# QUANTITATIVE ANALYSIS OF TOOL WEAR IN DEEP HOLE DRILLING

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*Abstract: This paper presents an experimental procedure for the automatic detection and quantitative evaluation of surface wear on drills used in deep hole drilling processes. The analysis was based on images of the cutting edge captured by an industrial camera under controlled conditions, with a particular focus on the curved edge segment, which is especially prone to wear. A custom image processing algorithm was developed within the MATLAB programming environment, employing a multi-stage approach—preprocessing, surface condition classification, and distance analysis of worn zones from the curved edge—to calculate VB_mean as an indicator of wear severity. The algorithm successfully distinguishes between healthy regions, grinding marks, mechanical damage, and active wear, significantly reducing the risk of misinterpretation. Quantitative analysis performed on a dataset of 50 samples demonstrated repeatability of the results and potential for further industrial application. The observed wear patterns may serve as a basis for optimizing process parameters and implementing predictive maintenance strategies. The proposed methodology represents a step toward automated tool condition monitoring under demanding machining conditions, with the potential for integration into broader technical diagnostics systems.*

*Keywords: deep drilling, tool wear, image processing.*

## 1. INTRODUCTION

In modern manufacturing processes, deep hole drilling holds a significant place, particularly in industries with strict demands for precision, reliability, and surface quality—such as aerospace, energy, and precision engineering. The technologies used for this type of machining enable efficient material removal at considerable depths, but also subject the tool to substantial mechanical and thermal loads. During operation, the cutting edge of the drill is exposed to complex stress mechanisms—a combination of friction, elevated temperatures, and abrasion. As a result, cutting edge wear occurs, which directly affects process stability, surface quality, and the overall tool life. Recognizing and analysing these changes is essential for process optimization and timely tool replacement [1,2].

Most commonly in practice, wear monitoring is accomplished through visual observation or manual measurements, which, apart from being time-consuming, are also prone to

subjective interpretation. As even small deviations from the tool geometry can lead to significant errors in dimensional accuracy, surface roughness, and tolerance generation, it becomes obvious that the need is for an objective and precise quantitative evaluation method. Automation of the process enables the rapid analysis of a large number of samples and offers opportunities for integration in industrial monitoring systems [3-5].

In this study, we focused on the analysis of the surface condition of drills used in deep hole drilling processes based on images acquired by an industrial camera. Our target was the development of an experimental algorithm for automatic detection, and quantification of wear zones, with particular emphasis on calculating the parameter VB_mean—the average wear width along the curved cutting edge of the tool.ool.

The algorithm was designed to identify different types of surface changes—healthy regions, wear zones, grinding marks, and potential damage—using multi-channel binary segmentation. Additionally, we introduced a calibration feature based on a 1 mm reference marker, allowing the results to be expressed in real-world units rather than pixels. This enabled quantitative comparison across different samples and facilitated the interpretation of results in a practical context.

This approach not only contributes to a deeper understanding of wear processes under deep drilling conditions, but also paves the way for further improvement of tool condition monitoring methods in industrial environments.

## 2. MATERIALS AND METHODS

### 2.1 Experimental setup

For this experimental analysis, we examined drills that had been exposed to actual working conditions during industrial use. The machining was carried out on a TBT T30-2-500 horizontal deep hole drilling machine (TBT Tiefbohrtechnik GmbH+Co). Thanks to its high positioning accuracy, rigid construction, and efficient internal coolant system, this machine enables reliable execution of deep drilling processes (up to 500 mm depth) within a diameter range of 4 to 30 mm, at spindle speeds ranging from 550 to 6400 rpm, feed rates from 35 to 320 mm/min, and coolant pressures up to 80 bar.

The experimental setup involved horizontal fixation of the drill using a precision prism, with simultaneous image acquisition from two cameras: an industrial camera (48 MP FHD Camera V8, C-mount lens, optical zoom 8×–100×) equipped with side-mounted ring lighting, and a front-facing Vividia 2.0 MP handheld USB digital microscope. This configuration enabled high-resolution imaging of the curved cutting edges, providing sufficient detail for subsequent image processing and quantitative wear analysis (Fig.1).



**Figure 1.** Experimental setup for visual analysis of drill wear

This configuration enables simultaneous observation of both the lateral surface and the tool's tip (Fig. 2), providing comprehensive visual information about the condition of the cutting edge. The lighting system was optimized to eliminate shadows and reflections, while image acquisition was performed via a computer under controlled, vibration-free conditions.
All images were captured at a constant distance and fixed orientation of the camera

relative to the tool, using a stable laboratory platform.
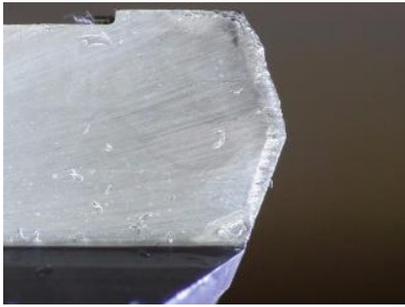


a)
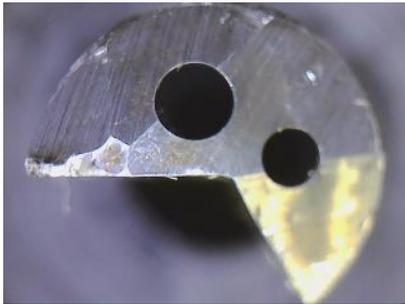


b)

**Figure 2.** Representative images of tool wear captured from two angles: (a) side view, (b) frontal view captured with a microscope camera

## 2.2 Algorithm for tool wear detection

A custom - developed algorithm, implemented in the MATLAB environment, was applied for image processing of the tool edges, enabling automatic detection and visual representation of wear [6,7]. The algorithm performs segmentation of the tool geometry, identification of worn areas, and calculation of the average wear width (VB_mean) along the curved cutting edge.

The algorithm structure is organized into three logical stages (Fig. 3):

1. The preprocessing phase includes importing the input image and preparing it for further analysis. The image is first converted to grayscale (Fig.4a), followed by local contrast enhancement using the CLAHE (Contrast Limited Adaptive Histogram Equalization) (Fig.4b) method with parameters: tile grid size 8×8 and clip limit 0.01. Gaussian filtering ($\sigma = 0.8$) is then applied to reduce noise. To enhance the visualization of surface texture, a so-

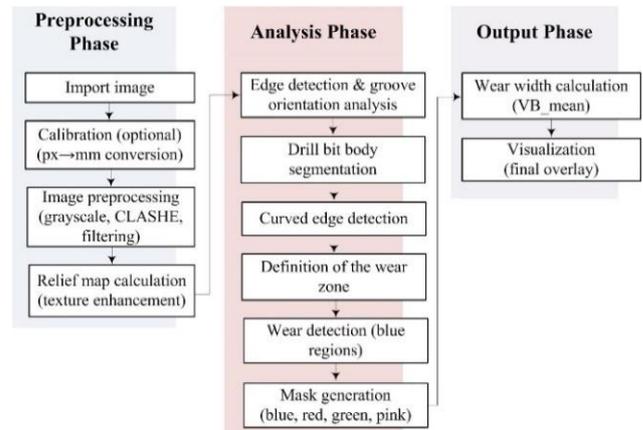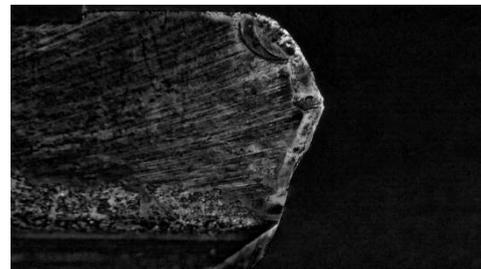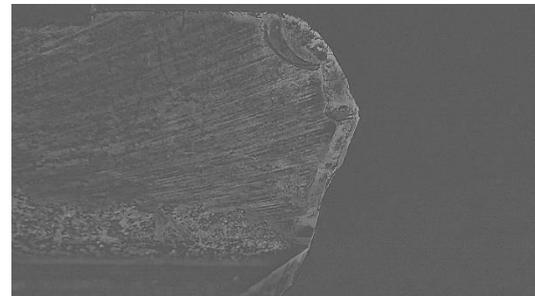called relief map is extracted based on local contrast variations;



**Figure 3.** Tool wear detection algorithm



a)



b)

**Figure 4.** Preprocessing phase: a) Grayscale image, and b) Local contrast enhancement

2. The analytical phase involves segmentation of the drill body and extraction of the curved edge on the frontal surface. Wear regions (blue zones) are identified using a robust threshold defined by the median and robust standard deviation ($k = 0.5$). Simultaneously, an analysis of groove orientation is performed to detect grinding marks (green regions) and mechanical damage that deviates from the dominant direction (red regions);

3. The results phase includes quantitative evaluation of wear. The VB_mean parameter is calculated as the median distance of the detected blue regions from the curved cutting edge. The result is presented as a colour map (Fig.5) allowing for intuitive visualization of the tool condition.

**Figure 5.** Drill condition map (pink - healthy surface, blue - wear, green - grinding marks, red - damage)

The analysis was conducted on a dataset of 50 images obtained under controlled laboratory conditions. The applied calibration, based on a 1 mm reference marker, enabled the conversion from pixels to millimetres and provided an approximate metric interpretation of the results.

## 3. RESULTS

The experimental algorithm was applied to a sample of 50 tool images with the aim of quantitatively and visually assessing tool wear. The key processing stages—preprocessing, surface classification, and extraction of relevant regions—were presented in the previous section (Fig. 4 and Fig. 5). Based on the extracted blue regions (identified as wear) and their distance from the curved edge, the average wear width (VB_mean) was calculated.

For the representative example, the average wear width was determined to be VB_mean = 90 px (approximately 109.51 px = 1 mm).

VB_mean is a simple yet effective quantitative parameter for defining the intensity of wear along the active cutting tool edge. Its use offers a handy opportunity for comparison of images regularly without actual

measurement, and it reduces subjective error significantly.

Additionally, the local distribution of the shown worn areas also testifies to local loading—dominant in this case in the upper right portion of the edge (Fig. 5). It is a result of faulty cutting conditions, tool geometry, or poor heat removal during the drilling process. The visual examination of the classified image also facilitates the identification of other potentially harmful features, including grinding marks (potentially indicating prior sharpening) and localized damage (also in need of analysis). Through this, the output from the algorithm contributes to further knowledge about the condition of the tool, enabling not only evaluation of current wear but also potential classification of samples by level of degradation.

## 4. DISCUSSION AND CONCLUSION

The obtained results demonstrate that the developed algorithm effectively detected and quantified surface wear on the tool. Metrics such as VB_mean enabled objective comparison between samples, confirming the applicability of the method in the context of automated tool condition analysis. In the representative example (Fig. 5), a tendency toward localized wear was observed in the upper right area of the curved edge. Although currently illustrative, this pattern may indicate an asymmetric distribution of load and thermal flow during the machining process. Such wear patterns are consistent with known wear mechanisms in deep hole drilling, particularly when working with difficult-to-machine materials under pronounced thermomechanical stress [1,5,8].

While this study focuses on image-based analysis of tool wear under controlled laboratory conditions, these findings are complementary to existing industrial approaches, where real-time process data and machine learning models have been employed to predict tool wear during CFRP drilling [8]. Integrating image-based

diagnostics with in-process monitoring can provide a comprehensive framework for predictive maintenance in drilling operations. Building on advances in Python-based image analysis for drilling damage assessment [7], the proposed algorithm extends these capabilities by automatically distinguishing between different types of surface changes — wear, grinding marks, and damage — which significantly improves diagnostic accuracy. This prevents misinterpretation of traces from previous interventions (e.g., sharpening) as active wear, thereby increasing the reliability of tool condition evaluation. Such capability is particularly valuable in the context of ongoing research on optimizing drilling methods and tool design, where accurate surface characterization is essential for understanding wear mechanisms and improving process performance.

Compared to conventional inspection methods (visual assessment, manual measurements), the digital approach offers a higher degree of repeatability, eliminates subjective error, and enables potential integration into predictive maintenance systems. Particularly noteworthy are the results related to the precise detection of the VB_mean line, which not only quantifies the degree of wear but can also serve as an input parameter for predictive models of the tool's remaining useful life [7,8].

In conclusion, this study presents the development of an experimental procedure for visual and quantitative evaluation of drill wear in deep hole drilling, based on industrial camera imaging and image processing techniques. The algorithm enabled automatic identification of wear zones along the curved cutting edge and calculation of VB_mean as a relevant wear parameter. This approach provides reliable wear mapping and contributes to a deeper understanding of tool behaviour during operation.

Future research will focus on analysing a larger number of samples, correlating results with operational parameters, and integrating the method into predictive maintenance systems under real industrial conditions.

## ACKNOWLEDGEMENT

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