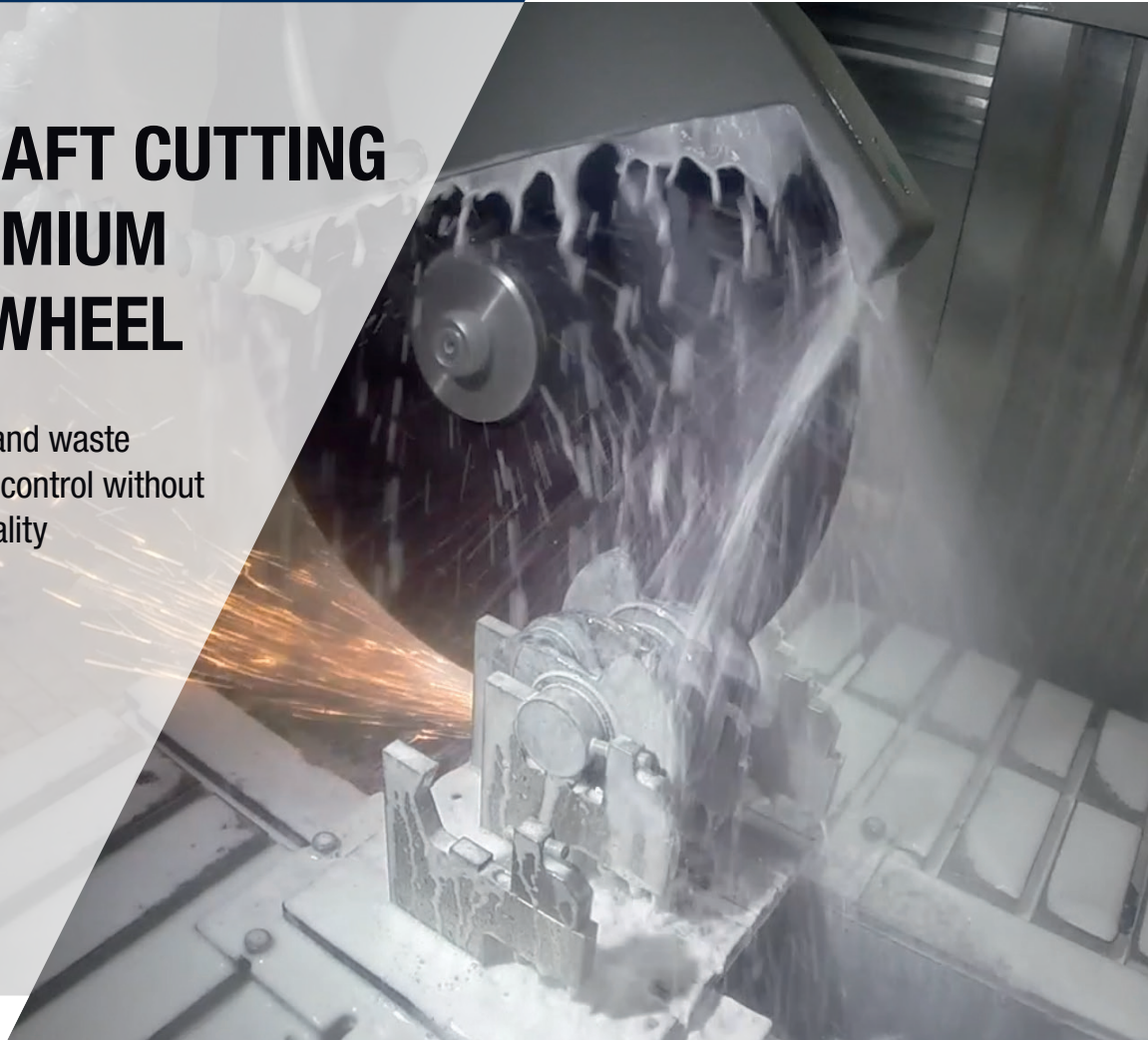


CRANKSHAFT CUTTING WITH PREMIUM CUT-OFF WHEEL

How to reduce time and waste
in crankshaft quality control without
compromising on quality



SOLUTION REPORT

PREFACE

Materialographic cutting is a multi-physical discipline with numerous parameters that need to be observed. This solution report goes through some of the most important parameters for materialographic cutting of a surface-hardened crankshaft. These are:

- Cut quality
- Accuracy
- Time study
- Wheel wear



Figure 1: Crankshaft in the customized clamp during cutting.

CUTTING RESULTS: CUT QUALITY

Materialographic cutting, as opposed to conventional sectioning such as sawing or parting, requires that the effect of the cutting process on the material is minimized. The sample must reflect the true structure of the material. If this is not the case, the other parameters (accuracy, speed and wheel-wear) are unimportant. Therefore, cut quality will be the first parameter we look at.

In many cases, the quality of the cut is acceptable if the cut surface is untainted, smooth and without homogeneous scratches or burrs. The inevitable mechanical or thermal damage from cutting is eliminated most effectively by a short plane grinding process that removes material with the affected microstructure.

When studying wheel wear, cutting accuracy and lead time simultaneously, it is important to have a

quantitative parameter for the quality of a cut. In this study, cutting quality is defined by the damage caused to the hardened surface by the heat generated during cutting. The quantitative measure is the loss in hardness to the hardened outer zone, measured directly on the raw cut surfaces. Two parameters are analyzed in this regard: feed speed and different types of cut-off wheels.

Reference measurements are made on the sample at the point where the cut-off wheel enters and heat deformation is presumed to be zero. Heat deformation is measured at three positions along the lower left edge of the sample (at 20°, 45° and 70° from the feed speed (FS) direction, see figure 2), where deformation is typically largest. Hardness measurements taken at the three positions are averaged to a single hardness measurement for each cut.

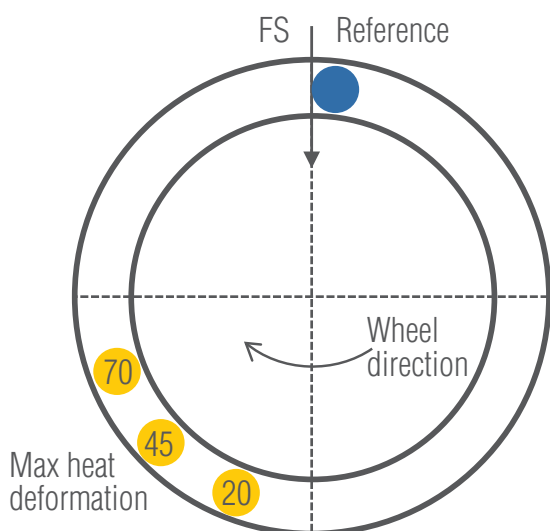


Figure 2: Measuring positions on the surface of the hardened sample.

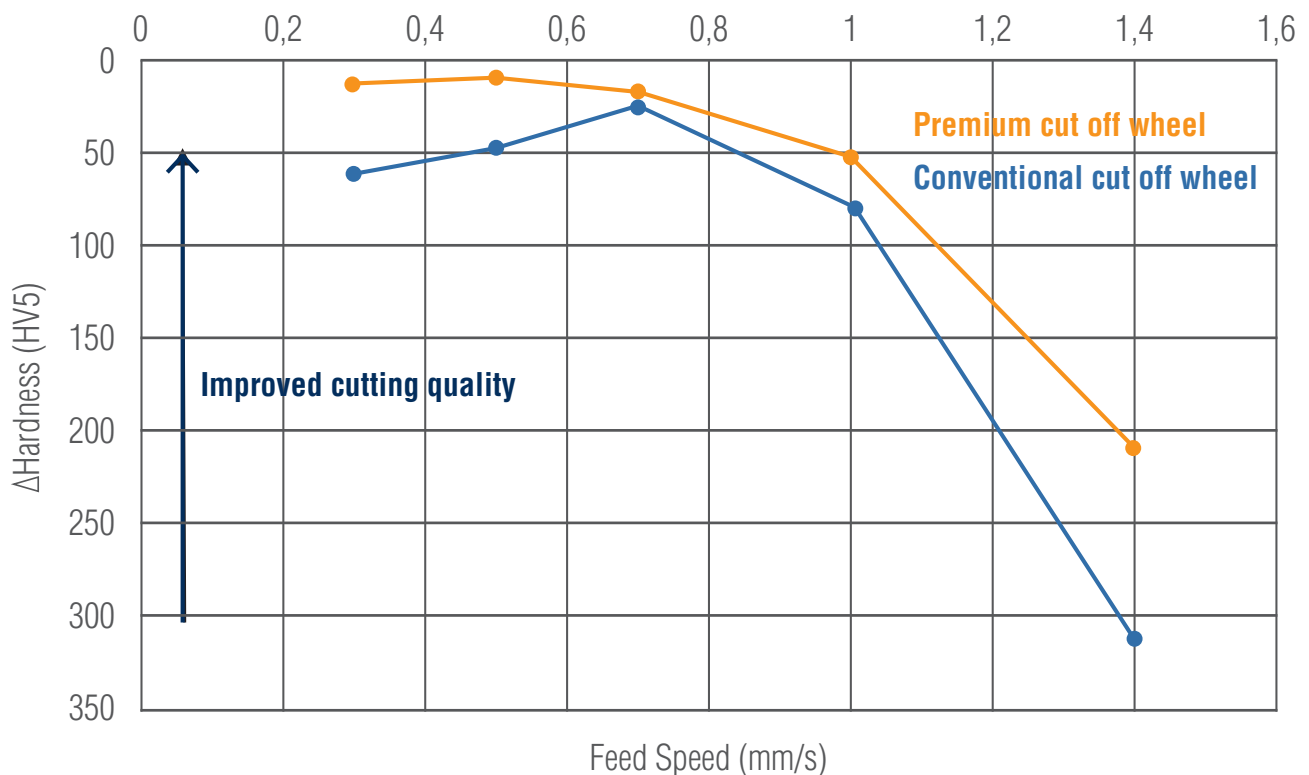


Figure 3: Measured hardness loss as a function of feed speed for the two wheel types.

The hardness loss measurements in figure 3 show that cutting quality is affected by both the choice of cut-off wheel and feed speed. A low level of damage (a high quality cut) can be achieved by selecting a cut-off wheel with a combination of abrasives, bond and wheel dimensions suitable for the given material, sample size and geometry. In general, the thinnest possible cut-off wheel is preferred, as a small contact area between the material and the wheel has a limiting effect on the heat input into the material.

The feed speed should be controlled for good cutting quality, which in this case is performed by an automated cut-off machine. In manual cutting, this can only be achieved by a very skilled operator.

For obvious reasons, cooling is crucial for the study of heat input during metallographic cutting. This parameter is removed from this case and kept constant for all tests.

CUTTING RESULTS: ACCURACY

Effective metallographic cutting aims for precision in terms of 1) proximity to the point of interest, so no additional material removal is necessary; 2) dimensional compliance, which means, for example, that the plane parallelism is adequate for the next preparation or inspection step and is similar for all samples.

For a large and complex component, such as a crankshaft, the accuracy of the cutting process is largely defined by the ability to repeatedly align the sample with the cut-off wheel, in combination with the cut-off wheel's resistance to deflection during the cutting process. In this case, a clamp customized for the crankshaft is fixed to the XY table in order to ensure a well-defined starting point for each of the cuts

in the cutting sequence (see figures 4A and 4B).

A cut-off machine with a multi-cut function and stroke length suitable for a cutting sequence of 9 cuts within 170 mm will enable an accurate cut (see figure 5).

Obviously, an XY table that can accommodate a 420 mm long component is a prerequisite, and in this case a Struers Magnutom is used (see figure 6).

The thickness of the cut-off wheel is a parameter used to calculate the X positions required for programming the cutting sequence. Assuming all other parameters remain the same, a thin wheel decreases variations in the sample's thickness due to the smaller volume of material removed and the easier positioning of the cut-off wheel. A standard 432 mm cut-off wheel is 3 mm thick, while a Premium cut-off wheel is only 2.7 mm (see figure 7).

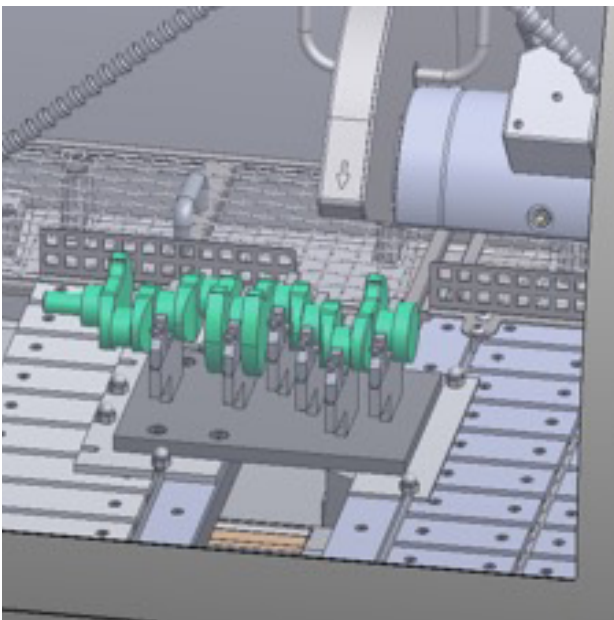


Figure 4A: Set-up for cutting sequence 1-9 in the Magnutom-500.

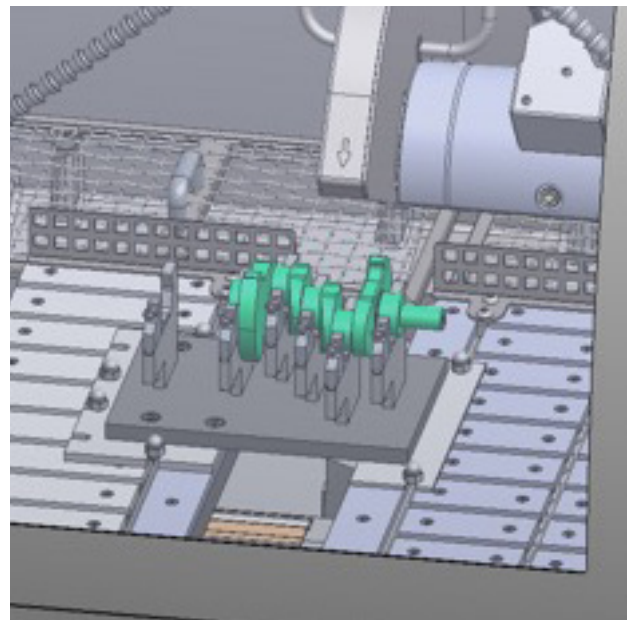


Figure 4B: Set-up for cutting sequence 10-18 in the Magnutom-500.

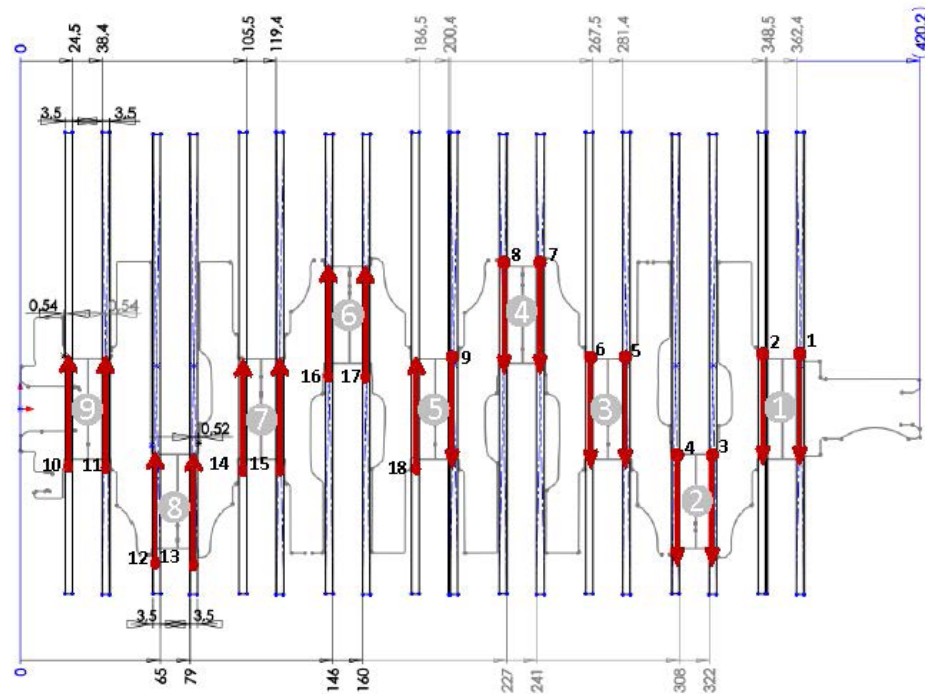


Figure 5: Illustration of the crankshaft with sample numbers 1-9 and cutting sequence 1-18, with 14-15 mm samples with a total length of 420 mm.

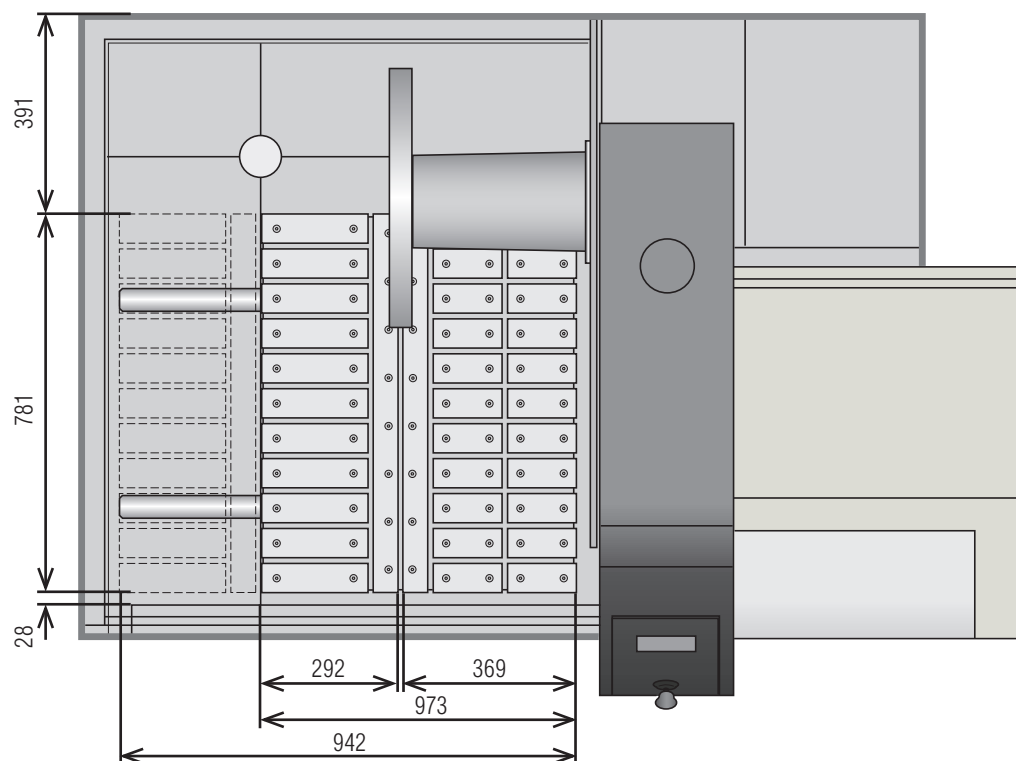


Figure 6: XY table dimensions on the Magnutom-500. It accommodates a 420 mm component and has a stroke sufficient for 2 x 9 cut sequences.

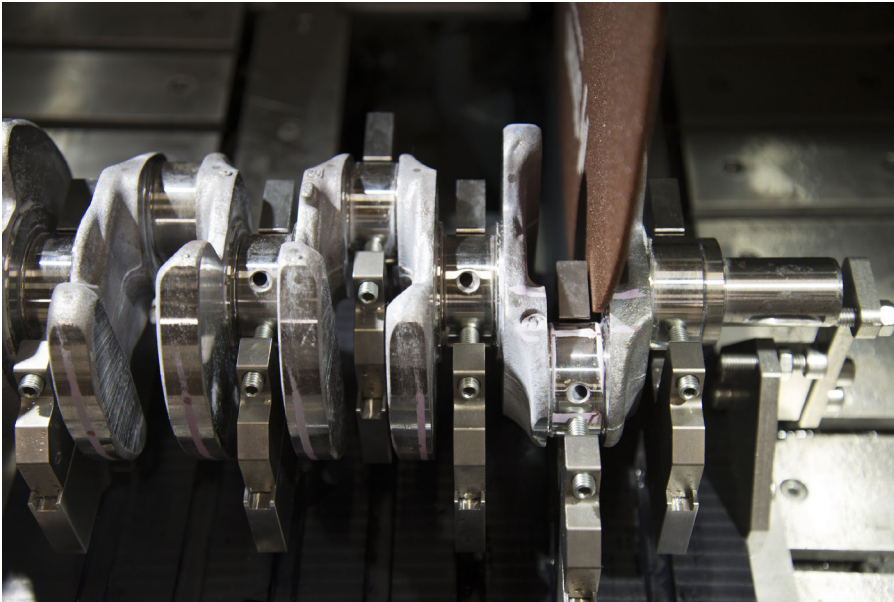


Figure 7: A conventional 432 x 3 mm cut-off wheel permits only very limited inaccuracy on the X axis. The Premium cut-off wheel has a thickness of 2.7 mm.

Figure 8 shows the final cut samples in the clamp. The output of the cutting process is 9 plane samples with low sub-surface damage and a thickness within the defined range of 14-15 mm.

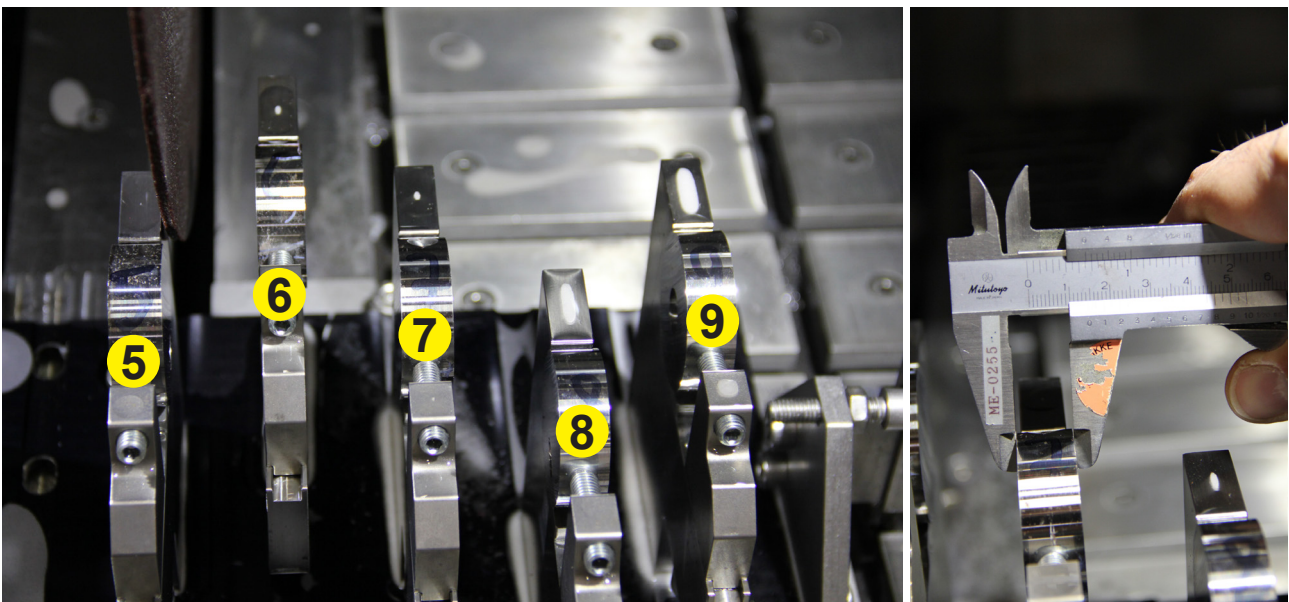


Figure 8: Image of samples 5-9 after the cutting process, showing how the samples are fixed to enable accurate cuts. The smaller image shows dimensional control with a caliper.

CUTTING RESULTS: TIME STUDY

For a mass produced component, in this case a car component, the duration of the quality control process is closely monitored. Since lead-time and time wasted in production often heavily affect the time taken for quality control, time optimization is also a feature of materialographic cutting.

Due to the complex geometry of a crankshaft, the positioning, clamping and cutting process, in this case of 9 bearing discs samples, often involves several hours of manual work at the cutting machine. Manual clamping is eliminated by the clamp, and manual positioning after each cut is eliminated by the automated cut-off equipment. In a cutting process designed for accuracy and the quality of the materialographic cut, time can often be optimized by balancing the feed speed and by including cut-off wheel consumption in the positioning parameters. A feed speed of 0.5 mm is used in the times given below.

Set-up of crankshaft in Magnutom: 1 x 3 min

Each of the 18 cuts takes: 18 x 2m30sec*

'Extra cutting distance' to allow cut-off wheel wear: 18 x 30 sec*

Positioning of cut-off wheel, from end of the previous cut to start of next cut 18 x 20 sec*

Removal of samples 1-4 and repositioning of the shaft in the clamp: 1 x 3 min

Total time for all cutting, clamping and re-clamping: 66 minutes

Times marked * can be reduced if cut-off wheel wear is small and/or well defined. This should be the case in a high quality materialographic cutting process.

As indicated by figure 9, both the starting point and the distance moved in cutting direction Y are affected by wear to the cut-off wheel. Low wear will decrease the time spent 'cutting in the air'; well-defined wear will enable the compensated Y start positions and the Y moving distance per cut to be inserted in the cut-off machine's software.

As an example, a 432 mm cut-off wheel cutting at 0.5 mm/s that is worn halfway will start an automated cutting operation >2 min before entering the sample if not compensated.

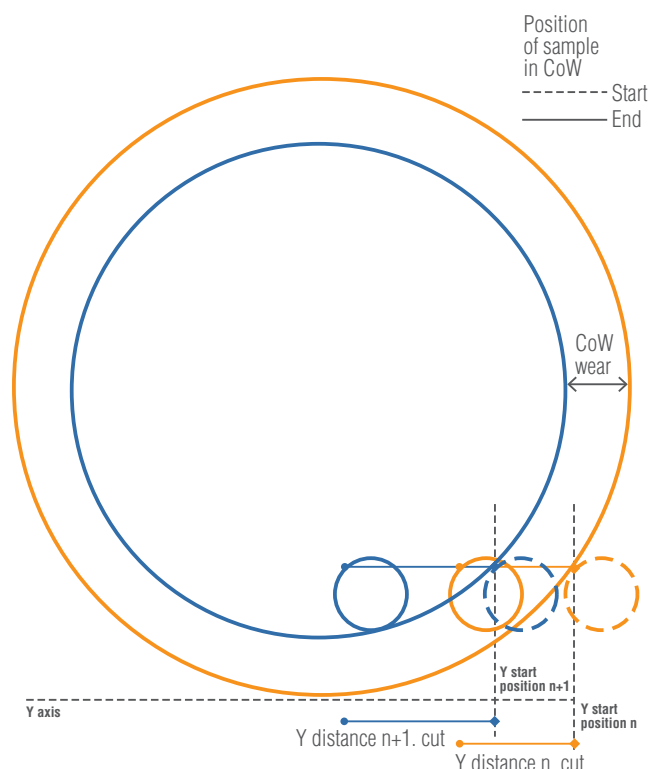


Figure 9: An illustration of the effect on cut-off wheel wear on start positions in the Y direction as well as the distance moved from the start to the end of a cut.

CUTTING RESULTS: WHEEL WEAR

In abrasive wet cutting, wheel wear is intentional, since the release of used and blunt abrasives reveals new fresh abrasives ready to cut the next volume of material. On the other hand, wear is associated with the consumption of products and time wasted in replacing worn wheels – and saving time on quality control operations is valuable.

With the above in mind, optimizing cut-off wheel performance is linked to 1) the wear characteristics defined in the wheel's development and construction; 2) the alignment of the wear profile to actual cutting sequences in order to plan for wheel replacement.

Wear characteristics for materialographic cut-off wheels are expressed by the G-value, which is the ratio between the material removed and cut-off wheel wear during cutting. The G-value is specific for each case, defined by a sample's material and geometry, as well as parameters such as clamping, feed speed and cooling.

In this case, two cut-off wheels with different wear characteristics are compared: a conventional materialographic cut-off wheel for surface-hardened

materials; and a Premium cut-off wheel with optimized features such as a higher operational feed speed range, and better quality and cut accuracy due to optimized composition, surface pattern and wheel thickness.

The G-value for the two types of cut-off-wheels is determined from a large number of cuts, where the cut-off wheel diameter is measured between cuts. In this case, the Premium cut-off wheel has a G-value of 3 compared to the conventional cut-off wheel with a G-value of 1.

A simple calculation for this crankshaft cutting set-up indicates an increase in the number of crankshafts cut with one cut-off wheel, from 3.5 to 11.5 by using the Premium cut-off wheel.

The additional yield effect from the high G-value is linked to the fact that replacing the cut-off wheel during a cutting sequence is not desirable. Therefore, the number of cuts before replacement has to be a multiple of nine (this allows cut-off wheel replacement to occur between cuts 9 and 10 when the sample is re-clamped).

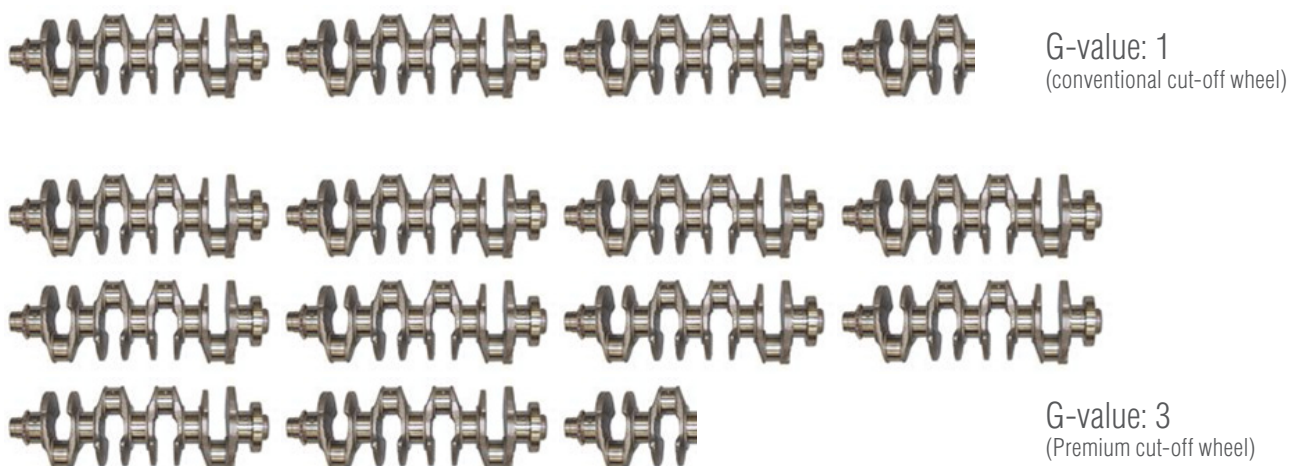


Figure 10: Illustration of the number of crankshafts cut with one cut-off wheel.

For this optimized cutting process of 18 cuts in 66 minutes, the time spent replacing cut-off wheels is negligible. For shorter cutting sequences, replacing the cut-off wheel after each sequence can be a substantial time waste.

Another type of waste is the fraction of a cut-off wheel that is insufficient for a complete cutting sequence and is therefore scrapped to avoid replacing the cut-off

wheel during an automated cutting sequence. For a low G-value cut-off wheel, this fraction will be larger compared to a high G-value cut-off wheel, especially in the case of a longer cutting sequence.

In the case described here, the scrapping ratio increase to 15% for a low G-value cut-off wheel, but is only 5% for a Premium cut-off wheel.

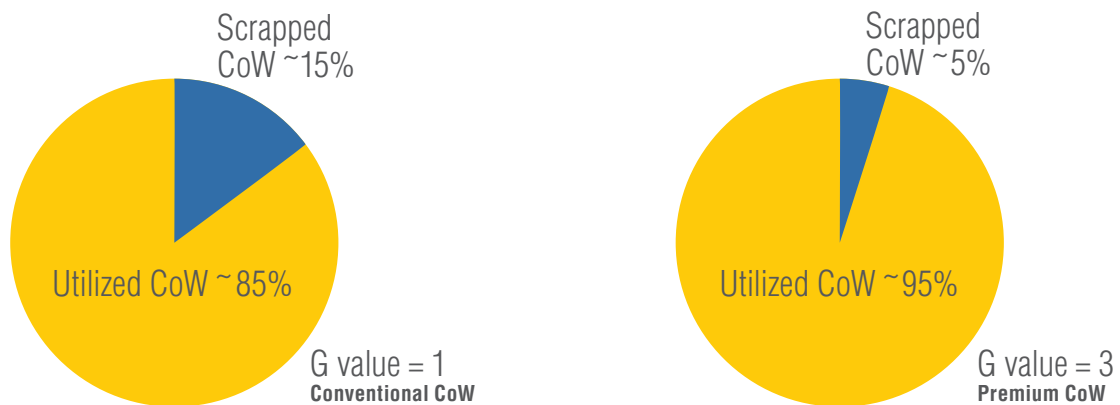


Figure 11: Difference in utilized and scrapped cut-off wheel between a Premium cut-off wheel and conventional cut-off wheel.

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