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Exploitation Characteristics of Teeth Flanks of Gears Regenerated by Three Hard-Facing Procedures

Svetislav Marković 1, Dušan Arsić 2, Ružica R. Nikolić 3,*, Vukić Lazić 2, Branislav Hadzima 3, Vladimir P. Milovanović 2, Renata Dwornicka 4 and Robert Ulewicz 5

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Abstract: Numerous phenomena that occur during the process of machine parts’ regeneration have a significant impact on the loss of their working ability. Therefore, the properties of the working surfaces of the teeth flanks of repaired gears were analyzed in this research. The hereditary properties of the gear teeth are expressed by the interdependence of their geometric and physical-mechanical-metallurgical parameters created during the technological operations of regeneration of worn teeth by welding/hard-facing. The hard-facing was executed with three filler metal types, namely: combination Inox 18/8/6 + EDur 600, Castolin 2 and UTP 670. The tested properties included geometrical accuracy, microstructure and microhardness. Evaluation of the executed regeneration procedures was done by comparing the mentioned parameters of the regenerated gears and the new ones. The tested gears were not withdrawn from production due to damage, but they were newly manufactured and intentionally damaged gears, made of the same materials, subjected to the same manufacturing process. In this way, all influences except for the considered filler metal type were eliminated. Based on results of the conducted experiments, it was possible to establish the influence of the filler metal type on the surface characteristics of the regenerated gears’ teeth flanks.

Keywords: regeneration; gear; hard-facing; hardness; microstructure; hereditary properties

1. Introduction

The objective of this paper was to present the dependence of the physical-mechanical-metallurgical parameters of the gear teeth flanks, which are the technological inheritance of the selected filler metals used for their regeneration by hard-facing. In addition to that, an attempt was made to prescribe the optimal technology for the reparatory hard-facing of the gear teeth by the so-called “hard” electrodes. These hard electrodes should be made up of filler metals that provide for the required surface hardness of the teeth without additional thermal-chemical treatment. The way of solving this, by no means an easy task, is illustrated by the presented results of the experimental investigation. To determine the influence of the filler metal on the acquired (inherited) properties of the regenerated gears, it was necessary to conduct voluminous experimental investigations on teeth regenerated by the hard filler metals, Inox 18/8/6 + EDur 600, Castolin 2 and UTP 670, by the application of the two different hard-facing procedures. The tested properties included the geometrical accuracy, microstructure and microhardness of the teeth flanks. Evaluation of the executed regeneration procedures was done by comparing the mentioned parameters of the regenerated gears to the same parameters of the new ones.
Investigations in the area of the regenerated gears, conducted until now, have shown that reparatory hard-facing of damaged working surfaces is the most reliable renewal method of shapes, dimensions and working characteristics of teeth. For the proper selection of an adequate reparatory hard-facing method, it is necessary to know all the mechanisms of wear of surfaces in contact. The regeneration of gears by hard-facing itself is a complex process, consisting of a large number of technological operations, the order of execution of which is extremely important and precisely determined.

Limited literature on the subject has induced the necessity to make the selection of the filler metals based on the authors own experimental experience, as well as that of other researchers. Lazić et al. [1,2] and Arsić et al. [3] have pointed to the possibility of using reparation for restoring the damaged parts of various machine systems. Desir [4] has presented the fact that the Castolin company was confronted with an increasing number of fractures of steel parts; thus they developed the procedures of reparatory welding and hard-facing and presented the metallurgical and technical justification for the presented solutions. Arsić et al. [5] have analyzed the fatigue properties of complex structures and the possibility of their reparation. Borego et al. [6] have analyzed parameters of reparatory welding and hard-facing in order to achieve better fatigue strength of steel for manufacturing casting molds. Atxaga and Irisari [7] have analyzed causes for engines’ shaft failure due to poorly executed reparation, which they have proved by metallographic investigation, while Czuprynsky [8] has pointed to the fact that the mechanical properties obtained by hard-facing could be similar to the properties of the original material of the repaired part.

Based on analysis of the available literature, one can conclude that a small number of authors have considered the influence of regeneration on the operational characteristics of gears, especially from the aspect of technological heritage. Various hard-facing methods and their application in the reparation process of gears were considered in the authors’ own investigations [9–13], where results of experimental metallurgical investigations of the repaired gear teeth were analyzed. It was concluded that the damaged gear teeth can be repaired by careful selection of the filler metal and welding technology [13,14]. The service life of gears regenerated by hard-facing is close to the service life of the newly manufactured ones. In preparing this manuscript, several other works were studied, which dealt with damage to gears and their restoration for continued use [15–26].

2. Preparation of Samples for Testing

This research did not deal with the regeneration of already damaged gears taken out of machine systems that had been in use for a certain period. On the contrary, new gears were made, which were then intentionally damaged and then regenerated. Thus, all the tested gears were made of the same material (steel for cementation, 20MnCr5, whose chemical composition is shown in Table 1) and belonged to one batch. In addition, they were all machined on the same machines with the same machining modes. The gears made this way, Figure 1, had the characteristics presented in Table 2.

| Alloying Elements, % | C   | Si  | Mn  | P_{max} | S_{max} | Cr  |
|----------------------|-----|-----|-----|---------|---------|-----|
|                      | 0.17–0.22 | 0.15–0.40 | 1.1–1.4 | 0.035   | 0.035   | 1.0–1.3 |

Since the chemical composition of steel primarily determines the behavior of austenite during the cooling, it proved necessary to find a simpler, unique system for evaluating the influence of carbon and various alloying elements on stability of austenite and, thus, on the possibility of its transformation into martensite during the welding process. Therefore, the concept of equivalent carbon (C_{eq}) was introduced as an indicator of the metallurgical weldability of steel. The equivalent carbon is calculated by adding the contents of the
Thus, it is necessary to preheat the gear prior to hard-facing, select the adequate welding criteria, the 20MnCr5 steel for cementation belongs to conditionally weldable materials. For the tested steel, that value is within the limits 0.55–0.71%, which is higher than the limit value (0.45%), thus the 20MnCr5 steel is sensitive to the appearance of cracks, and the application of preheating, prior to hard-facing, is necessary. The preheating temperature can be approximately determined according to Seferian’s formula:

\[ T_p = 350 \cdot \sqrt{C_E - 0.25} \]  

where, entering the limit values of equivalent carbon, gives the range of values 191–237 °C. The adopted value for these tests was 230 °C to compensate for the heat losses that appear due to carrying the gears from the furnace to the welding stand at the beginning of the hard-facing.

Other methods for weldability estimates exist today; however, according to all the criteria, the 20MnCr5 steel for cementation belongs to conditionally weldable materials. For the weldability estimate of alloyed steels, the most frequently used expression, recommended by the International Institute of Welding (IIW), is as follows:

\[ C_E = C + \frac{Mn}{6} + \frac{Ni}{15} + \frac{Cu}{15} + \frac{Cr}{5} + \frac{Mo}{5} + \frac{V}{5}. \]  

Steels for which the equivalent carbon value is greater the 0.45% belong to a group of conditionally weldable materials. For the tested steel, that value is within the limits 0.55–0.71%, which is higher than the limit value (0.45%), thus the 20MnCr5 steel is sensitive to the appearance of cracks, and the application of preheating, prior to hard-facing, is necessary. The preheating temperature can be approximately determined according to Seferian’s formula:

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Table 2. Characteristics of the tested gears [25].

| Characteristics              | Symbol | Value  |
|------------------------------|--------|--------|
| Module                       | m      | 6 mm   |
| Number of teeth              | z      | 43     |
| Base profile angle           | α      | 20°    |
| Tooth profile angle          | β      | 0°     |
| Pitch circle diameter        | d₀     | 258 mm |
| Profile correction           | x₀     | 0      |
| Base circle diameter         | d₁     | 270 mm |
| Addendum circle diameter     | d₂     | 243.6 mm |
| Circular pitch               | p      | 18.84 mm |

Figure 1. Newly manufactured gear.
Table 3. Notation and sizes of the used filler metals and applied current intensity.

| No. | Notation          | Manufacturer             | D (mm) | I (A) |
|-----|------------------|--------------------------|--------|-------|
| 1   | E-6-UM-55G - EDur 600 | Jesenice, Slovenia       | 2.50   | 70    |
| 2   | - - CASTOLIN 2   | Castolin Eutectic, Switzerland | 3.25   | 92    |
| 3   | - - UTP 670      | UTP, Germany             | 3.25   | 90    |
| 4   | E18.8.Mn6B20+    | Inox 18/8/6              | 2.50   | 70    |

Table 4. Chemical composition and mechanical properties of the applied filler metals.

| No. | C | Si | Mn | Cr | Ni | Mo | Other | Hardness  | Rm [MPa] | Rp0.2 [MPa] |
|-----|---|----|----|----|----|----|-------|-----------|----------|------------|
| 1   | 0.5 | 2  | 9.5 | -  | -  | -  | -     | 54        | -        | -         |
| 2   | -  | 85 | 0.85 | +  | -  | +  | -     | 57–62     | -        | -         |
| 3   | 0.4 | 0.8 | 9.7 | 0.6 | 1.5 V | >600 | -     | -         | -        | -         |
| 4   | 0.12 | 7.0 | 19.0 | 9.0 | -  | -  | -     | 590–690   | >350      | >900      |

The hard-facing method was selected based on the available resources and equipment at the moment, as well as because the MMA welding procedure was proven to be very reliable during the execution of some former reparation processes [2,3,9,26]. Other hard-facing methods, which can be used should also be mentioned, such as GMAW (gas metal arc welding), plasma hard-facing or laser cladding, the application in practice of which is constantly increasing. For instance, if one considers laser hard-facing, it is well known that such a process uses a laser beam to fuse a material with enhanced thermal and mechanical properties on a substrate. The added material is introduced into the process directly, using inert gases, such as argon or helium. The laser cladding can achieve excellent metallurgical bonding between the substrate and the added material, while the cladded layer is relatively pure [27]. Laser hard-facing is employed in the reparation of gears, as well [28,29], and its application also produces good results. The advantage of laser hard-facing lies in the fact that the heat source is narrowly concentrated at a certain point on the material, which results in better accuracy during the hard-facing, as well lesser influence of the heat on the surrounding base metal, which significantly reduces the size of the heat-affected zone and eliminates the appearance of the brittle phases and cracks.

Technological processes of the gears’ regeneration by reparatory hard-facing with “hard” filler metals are different for the first procedure with respect to the other two. The regeneration process with Inox 18/8/6 and EDur 600 is done by hard-facing in two layers, while hard-facing with the other two types of the filler metals (Castolin 2 and UTP 670) is somewhat simpler and faster, Figure 2a,b. The complete technological process with a detailed description of all the operations for the two types of regenerations is presented in [13].

Hard-facing of teeth was done in two passes. In the first pass (I), the tooth base and part of the head were hard-faced, while, after removing the slag, in the second pass (II), the remaining portion of the tooth head was hard-faced. The appearance of the tooth after the hard-facing, heat treatment and machining is shown in Figure 2c. During the hard-facing, it was taken into account that the thickness of the weld must be increased by the size of the additions for the intended subsequent machining. The appearance of the gear regenerated by the hard-facing is shown in Figure 3.
Figure 2. Schematic presentation of the tooth: (a) prepared for hard-facing; (b) hard-faced in two passes (I—the first pass, II—the second pass); (c) cross-section after the hard-facing and machining: 1—tooth core, 2—cemented layer, 3—hard-faced portion.

Figure 3. Appearance of the tooth regenerated by hard-facing.

It should be emphasized that the process of this work-piece (tooth) manufacturing was not a simple one, due to the material’s high hardness. That is, after the hard-facing of the gear’s tooth, the problem appeared of the material’s machining and selection of the cutting tool that is capable of providing a tooth surface of the required quality. The problem was solved by the application of super-hard diamond cutting platelets with intensive cooling by a special coolant and lubricant, while some gears were machined directly by profiled whetstone grinding.

3. Tribological, Metallurgical and Hardness Investigations

The geometrical measures of samples were controlled by universal and special control/measuring devices. The tooth profile, the tooth flank directions and radial deviation were checked on an involute-meter the “Klingelnberg”, while the regenerated surfaces quality was investigated by the comparative method, i.e., the controlled surface was compared to the corresponding standard with the profile’s medium arithmetic deviation $R_a$. Surface hardness was measured on the “Leitz Wetzlar” device by the Rockwell method (HRC). The measured values of characteristic parameters are presented in Table 5 [26].

The tribological investigation was performed on model samples, prepared from the hard-faced surfaces, on a tribometer by the “block-on-disc” method, similar to some previous testing [30,31]. The samples were prepared in such a way to simulate the operation conditions of teeth of the coupled gears. Based on the conducted tribological tests, the topography of the hard-faced surfaces was determined, namely the width of the wear trace was measured on the universal microscope, ULM-21, which is presented in Table 6 [12,26]. The results of calculated friction coefficients are included in Table 6, as well.
### Table 5. Parameters of geometrical and kinematical accuracy of the controlled gears [12].

| Controlled Parameter                              | Required Values | Gears Hard-Faced by |
|--------------------------------------------------|-----------------|---------------------|
|                                                  |                 | Inox 18/8/6 and EDur 600 | Castolin 2 | UTP 670 |
| Base circle diameter $d_b$ (mm)                  | 270$-0.5$       | 269.82              | 269.77    | 269.77 |
| Measure over 5 teeth $W_5$ (mm)                  | 83.32           | 83.12               | 83.18     | 83.11  |
| Tooth profile tolerance $T_{ev}$ ($\mu$m)        | 16              | 11                  | 15        | 13     |
| Tooth flank line deviation $T_\beta$ ($\mu$m)    | 15              | 10                  | 14        | 12     |
| Radial tooth deviation $T_r$ ($\mu$m)            | 78              | 33                  | 60        | 52     |
| Tooth surface machining quality                  | N7              | N7 *                | N7 *      | N7 *   |
| Surface hardness (HRC)                           | 55–58           | 56.4                | 56.2      | 55.8   |

* $R_a = 1.60 \mu$m.

### Table 6. The friction coefficients and the wear trace widths for samples hard-faced by different filler metals [12].

| Disc       | Block | Material       | Hardness (HRC) | Filler Metal | Friction Coefficient | Wear Trace (mm) |
|------------|-------|----------------|----------------|--------------|----------------------|-----------------|
|            |       | 20MnCr5        | 55–58          | Inox 18/8/6 + EDur 600 | 0.064               | 0.960           |
|            |       |                |                | Castolin 2   | 0.115               | 1.028           |
|            |       |                |                | UTP 670      | 0.090               | 0.955           |

From Table 6, one can see that the best quality of surface (the smallest value of the wear trace width and the friction coefficient) was obtained for the hard-facing performed with the combination of the filler metals Inox 18/8/6 + EDur 600, while the worst quality was obtained for the hard-facing with the Castolin 2 filler metal.

Metallographic investigations were conducted on a quantitative optical metallographic microscope of the “Polyvar-Met” type (produced by “Leica Reichert-Jung, Vienna, Austria) at magnifications of 20$\times$ to 20,000$\times$. The microstructural analysis was performed on the “Leica Q500MC” device, while the photography and measurements were done in the “QWin” program.

The hard-faced layers’ microstructure, obtained by the combination of filler metals (Inox 18/8/6 + EDur 600), is presented in Figures 4 and 5. On the left-hand side of Figure 4, one can notice the needle-like dendritic structure of the hard-faced layer executed by the “hard” electrode EDur 600. In the central area of the figure, one can see the weaker exhibited dendritic structure, which was obtained by hard-facing with the Inox 18/8/6 filler metal, while in the right-hand portion is the heat-affected zone. The joining line between the FM Inox 18/8/6 layer and the HAZ of the base metal is relatively clearly visible, and it is quite uneven. One can notice the mixing of the two materials within the HAZ, Figure 5.
Figure 4. Appearance of microstructure of the hard-faced sample obtained by the two filler metals combination: FM EDur 600—left, FM Inox 18/8/6—middle; HAZ—right.

Figure 5. Appearance of microstructure of the hard-faced sample obtained by the two filler metals combination: transition from the HAZ (left) to the FM (right).

Appearance of microstructure of the hard-faced sample obtained by the Castolin 2 filler metal is presented in Figures 6 and 7, while the microstructure obtained by hard-facing with the UTP 670 filler metal is given in Figure 8.

Figure 6. Appearance of microstructure of the hard-faced sample obtained by the Castolin 2 filler metal at the transition between the hard-faced layer and the heat-affected zone.
According to Figures 6 and 7, hard-facing with filler metal Castolin 2 produced a prominent dendritic structure of the hard-faced layer. The average width of the dendritic needles was 10 to 15 µm, which is very convenient. However, the dendrites were characterized by inhomogeneity, which was proven by the various level of surface etching. The carbide phase (primary carbides) was present in the hard-faced layer, as well, mainly extruded along the grain boundaries. The dendrites’ growth direction was mainly perpendicular to the hard-faced layer surface.

The tooth hard-faced with the UTP 670 filler metal possessed a medium-coarse structure with an individual dendrite width of 30 to 80 µm. A high share of the carbide phase was present in the structure, which can be seen as the brighter areas in Figure 8. Carbides were extruded along the grain boundaries; however, the largest portion was in the grains themselves.

Regarding the size and width of the dendrites, the optimal shape of the dendritic phase was obtained by hard-facing with the Castolin 2 filler metal. The microstructure of the surface and subsurface layers of the hard-faced samples obtained by the MMAW welding procedure and the UTP 670 filler metal was somewhat better than for the other filler metals.

The surface hardness was measured on the “Leitz Wetzkal” device by the Rockwell method (HRC) on the hard-faced teeth, at five points. The hardness average values are
presented in Table 7. The measured surface hardness values were within the required limits, 58 ± 3 HRC.

Table 7. The surface hardness and macrohardness of the hard-faced and newly manufactured samples.

| No. | Hardness HRC       | Macrohardness HV 30/15 | Corresponds to HRC |
|-----|-------------------|------------------------|-------------------|
| 1   | Inox 18/8/6 + EDur 600 | 57.5                  | 63.3              |
| 2   | Castolin 2        | 58                     | 62.2              |
| 3   | UTP 670           | 55.5                   | 63.4              |

The microhardness was measured along the cross-section of individual teeth, by the Vickers method (HV0.1) with a load force of 1 N and indentation time of 15 s. Results are presented in Tables 8–10 and Figure 9.

Table 8. Microhardness of the sample hard-faced with the Inox 18/8/6 + EDur 600 filler metals.

| Distance from the surface (mm) | 0.05 | 0.10 | 0.15 | 0.20 | 0.25 | 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.60 | 0.70 | 0.80 |
|-------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Hardness HV0.1                | 820  | 820  | 787  | 787  | 757  | 726  | 787  | 787  | 787  | 787  | 787  | 787  | 757  |
| Corresponds to HRC            | 64.7 | 64.7 | 63.6 | 63.6 | 62.4 | 61.2 | 63.6 | 63.6 | 63.6 | 63.6 | 63.6 | 63.6 | 62.4 |

| Distance from the surface (mm) | 0.90 | 1.0  | 1.25 | 1.5  | 1.75 | 2.00 | 2.50 | 2.00 | 2.50 | 3.00 | 3.50 | 4.00 | 4.50 |
|-------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Hardness HV0.1                | 787  | 787  | 787  | 480  | 440  | 426  | 401  | 480  | 514  | 496  | 452  | 452  | 350  |
| Corresponds to HRC            | 63.6 | 63.6 | 51.1 | 47.7 | 44.5 | 43.2 | 40.9 | 47.7 | 50.1 | 48.8 | 45.5 | 35.5 | 27.2 |

Table 9. Microhardness of the sample hard-faced with the Castolin 2 filler metal.

| Distance from the surface (mm) | 0.05 | 0.10 | 0.20 | 0.30 | 0.40 | 0.50 | 0.60 | 0.70 | 0.80 | 0.90 | 1.00 | 1.25 |
|-------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|
| Hardness HV0.1                | 757  | 757  | 700  | 757  | 726  | 787  | 787  | 787  | 634  | 634  | 496  | 514  |
| Corresponds to HRC            | 62.4 | 62.4 | 60.1 | 62.4 | 61.2 | 63.6 | 63.6 | 63.6 | 57.0 | 57.0 | 48.8 | 50.1 |

| Distance from the surface (mm) | 1.50 | 1.75 | 2.00 | 2.50 | 3.00 | 3.50 | 4.00 | 4.50 | 5.00 | 6.00 | 8.00 |
|-------------------------------|------|------|------|------|------|------|------|------|------|------|------|
| Hardness HV0.1                | 514  | 473  | 401  | 452  | 401  | 440  | 401  | 440  | 350  | 350  | 350  |
| Corresponds to HRC            | 50.1 | 47.2 | 40.9 | 45.5 | 40.9 | 44.5 | 40.9 | 44.5 | 35.5 | 35.5 | 35.5 |

Table 10. Microhardness of the sample hard-faced with the UTP 670 filler metal.

| Distance from the surface (mm) | 0.05 | 0.10 | 0.15 | 0.20 | 0.25 | 0.30 | 0.35 | 0.40 | 0.45 | 0.50 | 0.60 | 0.70 | 0.80 |
|-------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Hardness HV0.1                | 820  | 820  | 820  | 820  | 820  | 757  | 757  | 757  | 787  | 787  | 787  | 787  | 820  |
| Corresponds to HRC            | 64.7 | 64.7 | 64.7 | 64.7 | 64.7 | 62.4 | 62.4 | 62.4 | 63.6 | 61.2 | 61.2 | 63.6 | 63.6 |

| Distance from the surface (mm) | 0.90 | 1.00 | 1.25 | 1.50 | 1.75 | 2.00 | 2.50 | 3.00 | 3.50 | 4.00 | 5.00 | 6.00 | 8.00 |
|-------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Hardness HV0.1                | 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 |
Thus extremely important that the layers are well welded and joined to each other, so that no point could exist that could later act as a stress concentrator. It is addition, it should be emphasized that the initial damage is the most likely to appear on the joint of the two electrode passes during the hard-facing. The appearance of pitting can be delayed by increasing the surface layers’ hardness [26]. In addition, it should be emphasized that the initial damage is the most likely to appear on the joint of the two electrode passes during the hard-facing. It is thus extremely important that the layers are well welded and joined to each other, so that no point could exist that could later act as a stress concentrator.

The gears’ regeneration resulted in numerous savings. Economic analysis of applied regeneration procedures assumes comparison of costs of the regenerated and newly manufactured gears. The regeneration price includes material and labor costs, as well as overheads. Compared to the price of the newly manufactured gears, considering the time of their service life, the advantages of hard-facing are multifold. The calculation of the techno-economic specific parameters, such as indicator of economic justification of regeneration, coefficient of the exploitation reliability and condition for the economic rationality of regeneration, are not given in this paper. In the previous research, by the authors of this paper, such a calculation was provided for a similar regeneration procedure, which confirms the aforementioned statements [1,13,32].

5. Conclusions

Research, results of which are reported in this paper, aimed to present the dependence of the physical–mechanical–metallurgical parameters of the gear teeth flanks, which are the technological inheritance of gears’ regeneration by hard-facing, on the type of the applied
filler metal(s). The reparatory hard-facing of the gear teeth was executed by so-called “hard” electrodes, where the hard electrodes are made up of filler metals whose application results in such properties (mainly hardness) of surfaces that additional thermal-chemical treatment is not necessary.

The gears that were regenerated were not “pulled out” from use due to being damaged, but they were the newly produced and deliberately damaged gears. This ensured that all the tested gears were made of the same material (steel for cementation, 20MnCr5), belonged to one batch, all machined on the same machines by the same machining process. In this way, the results of experimental investigations reflected only the influence of application of the three different filler metals, while all other influences were eliminated. The three filler metals, used for regenerating hard-facing, were combination Inox 18/8/6 + EDur 600, Castolin 2 and UTP 670. The tested properties included geometrical accuracy, microstructure and microhardness. Evaluation of the executed regeneration procedures was done by comparing the mentioned parameters of the regenerated gears to the same parameters of the new ones.

Based on analysis of the obtained results from experimental investigations of the regenerated gears, the following conclusions were drawn:

• Geometrical characteristics, prescribed tolerances and deviations, as well as the quality of surfaces of the regenerated gears’ teeth flanks completely comply with prescribed and standardized values for the newly manufactured gears.
• The required mechanical properties, primarily the surface hardness, are easily obtained by the application of the adequate filler metal(s).
• The flanks of the regenerated gears possess a hardness almost equal to the hardness of the newly manufactured gears, provided that quality hard-facing and subsequent machining are ensured.
• Considering that electrodes, used for hard-facing, are characterized by the low heat input into the layers’ deposition zone, it is metallographically confirmed that the form of obtained surface microstructure is adequate.
• Analysis of the microhardness shows that the hard-faced layers executed by the “hard” filler metals possess a higher microhardness than the cemented and quenched base metal.

The general conclusion is that the best results of all the investigated characteristics are obtained for the teeth flanks of gears regenerated with the combination of filler metals Inox 18/8/6 + EDur 600. Thus, their application is recommended for reparatory hard-facing of damaged gears made of the steel for cementation, 20MnCr5.

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