11th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2007, Hammamet, Tunisia, 05-09 Septembar, 2007.

TRIBOLOGICAL CHARACTERISTICS OF GEARS REPARATORILY HARDFACED WIT "HARD" AND "SOFT" ADDITIONAL MATERIALS

Dr. Eng. Svetislav Lj. Markovic,
Higher Technical School, 32000 Cacak,
Svetog Save 65, Serbia, E-mail: svetom@ptt.yu,

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.

Keywords: *gears, regeneration, tribological characteristics.*

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

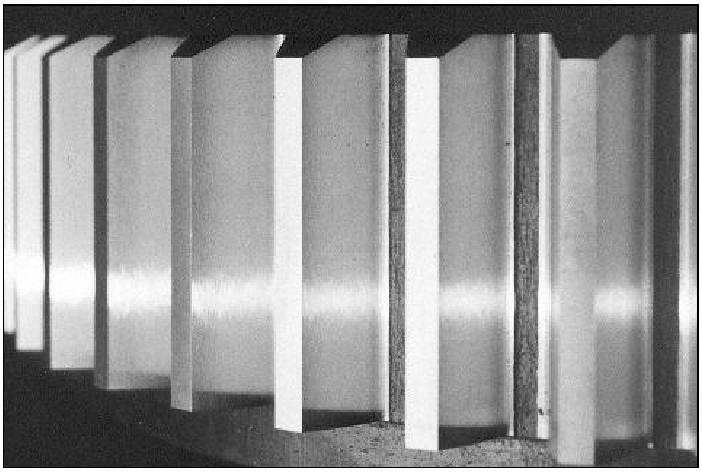

Figure 1. A newly made gear

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**.**
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 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 $T=230^0C$ and keeping at the existing temperature in duration $t=2^h$,
- drying of electrodes at the temperature $T=350^0C$ 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 $1^{\pm0{,}1}$ 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. 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 $98\cdot10^6$ 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 $70\cdot10^6$ cycles. After $98\cdot10^6$ cycles, about 32% of the working surface of the most endangered tooth was damaged (Figure 2). 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.

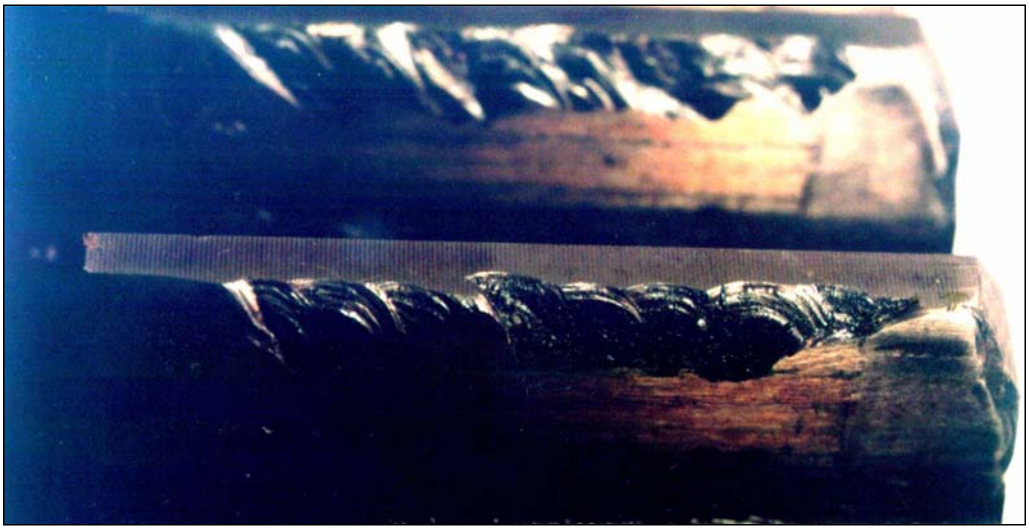

Figure 2. Working surfaces of the teeth hardfaced with additional material UTP 670 after $98\cdot10^6$ cycles

At the teeth MMA hardfaced with electrode EVB2CrMo, and then cemented, tempered and released, the incidence of the initial pits is noticed after $70\cdot10^6$ 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 3). After the ceasing of investigation (since $98\cdot10^6$ 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.

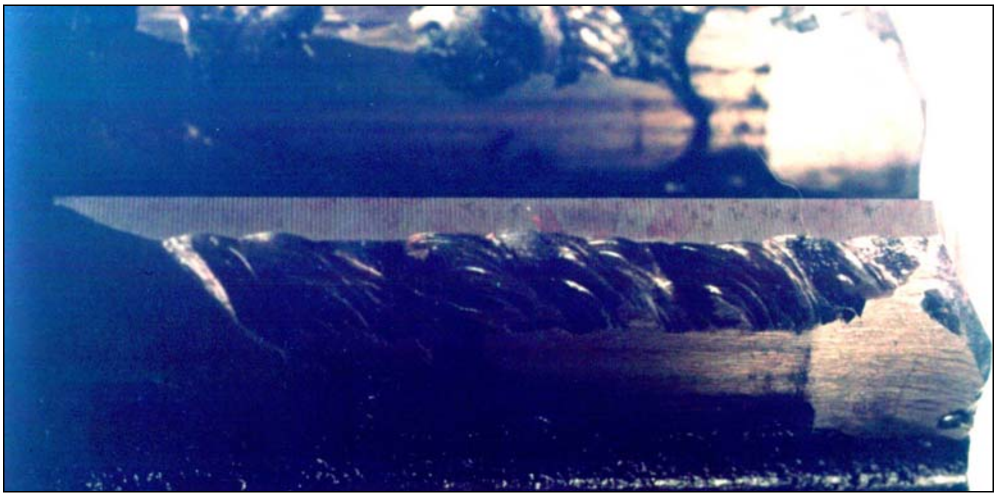

Figure 3. Teeth damaged by pitting and hardfaced with additional material EVB2CrMo after $98\cdot10^6$ cycles

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 4 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 5). 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.

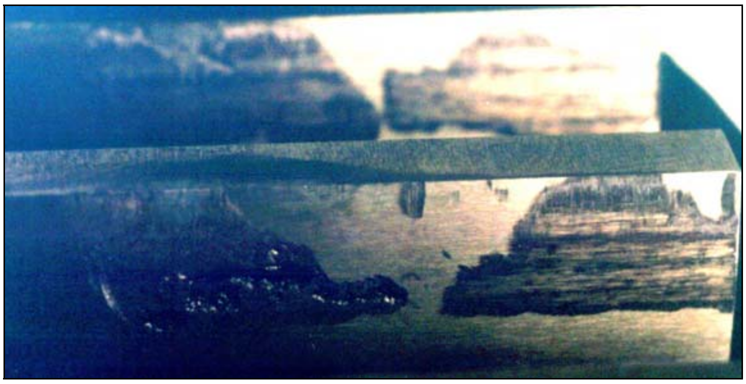

Figure 4. One of the initial phases of the destructive pitting of the working surfaces of the teeth of the newly-made gears

Figure 5. Newly-made teeth damaged by the destructive pitting after $98 \cdot 10^6$ cycles

4. 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.

5. REFERENCES

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