furnace,
- milling on for obtaining pre-mesure (with the additional part for grinding) on the grinding machine for the making of gears by Pfauter method,
- soft annealing,
- cementation in the composition CO_2+CO onto the depth $1^{\pm 0{,}1}$ mm with cooling in the pit,
- tempering in the melt of salt and releasing,
- grinding of the hardfaced teeth on the grinding machine for gears grinding machine “Niles”.

Fardfacing of all the teeth was done on two passages. In the first passage, the leg and a part of the head of the gear were hardfaced, and after the removing of slag, the rest of the head was hardfaced. The apparatus for hardfacing of “Fronius” brand was used for the performing of the hardfacing operations.

3. INVESTIGATING OF MICROSTRUCTURE

Metallographic investigations were carried out on the quantitative optical metallographic microscope of “POLYVAR-MET” type (“REICHERT-JUNG”) at the magnifyings from 20 up to 2000 times. Microstructural analysis of the Figure was carried out on the device “Leica Q500MC”.

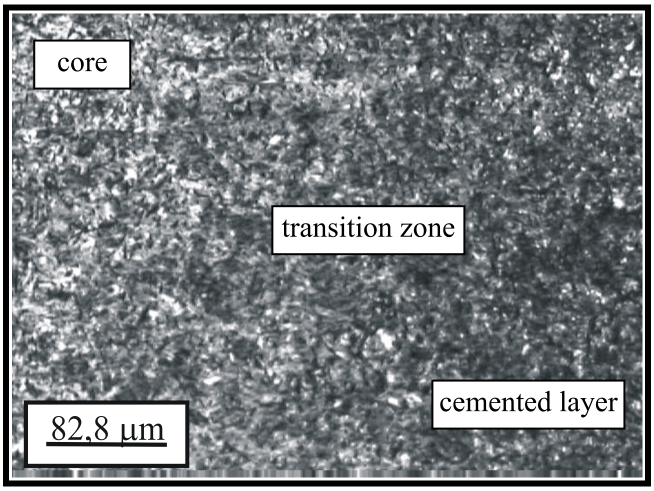

Figure 2: *Microstructure of the transition zone of the newly-built tooth (core-transition zone-cemented layer)*

Microstructure of the surface and under-surface layer (of the cemented layer and the core) of the newly-made tooth is shown on Figure 2. The basic microconstituent of the cemented layer of the tooth is the released martensite. According to the analysis, the difference between microstructure of the cemented layer (the right part of the Figure), microstructure of the transition zone (the middle part of the Figure) and the microstructure of the core (the left part of the Figure) is clearly noticed. In the transition zone, single ferrite grains are seen (the bigger light areas), the number of which is considerably greater in the core.

The tooth hardfaced with the additional material UTP 670 has medium up to coarse-grained structure of the facing (with the width of the separate dendrite columns from 30 up to 80 μm). In the structure, the high share of the carbide phase is present (light areas on Figure 3), which is separated at the boundaries of the grain, but, with its largest part in the crystal grains themselves.

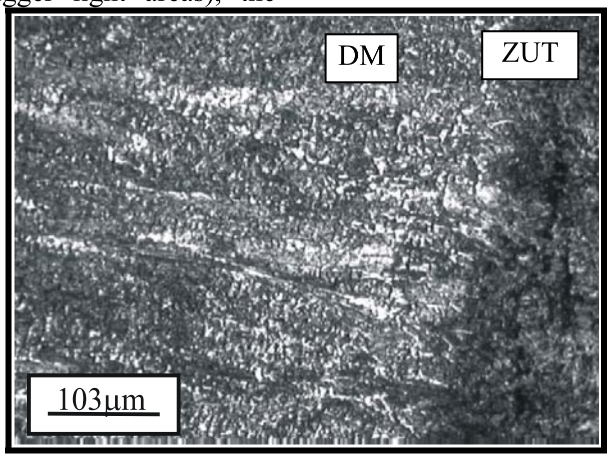

Figure 3: *Microstructure of the facing with DM UTP 670 (light area) and ZUT (dark area)*

Microstructure of the cemented layer in the facing with the additional material EVB2CrMo is shown on Figure4. The basic microconstituent in the zone of the hardfaced layer is the released martensite. The hardfaced layer in the light area, and the basic material (that is, the zone under the influence of heat) is the dark area. Based on the difference in the degree of etching in the basic material and the facing, it can be concluded that there is the more prominent difference regarding their chemical compositions.

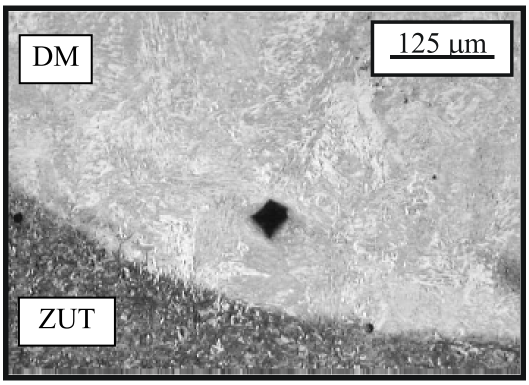

Figure 4: *Microstructure of the transition between facing with DM EVB2CrMo (light area) and the basic material (ZUT); state: hardfaced + soft annealed + cemented + heat treated*

4. INVESTIGATING OF THE HARDNESS AND MICROHARDNESS

A very important indicator of the resistance to wearing out of the regenerated gears surely is the hardness of the working surfaces of the teeth.Besides the surface and the macrohardness, it is necessary to check their microhardness per section of tooth, too.Within the carrying out of the experimental part of this study, the following measurements were carried out:

- ✓ of the surface hardness, by Rockwel method,
- ✓ of the macrohardness, by Vickers method, and
- ✓ of microhardness, by Vickers method.

The surface hardness is measured on the “LEITZ-WETZLAR” device by Rockwel method (HRC) on the hardfaced teeth in five places. The average values of the hardness according to Rockwel were entered into Table 3. It is noticed that the newly-made teeth have the greatest hardness, but surely the most important conclusion is that the surface hardness of all the facings is within the required limits (58±3 HRC). Macrohardness of the hardfaced layers is measured on the device of the same producer, with the cold work (impressing) force of 300 N in the time interval of 15 seconds. Measuring is also done in five places, and the average values of the macrohardness are given in Table 3. It must be pointed out that these results for the gears hardfaced with “soft” additional material, then cemented and thermally processed, as well as the newly-made gears, must be conditionally understood. Namely, as it was presumed, even besides the soft annealing, the differences in the structure of the basic and additional material remain, because of the difference in the value of the coefficient of diffusion of carbon in the basic material and the facing. On the other hand, the homogeneity of the hardfaced layer is not the same as in steel, so that the aberrations of the results of measuring of macrohardness from place to place are relatively high.

Table 3. The surface hardness and macrohardness of the hardfaced and newly-made samples

Ord. No.	Method of regeneration	Hardness HRC	Macrohardness	
			$HV_{30/15}$	Corresponds to HRC
1.	MMA hardfacing DM UTP 670	55,5	782	63,4
2.	MMA hardfacing DM EVB2CrMo + C + HT	56	763	62,6
3.	Newly-made one (C4321 + C + HT)	59	763	62,6

Microhardnesses were measured per section of the single teeth. Hardness per section of teeth (microhardness) was measured on the device for measuring of hardness “LEITZ WETZLAR” by Vickers method ($HV_{0,1}$) with the force of 1 N and time of cold work (impressing force) of 15 seconds. The results of the measuring of microhardness are shown in Tables 4, 5 and 6.

Table 4. Microhardness of the sample of the hardfaced DM UTP 670

Distance from the surface [mm]	0,05	0,1	0,15	0,2	0,25	0,3	0,35	0,4	0,45	0,5	0,6	0,7	0,8
Hardness $HV_{0,1}$	820	820	820	820	820	757	757	787	726	726	787	787	820
Corresponds to HRC	64,7	64,7	64,7	64,7	64,7	62,4	62,4	63,6	61,2	61,2	63,6	63,6	64,7
Distance [mm]	0,9	1,0	1,25	1,5	1,75	2,0	2,5	3,0	3,5	4,0	5,0	6,0	8,0
Hardness $HV_{0,1}$	726	726	700	757	757	496	585	547	514	514	496	466	254
Corresponds to HRC	61,2	61,2	60,1	62,4	62,4	48,8	54,4	52,1	50,1	50,1	48,8	46,5	22,9

Table 5. Microhardness of the sample from C4321, cemented and heat treated

Distance [mm]	0,05	0,1	0,15	0,2	0,25	0,3	0,35	0,4	0,45	0,5	0,6
Hardness $HV_{0,1}$	675	675	700	690	634	634	650	650	650	640	650
Corresponds to HRC	59,0	59,0	60,1	59,7	57,0	57,0	57,8	57,8	57,8	57,3	57,8
Distance [mm]	0,7	0,8	0,9	1,0	1,25	1,5	1,75	2,0	2,5	3,0	3,5
Hardness $HV_{0,1}$	634	675	547	566	547	480	452	480	452	440	440
Corresponds to HRC	57,0	59,0	52,1	53,3	52,1	47,7	45,5	47,7	45,5	44,5	44,5

Table 6. Microhardness of the sample of the hardfaced DM EVB2CrMo, cemented and HT

Distance [mm]	0,05	0,1	0,15	0,2	0,25	0,3	0,35	0,4	0,45	0,5	0,6
Hardness $HV_{0,1}$	634	634	634	634	634	634	634	634	634	634	585
Corresponds to HRC	57,0	57,0	57,0	57,0	57,0	57,0	57,0	57,0	57,0	57,0	54,4
Distance [mm]	0,7	0,8	0,9	1,0	1,25	1,5	1,75	2,0	2,5	3,0	3,5
Hardness $HV_{0,1}$	585	547	530	496	496	440	426	426	390	414	390
Corresponds to HRC	54,4	52,1	51,1	48,8	48,8	44,5	43,2	43,2	39,8	42,2	39,8

Comparing the distribution of microhardness of the newly made and of "hard" hardfaced samples, it is noticed that the facings applied with the "hard" additional materials have considerably higher microhardness of the under-surface layer than the cemented samples. From the point of view of the distribution of microhardness of the "softly" hardfaced samples, facings with the additional material EVB2CrMo have the microhardness which is very close to the newly-made ones.

5. TRIBOLOGICAL INVESTIGATIONS OF GEARS

Tribological investigations of the regenerated and the newly-made gears were carried out on the device with the closed circuit of power and the reactive moment. Aiming at the protection of the investigated gears from damaging in the interval of running, the maximum torque at which the investigation was carried out was not immediately brought into the closed circuit of the strength of the device for investigating.

Namely, the torque moment is increased little by little, according to the following plan:

- ✓ in the first 10^6 cycles torque moment is T=600 Nm,
- ✓ then, in 10^6 cycles torque moment is T=1200 Nm,
- ✓ in the next 10^6 cycles of torque moment is T=1800 Nm,
- ✓ then, in 10^6 cycles of torque moment is T=2400 Nm,
- ✓ at the end, until the ceasing of investigation, T=3000 Nm.

Investigations had the duration $98 \cdot 10^6$ cycles, that is 1950 working hours.

The first initial pits in the teeth hardfaced with DM UTP 570 were spotted in the transition of the two passages (facings), which is situated on the head of the tooth. They appeared after $70 \cdot 10^6$ cycles. After $98 \cdot 10^6$ cycles, about 32% of the working surface of the most endangered tooth was damaged (Figure 5). It must be noticed that mainly heads of these teeth were damaged, while on the other surfaces separate pits of smaller dimensions and less depth are noticed.

Figure 5: *Working surfaces of the teeth hardfaced with additional material UTP 670 after $98 \cdot 10^6$ cycles*

At the teeth MMA hardfaced with electrode EVB2CrMo, and then cemented, tempered and released, the incidence of the initial pits is noticed after $70 \cdot 10^6$ cycles. The legs of the teeth, as well as the heads were destructed, but the bridging over of these independently created damages by wedges which are almost vertically in relation to the direction of the tooth is also noticed (Figure 6). After the ceasing of investigation (since $98 \cdot 10^6$ cycles were realized) the surface which was influenced by the distructive pitting totalled around 50% of the total working surface of the side of tooth.

Figure 6: *Teeth damaged by pitting and hardfaced with additional material EVB2CrMo after $98 \cdot 10^6$ cycles*

The beginning of pitting, that is the incidence of the initial pits, rgarding the newly-made teeth, is noticed very early, at the $69 \cdot 10^6$ cycles. Gradually and very slowly, the other pits started to appear. The incidence of the initial fatique holes at the teeth of the newly-made gears is the "privilege" exclusively of the leg of the tooth. Only considerably later (after 12-15 million of cycles), the signs of the destructive pitting started to appear also on the legs of the new teeth. On Figure 7 pits created under the diameter pitch of the tooth in the phase immediately before the creation of the wegde are clearly noticed. The special interesting thing is the data that also on the photograph the change of the colour of the working surfaces of the teeth due to fatique, which precedes the creation of the destructive pitting, can be easily seen. The fact is that the development of the destructive pitting regarding the new teeth is a little bit slower than regarding the regenerated ones. At the completing of the investigation, that is after $98 \cdot 10^6$ cycles, it is estimated that 18% of the working surface of the side of the tooth is affected by pitting (Figure 8).

It is also important to point out that all the teeth are of the similar level of damage, which is not the case at the hardfaced ones, where the differences in the level of damage (in the percentage of the surfaces destructed by pitting) of certain teeth are considerably greater.

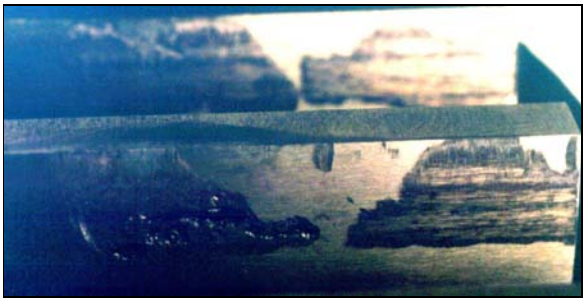

Figure 7: *One of the initial phases of the destructive pitting of the working surfaces of the teeth of the newly-made gears*

Figure 8: *Newly-made teeth damaged by the destructive pitting after $98 \cdot 10^6$ cycles*

6. CONCLUSION

It is shown experimentally that the initial pits of pitting on the teeth occurred almost concurrently in both procedures of the reparatory hardfacing, and it was a little bit later than those of the newly-made ones. However, the speed of the development of pitting at the regenerated teeth is somewhat greater than at the new ones. From that point of view, the teeth hardfaced with the "hard" additional material UTP 670 are a little better.

The complexity of the choice of the type of hardfacing, that is of the corresponding technique and technology of the reparatory hardfacing is reduced neither by the very broad assortment of the existing additional materials for hardfacing nor the great number of the different procedures of the reparatory hardfacing which are developed in practice.

7. LITERATURE

[1] Markovic S.: *Uticaj vrste navarivanja na radne karakteristike regenerisanih zupcanika*, doctoral dissertation, Masinski fakultet, Kragujevac, 2003.