

# Surface analysis of gear wheels produced by electrochemical treatment

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**Abstract.** This paper provides a result of surface analysis of the gears of steel A290C1M electrochemically treated by the method of static-hydrodynamic electrolysis. Surface analysis of gear wheels was carried out via Jeol JCM-5700 scanning electron microscope. The processing parameters of electrochemical treatment, established in the present investigation, provide a good-quality of working surface of the teeth, containing defects nevertheless. It is concluded a necessity of further clarification the reasons of defects' appearance and an expediency of methodology improvement for treatment modes selection.

## 1. Introduction

The method of electrochemical treatment of metals or metallic surfaces exhibits essential advantages among non-mechanical processing techniques due to the ability to finish solid, hard-to-process or mechanically non-processable materials, as well as various non-rigid elements of parts without their deformation.

The developed method of miniature gears manufacturing [1] provides an electrochemical processing based on static-hydrodynamic electrolysis as a finishing treatment. It makes possible to increase the productivity of gear wheels manufacturing from hard materials, and also allows gear wheels producing from hard alloy, which is impossible when using traditional (mechanical) processing techniques. In addition, the proposed method of finishing provides higher performance characteristics of manufactured gears, compared with traditional finishing (grinding) method.

Electrochemical treatment is the process of material removing by anodic dissolution during electrolysis [2]. The advantages of electrochemical treatment include the ability of processing the materials regardless of their hardness, the possibility of obtaining a good-quality surface, even when processing a complex shapes, as well as manufacturing parts with stress-free and crack-free surfaces [3].

Klocke et al. [4] showed that non-traditional treatment methods, such as electrical discharge machining and electrochemical treatment are superior to traditional milling in technological and economic aspects at the turbine wheels production. The authors also note that electrical discharge machining is more applicable in the production of small batches, and electrochemical treatment is more appropriate in large scale production. The authors [5] demonstrated the effectiveness of electrochemical treatment application for manufacture of parts with complex geometry in aerospace industry.

Acidic, alkaline or neutral aqueous solutions can be used as the electrolyte. For steels treatment, it is preferable to apply aqueous solutions of acids due to their good dissolving ability, including ability to dissolve a various impurities contained in the metal [6]. For the hard alloys processing, in particular tungsten carbide, neutral and alkaline solutions are applied [7]. The reason it persists is because of the acidic electrolytes application lead to a passive oxide layer formation on surface of tungsten carbide, which significantly reduces the processing speed. Specific non-aqueous electrolytes, for example,  $\text{NH}_4\text{NO}_3 / \text{NH}_3$ , which is used to treat molybdenum products, can be also applied [8]. Most of the



used electrolytes are toxic to humans and the special production conditions are required to protect the machine operator from harmful effects. Also, electrolysis products, which are, as a rule, various metal salts, may also require special disposal conditions. This factor is one of the limitations for electrochemical application in a single and small batch production. It is economically unprofitable the exploitation of one or several equipment units which require an equipment for preparation, storage and recycling of electrolyte.

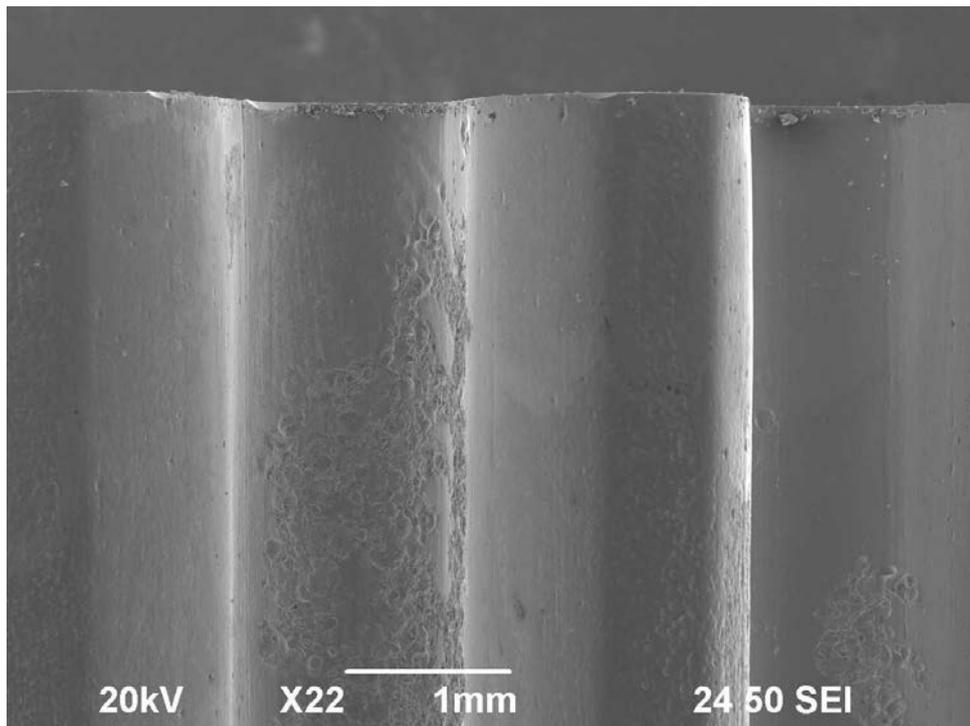
One of the relevant research areas is the treatment with application of neutral, non-toxic and environmentally harmless electrolytes, such as water [9] or citric acid [10]. The current trends in electrochemical processing are modeling and simulation of the electrochemical treatment. A significant contribution in this area was made by Minazetdinov et al. [11, 12] and by Deconinck et al. [13, 14]. Other relevant areas are an electrode-tool designing [15], an improvement of control and monitoring systems [16], as well as development of hybrid processing techniques, such as combined treatment [17].

## 2. Problem formulation

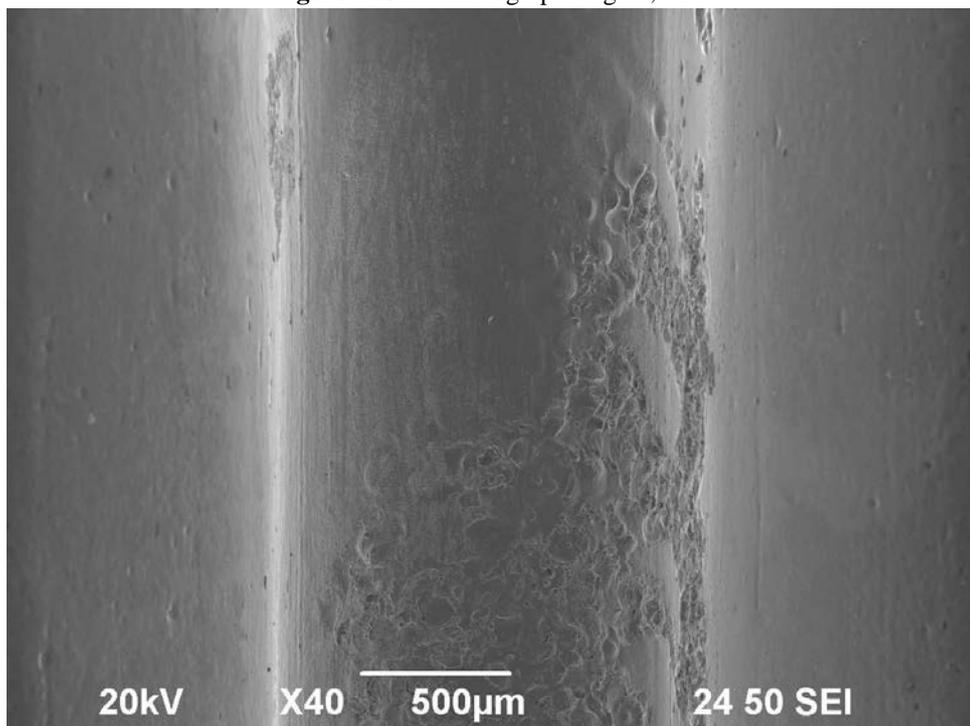
The literature review leads to the conclusion that the gears surface processed by electrochemical treatment are not well understood and further investigations is required in this direction. The morphology and various features of surface microrelief render a significant impact on the operational characteristics of the manufactured gears. The main goal of the paper is to study the morphology of the gears processed by electrochemical treatment and to select the optimal processing modes.

## 3. Materials and methods

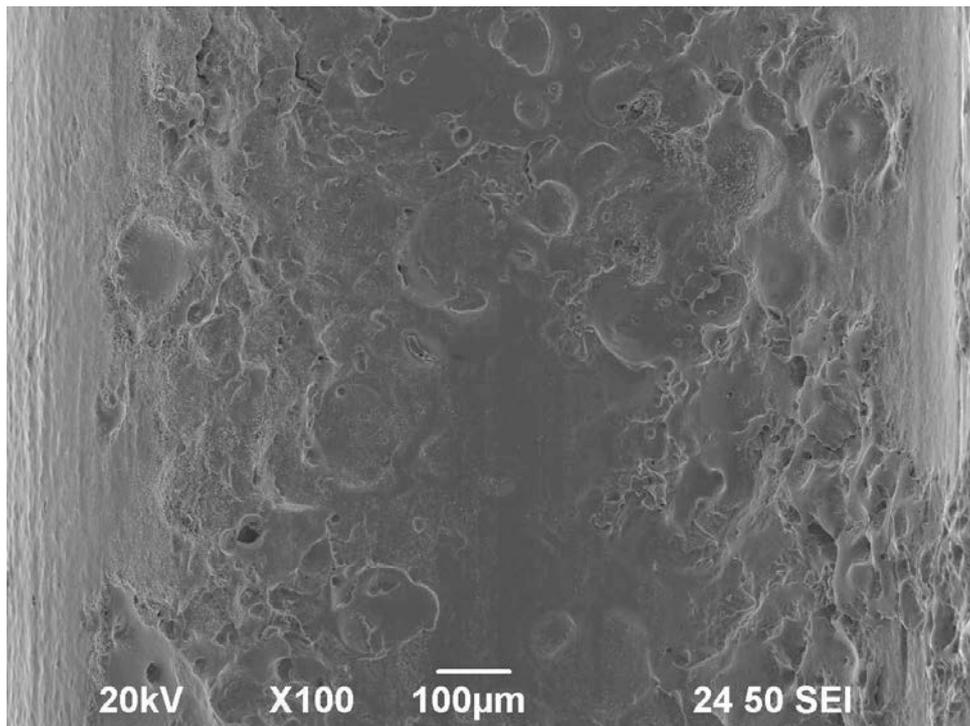
For the study, the gears were calculated according to the method [18]. Then the electrolyte is selected according to the reference data. To conduct the study, samples of gear wheels with module  $m = 1$  were produced of steel A290C1M on Sodick VZ300L electrical discharge machine, then electrochemical processing was carried out according to the principle of static-hydrodynamic electrolysis on a lathe machine, converted for dimensional electrochemical processing. A mixture of sodium nitrate 60 g/l, sodium sulfate 120 g/l, sodium acetate 30 g/l and kerosene 20 ml/l was used as an electrolyte. Electrolysis conditions were as follows: electrolyte consumption was 0.5 l/min, the voltage was 10 V, processing time was 2 minutes, one minute with the direction of rotation in different corners. The gears were produced by the developed technology and investigated via Jeol JCM-5700 scanning electron microscope equipped with an X-ray energy dispersive spectrometer in high vacuum mode. The signal type was secondary electrons (SEI). The SpotSize parameter was varied in the range from 20 to 30, with the accelerating voltage value 10 kV and magnification from  $22\times$  to  $300\times$ . The resulting micrographs are presented in Figures 1-4.



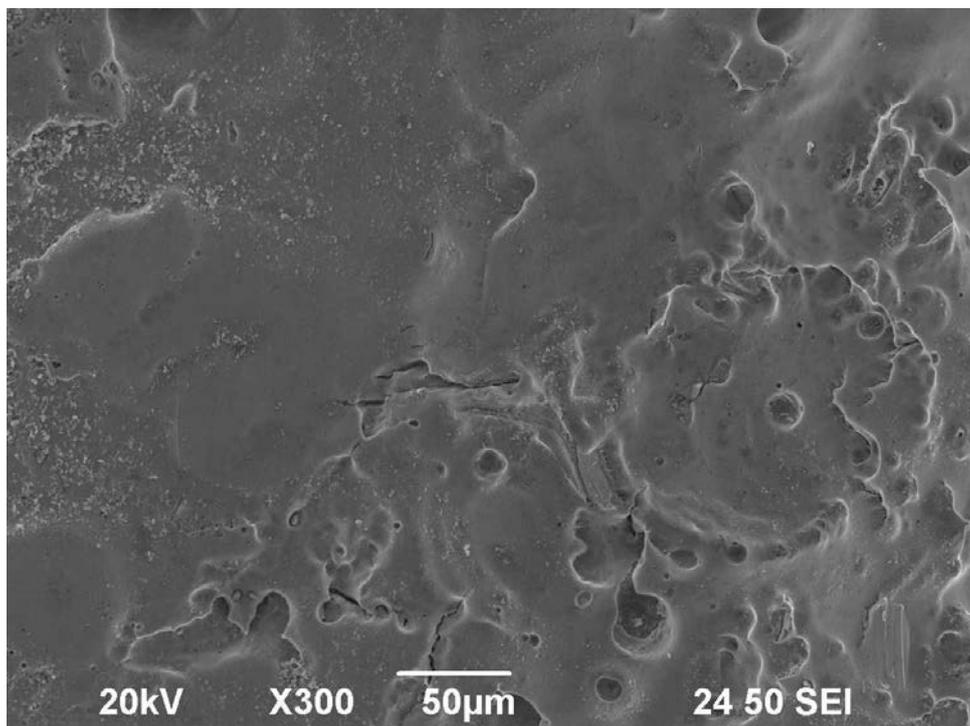
**Figure 1.** SEM micrograph of gear,  $\times 22$ .



**Figure 2.** SEM micrograph of gear,  $\times 40$ .



**Figure 3.** SEM micrograph of gear with the defect in the bottom land,  $\times 100$ .



**Figure 4.** SEM micrograph of gear with the defect in the bottom land,  $\times 300$ .

#### 4. Results and discussion

Figures 1 and 2 demonstrate the manufactured gear with magnification from  $22\times$  to  $40\times$ , respectively. A more detailed examination of the manufactured gear (Figures 3 and 4) show the region of defects on the bottom land. Figures 3 and 4 demonstrate that the treatment modes allow obtaining the required surface quality on the faces and top lands of the teeth. The minimum number of defects was found on these surfaces; they are homogeneous and are likely to provide good performance of the manufactured wheels, which will be tested in practice in further examinations. Defects are present on the bottom

lands (Figures 1–2) of the «coral-like relief» area. Figures 3–4 demonstrate the etched surfaces as a result of non-optimal processing conditions. Such defects are caused by improper electrolyte selection and / or insufficient electrolyte outflow rate from the nozzle. The flow rate, as is known, should be equal to the speed of mutual rolling around of the electrode surfaces. And, probably, the calculated speed was not maintained during the entire processing due to the imperfection of the laboratory setup. Defects were detected only in the bottom land due to less favorable processing conditions than on the face surface of the tooth, due to the longer retention time of electrolyte in this zone or because of the turbulent vortices formation in this zone. The obtained result can also be caused by complex of processes in electrolyte, whose electrical conductivity changes during processing. The properties of the electrolyte depend on temperature, therefore for high-precision processing, as a rule, a thermoconstant conditions are need to be created. In this study the electrolyte temperature was monitored only before treatment. The properties of electrolyte also depend on the gas bubbles formation, which break the continuous medium. The formation of these bubbles, in turn, depends on the fluid flow rate, its pressure and also the current density. A better understanding of these processes will allow more precise control of the processing modes. The authors [19] conducted a study of mass, heat, and electric transfer in the process of electrochemical treatment. The results of this study allow a better understanding and explanation the nature of the obtained defects.

The results show that it is necessary to conduct further investigation aimed to selection of the processing mode that provide higher quality of all treated surfaces. It is necessary to take into account the main achievements, methods and problems associated with mass transfer in the process of electrochemical treatment. These questions are well disclosed in a review article [20].

## 5. Conclusion

In this study, gears wheels treated by electrochemical technique were studied. The main results are formulated as follows. The selected modes allow obtaining a good quality of the tooth faces of the manufactured wheels. The defects detected in the bottom land indicates the non-optimal processing conditions and further investigation is required to obtain a surface with a minimum of defects.

## References

- [1] Linovsky A In 2017 *Dynam. of sys., mech. and mach.* T 5 – № 1
- [2] Mc Geough J A *Principles of electrochemical machining.* 1974:Chapman and Hall.
- [3] Sundaram M M and Rajurkar K 2010 *Field Manufacturing* CRC Press. p 173–212
- [4] Klocke F, Zeis M, Klink A and Veselovac D 2012 *Proc.of the 1st CIRP Global Web Con. on Interdisc. Res. in Prod. Eng.* Vol. 2, p 98–101
- [5] Pavlinich S, et al. *Russ. Aero. (Iz VUZ)* 51(3): p 330–8
- [6] Neergat M and Weisbrod K R 2011 *Corr. Sci.* Vol. 53(12): p 3983–90
- [7] Munda J, Malapati M and Bhattacharyya B 2007 *J. of Mat. Proc. Tec.* Vol. 194(1–3): p 151–8
- [8] Abbas Q, Binder L 2011 *Inter. J. of Ref. Met. and H. Mate.* Vol. 29(4): p 542–6
- [9] Huaiqian B, Jiawen X and Ying L 2008 *Chin. J. of Aero.* 21(5): p 455–61
- [10] Ryu SH 2009 *J. of Mat. Proc. Tech.* 209(6): p 2831–7
- [11] Minazetdinov N M 2009 *J. of App. Math. and Mech.* Vol. 73(1): p 41–47
- [12] Minazetdinov N M 2009 *J. of App. Math. and Mech.* Vol. 73(5): p 592–8
- [13] Deconinck D, Damme S V and Deconinck J 2012 Part I: Theoretical basis. *Electrochimica A.* 60(0): p 321–8
- [14] Deconinck D, Damme S V and Deconinck J 2012 Part II: Numerical simulation. *Electrochimica A.* 69(0): p 120–7
- [15] Zhiyong L and Zongwei N 2007 *Chin. J. of Aero.* Vol. 20(6): p 570–6
- [16] Wang X, Zhao D and Yun N 2007 *Chin. Mech. Eng.* 18(23): p 2860–4
- [17] Zeng Z et al 2012 *Prec. Eng.* Vol. 36(3): p 500–9
- [18] Linovsky A V, Fedorov A A, Tignibidin A V, Takauk S V, and Lavrentev S V 2019 *J. of Phys.: Con. Ser.*, 1210(1) doi:10.1088/1742-6596/1210/1/012081
- [19] Kozak J, Kim HK, AoS I and Rieger B B 2013 *IAENG Transc. on Em. Tech.* Editors Springer Netherlands. p 95107.2011
- [20] Volgin V and Davydov A 2012 *J. of Electrochem.* Vol. 48(6): p 565–9