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Production of Ultra-Fine-Grain Steel in Saw Blade Bodies aided by Artificial Intelligence

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Abstract

In the production of cold work tool steels, components are first subjected to heat treatment to set the desired parameters such as hardness and strength, and then ground to obtain the final geometric shape. Both processes are resource and energy intensive and highly complex due to many adjustable system and process parameters. Therefore, it is difficult to reliably control parameters such as stresses, microstructure, and dimensions due to the interaction between the individual processing steps. In industrial applications, this leads to a significant amount of rejected material that can only be detected late, which has an overall negative impact on overall efficiency.

This work focuses on saw blades bodies that are made of 75Cr1 with microstructural grain sizes of approximately 20 μm . Aided by artificial intelligence, the creation of a digital twin is presented to improve the production processes. It is intended to reduce the grain sizes to approximately 5 μm in order to improve the quality and the performance of the final products. The data is fed to the digital twin by data collection from the manufacturing machines, simulations, laboratory investigations, and metallographic results.

In addition, a basis is created to be able to map other processes and industrial sectors. By creating multi-scale and cross-process simulations with industrial machining data using artificial intelligence, it is possible to increase the understanding of the entire process chain.

All process data is to be recorded and simulations are carried out to improve the process parameters so that defective parts can be reduced and detected earlier. Furthermore, the component quality and the energy efficiency of the process shall be

increased by process optimization. This will lead to improved competitiveness in economic, ecological, and technological terms, especially for small and medium enterprises.

Keywords: artificial intelligence, digital twin, heat treatment, Industry 4.0, saw blades, ultra-fine-grain steel.

1 Introduction

The saw industry uses various thicknesses and diameters for saw blades depending on the processed material. The starting material gets heat-treated to get the desired properties like strength and hardness. Saw blade bodies are cut from the material and are ground to achieve their final geometry within the tolerances. Due to many parameters, these processes are highly complex as well as resource and energy intensive. Improving the product quality leads to a better technological position as well as an economic and ecological advantage.

The properties of heat-treated cold working steel depend on the grain sizes on a microscopical scale. Smaller grain sizes lead to a better performance [1]. To change the martensitic grain sizes, already the austenite grain sizes have to be very small. Therefore, it is important to change the grain size in austenite to gain smaller grain sizes in martensite and in the final product, respectively.

Grains need a nucleus to form itself. Because of the cold rolling process, many dislocations are produced. As consequence, the diffusion paths are short and dislocation supported. Because of the high density, many crystal nuclei are available. Therefore, the austenitizing temperature can be lowered by up to 80 K to obtain smaller grain sizes. All in all, this is more resource efficient because of a better performing steel and more energy efficient due to lower temperature during the heat treatment.

After the heat treatment, saw blade bodies are cut into their final form. This releases internal stresses and leads to distortion of the component. To get the final geometrical shape, the blade is ground final. This process is highly sensitive, because of high temperatures, which might be induced to the component. This has a direct impact on the microstructure itself. Therefore, different materials have to be tested, to define the direct impact.

Using various thicknesses in starting material as well as different grinding materials generates many datasets. With these different datasets a digital twin is constructed with which the whole process of heat treatment and grinding is described and better parameters for the process are predicted to get a higher resource and energy efficiency as well as getting a deep understanding of the two linked processes.

2 Methods

In Industry 4.0 applications like a digital twin, it is important to gather as much data as possible. This is especially important in highly sensitive processes like the heat treatment to obtain ultra-fine-grain steel with grain sizes of less than 5 μm . Therefore,

the situation is analysed and current as well as historic data is collected. As material the typical saw blade steel 75Cr1 is defined and two different geometrical dimensions are selected. The processing line is analysed and on specific spots, additional sensors are applied in order to collect additional data (edge devices). The process parameters like e.g. the temperature of the metal are considered, so an overall better insight of the process is ensured.

To get a better overview of each state of the heat treatment, especially the temperature of the steel directly before quenching is observed. For producing grain sizes with less than 5 μm , the austenitizing temperature has to get lowered, so the overall energy efficiency is rising. With this austenitizing temperature, ultra-fine-grain martensite is produced to improve the performance of saw blades [1]. Here, the microstructure of the steel is produced, and the hardness is adjusted in the martensitic structure [2]. With all monitored data, machine learning methods like convolutional neural networks are trained.

For modelling the whole process chain of heat-treated cold working steel, grinding is essential. This is necessary because of thermal distortion induced by the cutting of the blades out of the plates. Special focus is on the surface, where heat is generated, and the microstructure might be changed. Analogous to the heat treatment, the current process is analysed, and all data is collected and processed. This is necessary to build the digital twin of the process chain. First, this process is analysed as single process without the heat treatment to get an insight. In a following step, both processes, the heat treatment and the grinding, are linked together to get a better overview in the process chain and all its dependencies between each other.

3 Results

Resulting from the applied methods, a data model for heat-treated cold working steels in the saw blade industry is created. With this model, machine learning algorithms are created to generate a digital twin of this specific process. In detail, an artificial intelligence is trained to get a better insight of the linked processes. More precisely, a direct correlation between the set austenitizing temperature and the grain sizes are investigated.

The model consists of four main pillars (cf. Figure 1). Data collection and edge devices, simulations, laboratory investigations, and metallography. Metallographic examinations are performed during the processes in order to analyse the quality and consider the microstructure of the metal. Simulations (finite element method) and laboratory investigations generate more data and strengthen the artificial intelligence. With all these generated and collected data, an artificial intelligence is trained to generate an accurate digital twin describing reality. The main goal of this is to get a deeper insight of the linked processes and an increased control of the manufacturing including improved machining parameters [3].

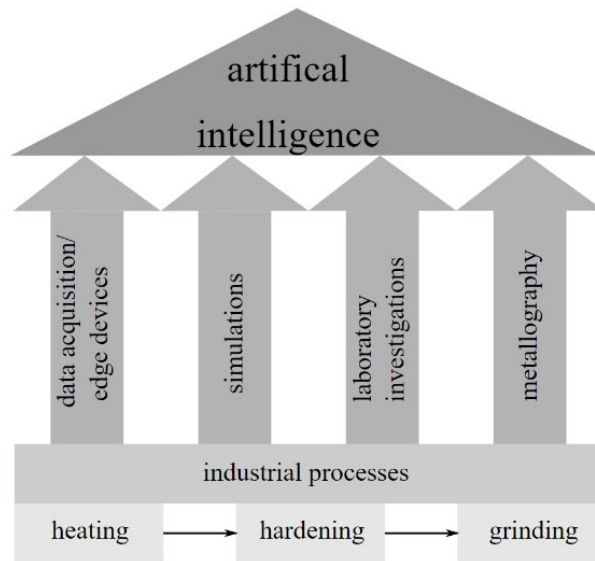


Figure 1: Structure of the artificial intelligence model

To complete the digital twin of the process chain, also the data of the grinding process is collected and added to the model. To generate more data, different grinding materials like cubic boron nitride and corundum are used to investigate differences on the surface structure between these materials. Special focus lays on the thermal and mechanical energy induced into the material, to research its influence on the new microstructure. At the end, the new saw blade bodies are investigated to find out how the new microstructure behaves under usage.

4 Conclusions and Contributions

The digital twin is optimized for the process in the saw blade industry. To test the data model, new parameters for the heat treatment shall be predicted. The goal is to lower the temperature by up to 80 K to obtain grain sizes, which are four times smaller than the current grains [4]. The change on the micro scale is shown in Figure 2. The current saw blades (left) got a grain size of around 20 μm , while the goal (right) is a grain size of less than 5 μm .

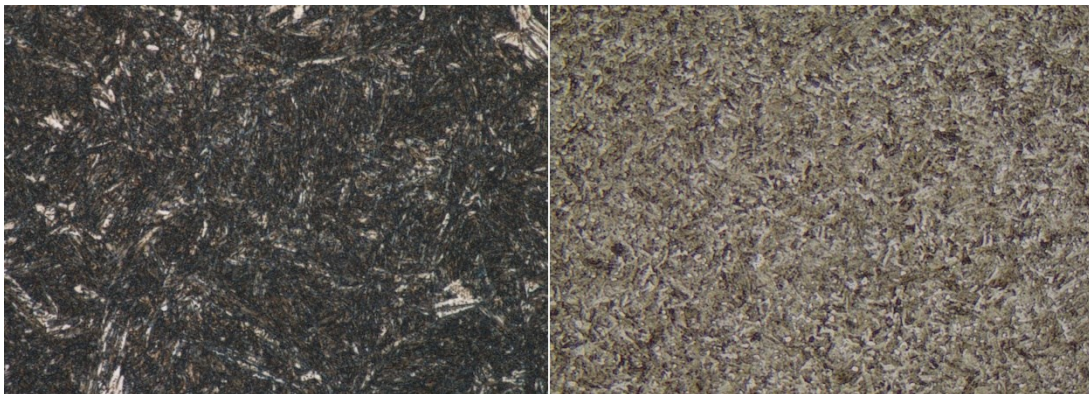


Figure 2: Comparison between the current (left) and the intended grain size (right)

With the change in microstructure, the overall hardness and resilience of the material is improved. To apply new techniques, similar processes like the heat treatment in combination with round grinding in ball bearings are analysed. There are many similarities as well as differences between these processes. The process chain is similar, while the materials as well as the final shape differ very much. Overall goal is to understand not only a single process, but the whole process chain, to get a better overall result, and an easier adoption for industry. With the same methods for the saw industry, the production of ball bearings is analysed. Based on the metal 100Cr6 simulations on macro, meso and micro scale as well as metallographic examinations are applied. With process parameters of the heat treatment, the data model is extended. After the heat treatment, the ball bearings are ground into its final shape. This underlines the overall transferability to other use cases, where similar procedures are applied [3].

With these applications of Industry 4.0, the overall efficiency of manufacturing is raised. Because of a higher quality material based on ultra-fine-grain steel and less materials rejections the resource efficiency is improved. Due to lower temperatures during the manufacturing process, the energy efficiency is changed, too. Therefore, the results are important to lower the ecological footprint and to achieve a technological advantage.

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