Determination of the Rotational Direction of an Angle Grinder Based on the Tool Marks

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ABSTRACT

In a case of a fatal accident in a chemical plant the rotational direction of the involved angle grinder's wheel needed to be determined. This article describes the criteria used to answer this question based on the tool marks.

Introduction

An explosion that included four casualties occurred in a chemical plant. During maintenance work on a pipeline, an angle grinder was used to cut into the pipeline. Unfortunately, the cut was made into the wrong pipeline, which contained flammable gas.

For the reconstruction of the accident, the prosecutors' office wanted to know the position of the worker relative to the pipeline while making the cut. The Marks Department of the Bundeskriminalamt was asked if the rotational direction of the grinding wheel could be determined by the tool marks to answer the submitted request.

Figure 1 is a picture of the cut. The ends of the cut were named here with the letters "A" and "B".

Criteria for the determination of the rotational direction

A request of this type was new territory for this author. A literature search was conducted; however, nothing relevant to the determination of rotational direction was found. Research was conducted to establish the criteria needed to make such a determination. The results of this research are contained within this paper. Valuable general information about the grinding process ithe individuality of the grinding marks was found in references 1 and 2.

Test cuts in steel samples were produced using different grinding wheel cutting machines with known rotational directions. The test cuts were examined by a light microscope and a scanning electron microscope (SEM).

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In this examination, four criteria that correlate with the rotational direction were found:

-Agglomerations of material (probably abrasion dust from the grinding wheel) on the end of the cut where the grinding wheel entered the workpiece (**Figure 2**)

Figure 1: The cut in the pipeline with notations of its ends

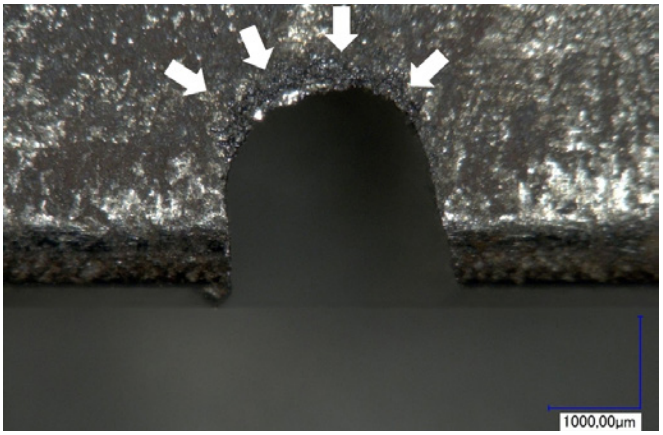

Figure 2: Insertion side of a test cut (rotational direction is away from the observer). The arrows highlight dark agglomerations

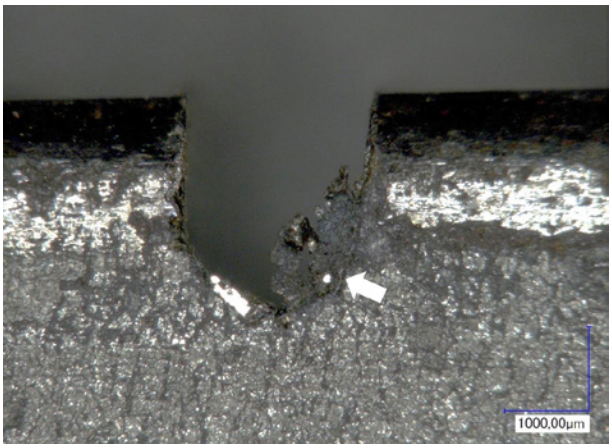

Figure 3: Test cut where grinding wheel left the workpiece (rotational direction is toward the observer). The arrow highlights the ridge

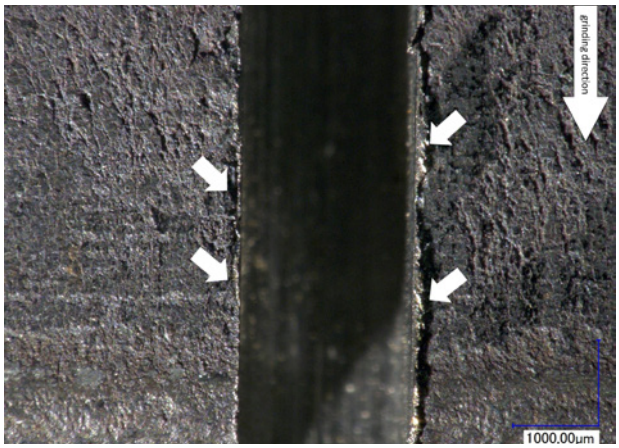

Figure 4: Edges of a test cut (rotation direction is downward). The arrows highlight some chips with a preferred orientation

-Ridges on the end of the cut where the grinding wheel left the workpiece (**Figure 3**)

-Orientation of chips on the edges of the cut (**Figures 4, 5 and 6**)

-Direction of cracks between chips and work piece on the ground of the cut (**Figures 7 and 8**)

The following pictures show examples of the mentioned characteristics. **Figures 2 through 6** were made using a light microscope (Keyence VHX 1000) and **Figures 7 and 8** were made by a scanning electron microscope (Zeiss EVO 60). Some features can only be detected by using the scanning electron microscope. They are not visible using light microscopy.

The orientation of the chips, shown in **Figures 4 and 5** is not always clear. In the test cuts, the majority of the chips had the same orientation relative to the grinding direction, but chips with opposite orientation were observed as well. The side of the cut on which the grinding wheel left the work piece, contained the majority of chips and they mainly showed the displayed orientation. But on the other side of the cut – the side where the grinding wheel moved into the work piece - there were chips with opposite orientation, but to a smaller extent (**Figure 6**). Because of this observation, this single criterion in determining the rotational direction should be used with caution.

By light microscopy it was not possible to gain an image of the bottom surface of the cut with sufficient resolution to identify the details visible in the SEM pictures. **Figure 9** is an example of a light microscopic image of the bottom surface

Figure 5: Chip on edge of test cut (rotational direction is downward). Grinding marks are visible. The line highlights the orientation of the chip and the grinding marks

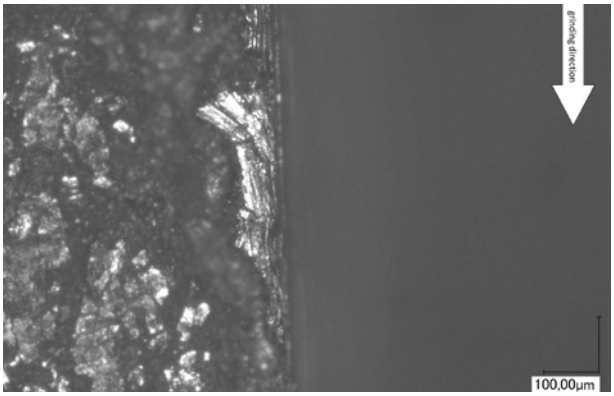

Figure 6: Edge of a test cut (rotation is downward). Grinding marks are visible on the chip in the center. The orientation of the chip is opposite to the one in Figure 5, despite the same grinding direction

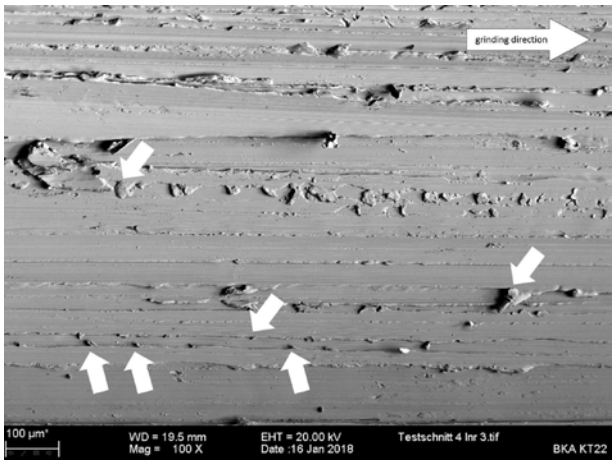

Figure 7: Bottom surface of a test cut (rotational direction left to right). Some chips which have been raised, but not totally separated from the workpiece, are highlighted with arrows. The cracks between the chips and the workpiece roughly point along the rotational direction of the grinding wheel

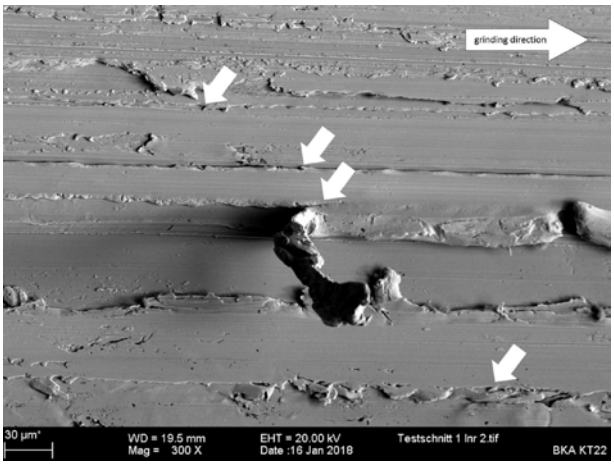

Figure 8: Bottom surface of a test cut at higher magnification (rotation direction left to right). The arrows highlight chips raised, but not totally separated from, the workpiece. Cracks between the chips and workpiece roughly point along the rotational direction of the grinding wheel, as does the large chip

of a test cut. Casting with silicone rubber did not improve the visibility. Please note that the magnification of **Figure 9** is higher than of **Figure 7**.

The four criteria are summarized in **Figure 10**.

Blind test

A blind test was conducted to ascertain if the observed criteria were reliable in determining the rotational direction of the grinding wheel. For this purpose, a person - not involved in the examination - prepared a steel sample with ten cuts. The cuts were made by means of an angle grinder and the rotational direction of the cuts was set randomly for each of the ten cuts. This author then examined the cuts, with both light microscopy and SEM, and determined the rotational direction based on the described criteria.

The results were compared with the known, true rotational directions. In all 10 cases, the direction was correctly determined.

In some cases, not all of the mentioned criteria were present to the same extent. The quality of the criteria changed throughout the samples, especially the features visible by light microscopy. If all criteria were observed together, the observations would lead to the correct result.

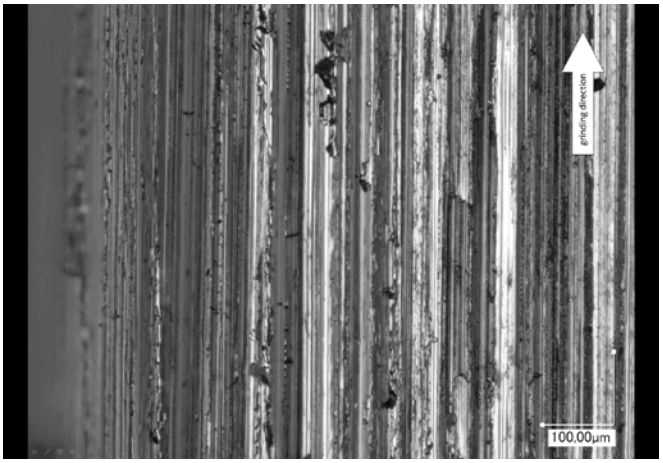

Figure 9: Photomicrograph taken with light microscope of the bottom surface of a test cut (rotational direction of the grinding wheel: upward)

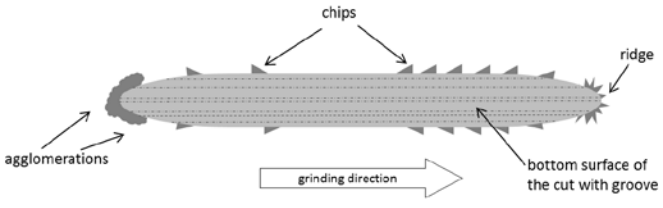

Figure 10: Schematic diagram of a cut with the described features

Results of the case

The cut in the pipeline was initially examined with a light microscope without damaging the item. **Figures 11 and 12** are the results of that examinations.

To verify the observations, the part of the pipeline with the cut was separated to enable a SEM examination. Afterwards the bottom surface of the cut was examined using the SEM. The results are presented in **Figures 13 and 14**. The results of the SEM examination were that the grinding wheel rotated from "A" to "B".

The conclusion in the case report stated: "The features found by the light microscopic and scanning electron microscopic examination (ridges, orientation of chips, agglomerations, cracks between chips and workpiece) consistently indicate that the surface of the grinding wheel, which had direct contact with the workpiece, moved in the direction from A to B".

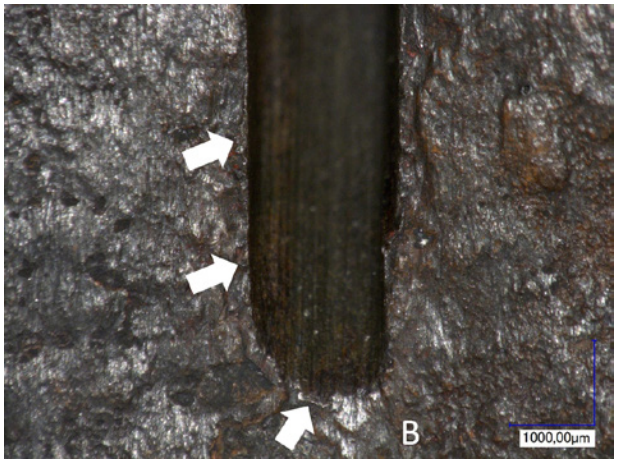

Figure 11: "B" end of the cut in the pipeline. The arrows indicate some small chips on the edges and a ridge at the end of the cut. Both criteria imply that the grinding wheel rotated from "A" to "B"

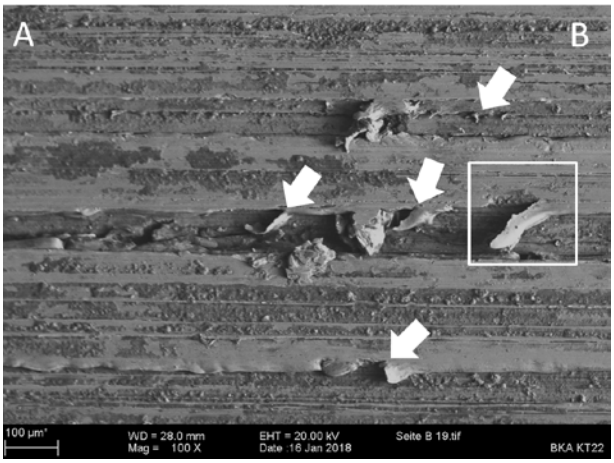

Figure 13: Bottom surface of the cut in the pipeline. The arrows indicate some chips and the cracks between them and the workpiece. In the white frame is a chip and the fracture surface from which the chip was separated and bent into the grinding direction

Figure 12: "A" end of the cut in the pipeline. The arrows indicate dark agglomerations that imply that the grinding wheel rotated from "A" to "B"

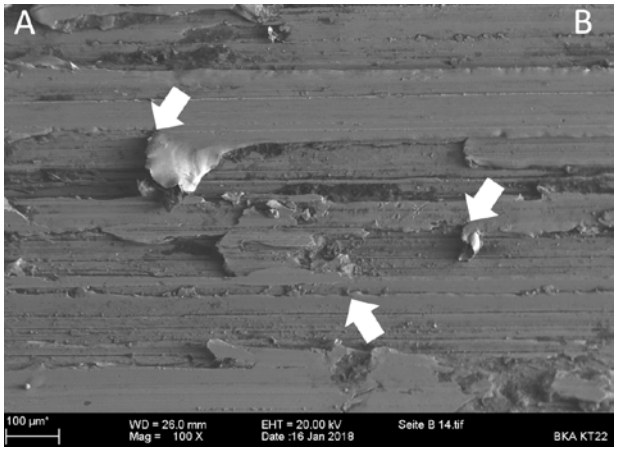

Figure 14: Bottom surface of the cut in the pipeline. The arrows indicate some chips and the cracks between them and the workpiece

References

[1] Monturo, C., "The Effect of the Machining Process as it Relates to Toolmarks on Surfaces," AFTE Journal, Vol. 42, No. 3, 2010, pp. 264-266.
[2] Monturo, C., "The Mechanics of the Grinding Process," AFTE Journal, Vol. 42, No. 3, 2010, pp. 267-270.