



# MICROSTRUCTURE AND FRACTOGRAPHIC ANALYSIS OF DAMAGE REASONS OF COGWHEEL

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## Resume

The article provides an analysis of the damaged cogwheel, which was used as the drive wheel (pinion) in the steering gear box of the construction machine. The degradation of the cogwheel arose during the warranty period, after seven months of using of the construction machine. The experimental analysis revealed that the cause of the degradation of the cogwheel was due to high mechanical stress in the operating conditions of construction machine.

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## 1. Introduction

The cogwheels provide the transmission of the torque from the engine to the drive shaft gear of the various machines and the equipments. The high quality which depends on the design of the cogwheel, using starting materials, good thermo-chemical treatment (carburizing process – the diffusional saturation with carbon, quenching and tempering), final finishing work (eg. grinding gear), is required due to their extreme stress. In operation can arise the contact fatigue or fatigue breach of components with complete loss of functional mechanisms [1÷6].

The paper presents an experimental analysis of the damaged cogwheel with the external teeth. The cogwheel was used in the spur gear with the parallel axes as drive wheel in the steering gear box of the construction machine (feeder with independent left and right traction).

The aim of the experimental analysis was to obtain detailed information for the reasons of the cogwheel damage.

## 2. Experimental methods and results

The experimental methods used in this investigation were: analysis of chemical composition, hardness measurement and microstructure analysis using light microscope and scanning electron microscope (SEM).

The summary view of the analyzed damaged cogwheel is shown in Fig. 1. Several failures were macroscopically observed on the cogwheel, for example: cracks, broken and turgidity gear, plastic deformation of cogwheel's material and the local separation of the material. More detailed view of the damaged cogwheel is shown in Figs. 2 to 5.

From the damaged teeth of cogwheel was cut sample, by cutting disc with cooling water. The sample was cleaned with acetone in ultrasonic cleaners and analyzed by scanning electron microscope TESLA BS 300.

The surface of cogwheel's tooth is documented in Fig. 6. In this figure we can observe plastic deformation, cracks and bruising

of the functional area of the tooth. More detailed view of the significant crack, which is spreading to the functional area of the tooth, is shown in Fig. 7. In the upper part of Fig. 8 can be seen the net of the cracks spreading in to the cross-section of material and separation of material from the

functional areas of the cogwheel's tooth. The net of cracks was also observed in the side face of the cogwheel. Similarly, elsewhere in the functional areas of the cogwheel's tooth further observe the cracks and the separation of the material (Fig. 9).

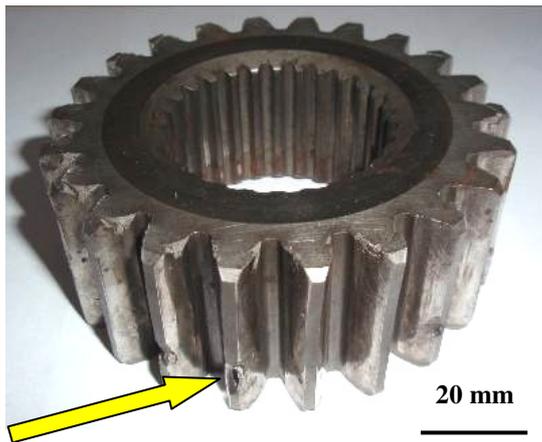


Fig. 1. View on the damaged cogwheel

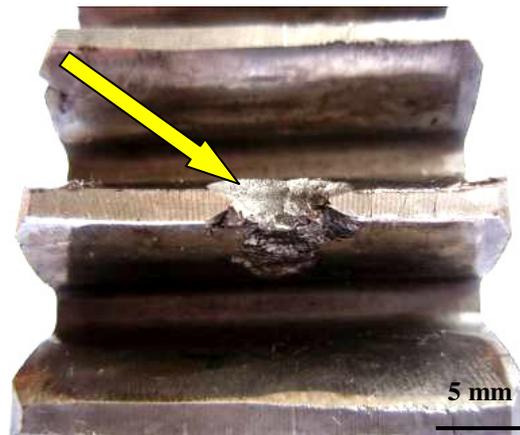


Fig. 2. Detail of the broken part of the tooth of cogwheel

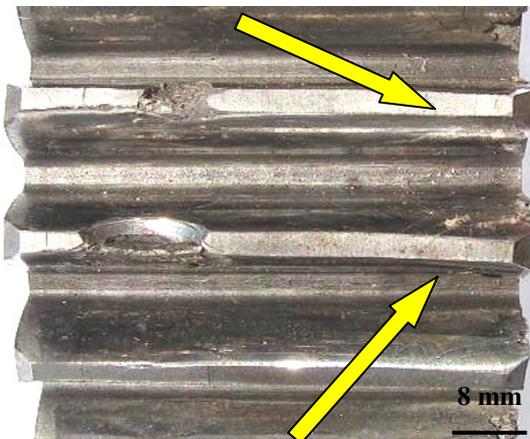


Fig. 3. View of deformed gear

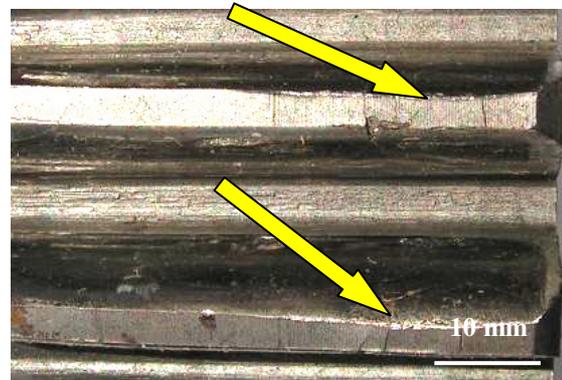


Fig. 4. Changes in geometry, significant wear of cogwheel's teeth

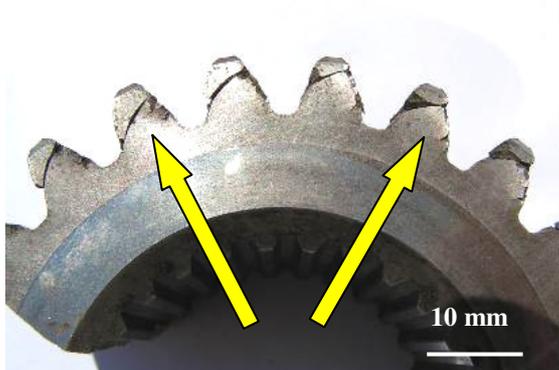


Fig. 5. View of the cracked tooth of the cogwheel

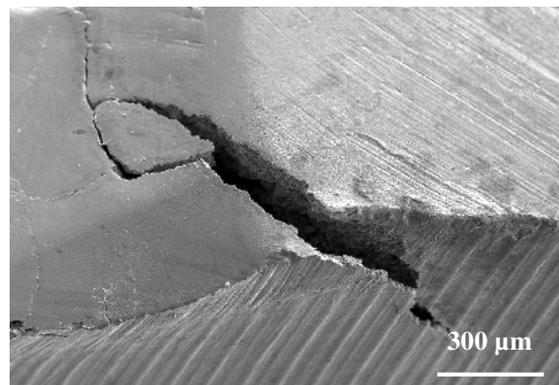


Fig. 6. Plastic deformation, cracks, bruising of cogwheel's tooth, SEM

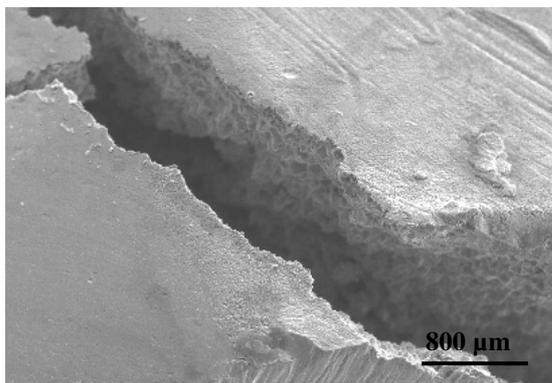


Fig. 7. The detail view of the crack, SEM

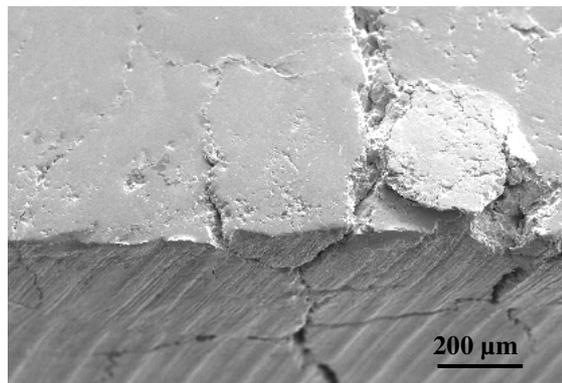


Fig. 8. The net of the cracks, SEM

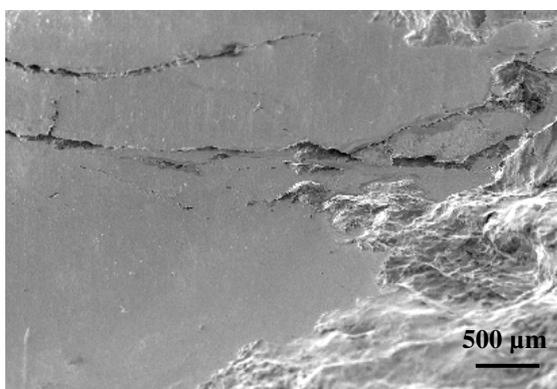


Fig. 9. The cracks and separation of material from the cogwheels, SEM

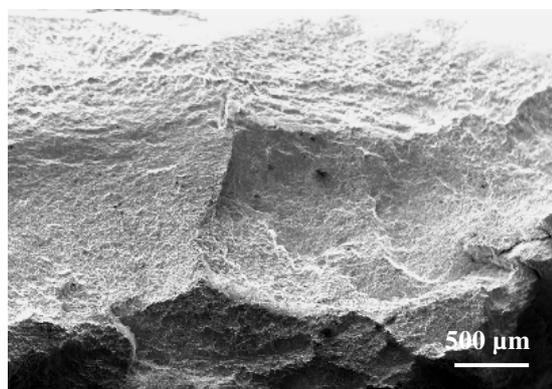


Fig. 10. The functional surface of cogwheel, fracture surface SEM

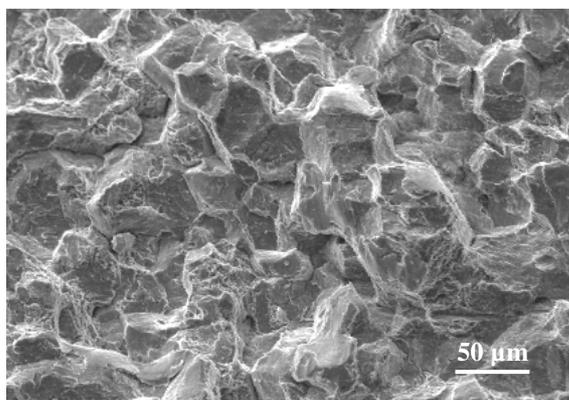


Fig. 11. The predominant ratio of the intercrystalline failure, SEM

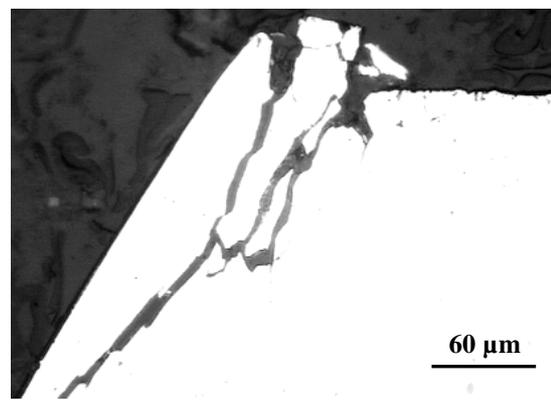


Fig. 12. The deformed cogwheels tooth, cracks, polished condition

Fig. 10 documents the fracture surface of the functional areas of the tooth in place of a separate material of cogwheel. In Fig. 11 is observed a dominant ratio of intercrystalline failure of material [7, 8]. The sample was cut from the damaged cogwheel upright to the tooth by cutting disc with cooling water. The sample was molded using press into the compound Phenocure by conventional metallographic

procedures. The cracked and deformed tooth of cogwheel is shown in Fig. 12 and 13. The large cracks spread in the cross-section of the cogwheel's tooth. The condition of sample after etching 3 % Nital is documented in Fig. 14 and 15. The spread of cracks at grain boundaries is observed in the microstructure of cross-section of the tooth. The microstructure of surface diffusional layer of cogwheel's teeth corresponds

to the state after carburizing and hardening. The microstructure was consisted of martensite and retained austenite (Fig. 16). The microstructure in the transitional area of diffusional layer was mainly formed of bainite (Fig. 17) and bainite and ferrite was formed in core (Fig. 18). The share of ferrite in the microstructure in cross-section of the tooth was approx. 10 % [9-14].

Chemical composition in the core of the material was analyzed by SPECTROTEST and results are given in the Table 1. Chemical

composition of material is suitable for 16MnCr5 DIN EN 10084, which is normally used for the production of gears [15, 16]. The evaluation of depth of surface diffusional layer was made in cross-section of middle diameter of cogwheel according to DIN 50 190. The hardness was measured by Vickers using Zwick 3212 with a micrometer shift table. The graph of hardness in the cross-section of the cogwheel's tooth is illustrated in Fig. 19. The depth of carburizing layer in accordance with DIN 50 190 corresponds to value 0.75 mm.

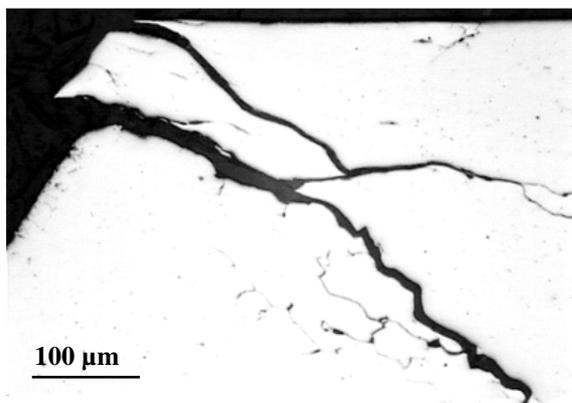


Fig. 13. The deformed cogwheel's tooth, cracks, another place, polished condition

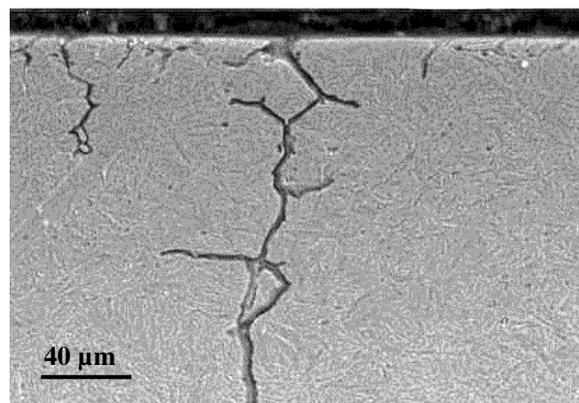


Fig. 14. The spreading cracks on grain boundaries, etched condition, REM

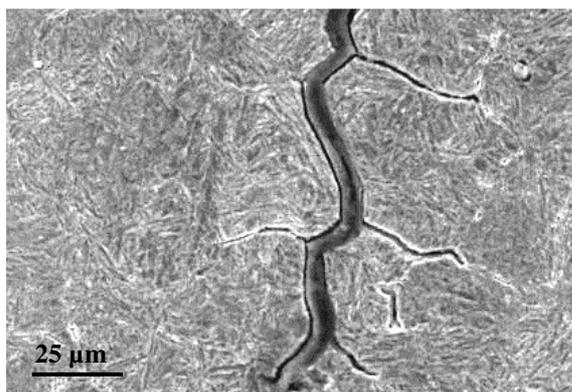


Fig. 15. More detailed view of Fig. 14, REM

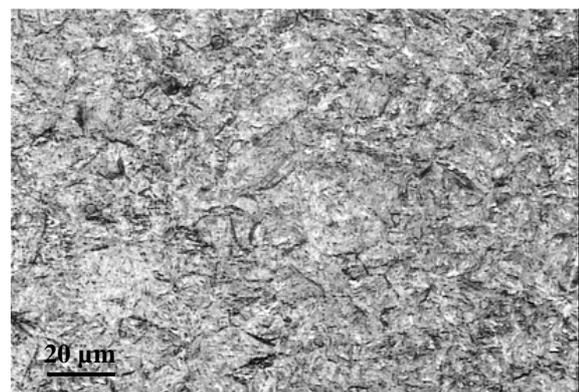


Fig. 16. Microstructure of surface diffusional layer, martensite and retained austenite, etched Nital 3 %

Table 1

Chemical composition of material in core of the cogwheel									
Chemical element	C	Si	Mn	P	S	Cr	Mo	Ni	Al
Content [wt. %]	0.19	0.267	1.126	0.020	0.020	0.824	0.016	0.035	0.031
Chemical element	Co	Cu	Ti	V	W	Pb	Sn	B	Fe
Content [wt. %]	0.01	0.069	0.001	0.005	0.010	0.001	0.008	0.0001	97.300



Fig. 17 The transitional area of diffusional layer formed by bainite, etched Nital 3 %



Fig. 18 The microstructure in the core of the cogwheel consisting of bainite and ferrite, etched Nital 3 %

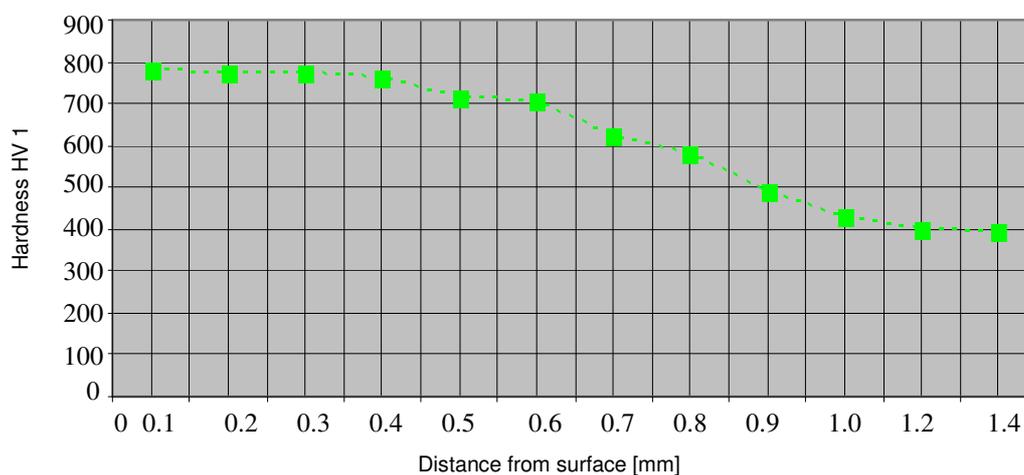


Fig. 19. The graph of hardness in the cross-section of the cogwheel's tooth

### 3. Discussion

The thickness of surface diffusional layer measured on the tooth of cogwheel corresponds to the value 0.75 mm, i.e. the minimum value of thickness. The plastic deformation of the material can be prevented by reinforcing of components with sufficient thickness of the surface layer. This surface layer is formed by martensite. In practice, the highly stressed gears of gearboxes of larger machines have a thickness of layer with a value from 1.0 to 1.3 mm. After the grinding of the functional surfaces of gear's teeth, it is necessary to use non-destructive defectoscopic control of grinding cracks,

respectively detection of quenching cracks. These quenching cracks may initiate degradation of material in difficult operating conditions.

### 4. Conclusions

The cogwheel teeth were significantly plastically deformed. The macroscopically spreading cracks in the teeth of cogwheel have a length of several millimeters. The local separation of the material (the teeth of the cogwheel) was observed, too. The fracture surface on the surface of the cogwheel's teeth showed predominantly intercrystalline brittle fracture. The large cracks are spreading from

the surface to the core of cogwheel. The microstructure of surface diffusional layer of the cogwheel was suitable. It was formed by martensite and retained austenite. In the surface diffusional layer was not found the secondary cementite on grain boundaries, which could be affecting the quality of the cogwheel negatively. The microstructure in the core of the cogwheel formed of bainite and the small amount of ferrite. The chemical composition of the material in the core of cogwheel accommodates to material used for carburizing and hardening process. The measured surface hardness of cogwheel was suitable.

Probable cause of the degradation of the cogwheel in operating conditions was due to difficult operating conditions of the machine, the formation of the cracks and a gradual separation of the material from the surface of the cogwheel's teeth. The damaged cogwheel's teeth were worn and plastically deformed by high mechanical stress.

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