HERZOG

Evaluation of sample cavities by analyzing the torque curve of the milling spindle

Abstract

Cavities on the milled surface of steel and iron sample have detrimental impact on spectroscopic analysis. Therefore, vision systems are used in automatic laboratory systems to detect cavities. Here, we show that torque of the milling spindle can also be used for highly precise determination of cavity length and position.

Key words

• **Torque curve**• **Cavities** • **Milling** • **Steel** • **Sample preparation**

Introduction

Steel and iron samples for optical emission (OES) or X-ray fluorescence (XRF) spectroscopy may show cavities. Usually, cavities form immediately after taking the sample from the hot melt. While flowing into the probe the liquid metal already starts to solidify at the outer wall of the mold. When the mold is almost completely filled the liquid metal cools down continuously from the outer wall to the sample center. The cooling process causes a decrease of the metal volume and leads to a metal stream from the sample center to the edge. If the material is not replaced cavities may remain in the solidified sample.

After milling, cavities can potentially get contact to the sample surface and leads to unusable OES or XRF results.

Therefore, cavity detection is a pivotal step in automated QC laboratories. Usually, surface inspection is done by automated vision systems before performing the spectroscopic analysis. Here, we show that sample cavities can be quickly and accurately detected using KPIs from the milling machine.

Methods

We used the HERZOG machine model HS-F1000 for milling of 1351 production samples from a German steel plant. The samples were of various hardness. We used a milling head with four cutting items (Sandvik Coromant R200-068Q27- 12L). Milling parameters were kept constant with spindle speed of 1000/min, milling depth of 8/10 mm, and milling head advance of 800 mm/min. After each milling operation, the surface of the sample was visually inspected for cavities (defined as discontinuity of the surface larger than 2 mm). We identified cavities in 98 milling operations.

In case we found a cavity we took a photograph. Within the photograph, we measured the start and end point of the cavity in relation to the outer sample edge (defined as entry point of the milling head). Furthermore, we evaluated the maximal cavity length in the milling direction (Figure 1).

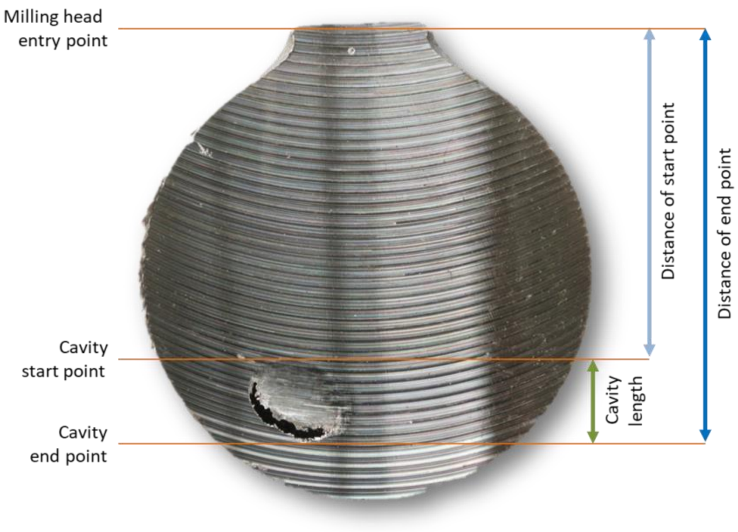

Figure 1: *Photographic evaluation of a milled QC sample containing a cavity. We measured the distance from the milling head entry point to the start and end point of the cavity. Furthermore, we determined the cavity length as the difference between the start and the end point.*

Simultaneously, the TCM module of the HERZOG PrepMaster Analytics software was applied to record the spindle motor torque during each milling operation. All torque curves were automatically normalized. The start and end position as well as length of the cavity were calculated based on torque values (Figure 2) and slope of each milling curve (Figure 3). For statistical analysis, we performed a student's t-test and computed the coefficient of determination for values based on photographic evaluation and values calculated from the torque curve.

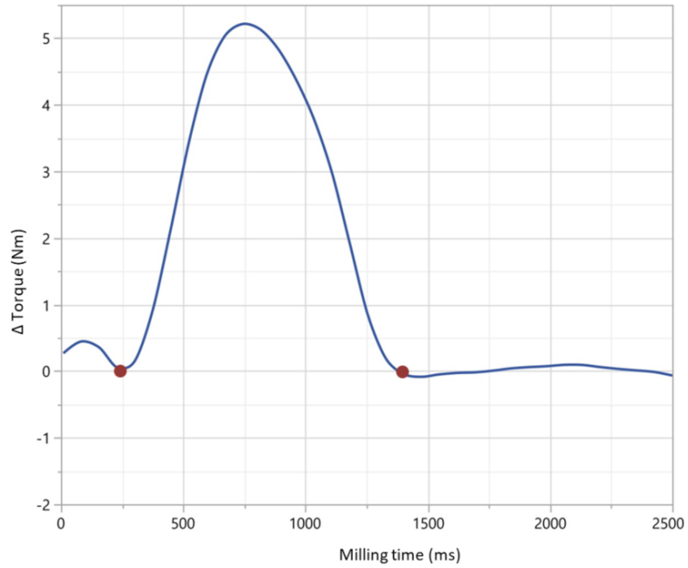

Figure 2: *Evaluation of cavity length and position using Δ torque values. Based on the feed speed the time values are converted into position values.*

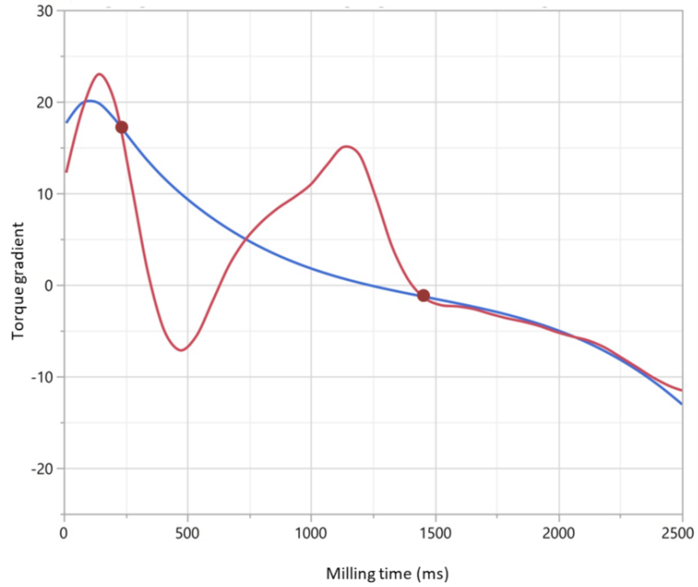

Figure 3: *Additionally we used slope of the torque curve for cavity characterization.*

Results

This study demonstrates a high consistency between photographic measurement and torque evaluation of cavity localization and length. Even small cavities in the range of 2 mm could be clearly detected by using spindle torque (Figure 4B).

In general, it can be challenging for automatic vision systems to detect cavities being shallow or covered by a thin metal layer. However, even these cavities were identified by torque curve analysis without any problems (Figure 4C). Also, torque analysis is capable of identifying two or more cavities in one sample.

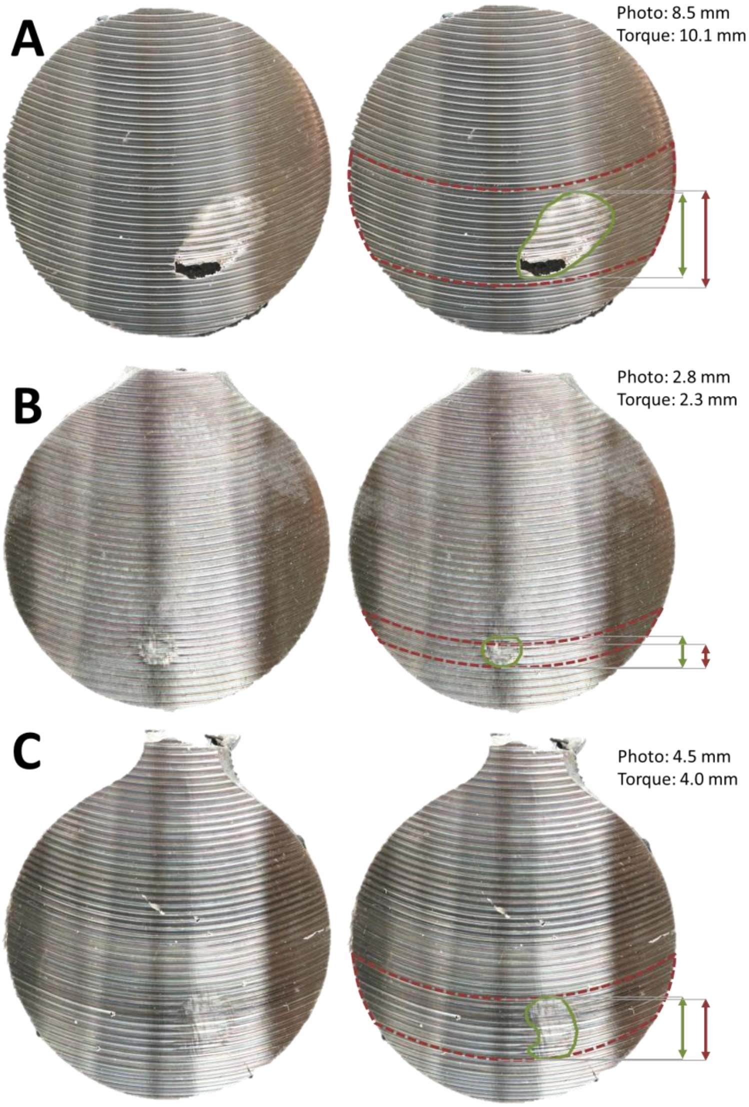

Figure 4: *Examples of samples with cavities evaluated by photographic means (green) or torque analysis (red). The values in the upper right corner show the cavity length of photographic and torque evaluation, respectively. The distance values for start and endpoint of the cavity calculated by torque analysis are projected onto the sample surface (dotted red line).*

The mean value for cavity length was 7.2 ± 3.1 mm (± standard deviation) based on photographic measurement and 7.9 ± 3.2 mm based on torque evaluation. The difference was not significant (student's t-test). Also start and end point of cavities referenced to the entry point of the milling spindle showed no significant difference (23.0 ± 5.4 mm and 30.2 ± 4.6 mm for photographic, 24.2 ± 5.5 mm and 32.0 ± 4.8 mm for torque evaluation).

Correlation analysis showed significant dependence between all three variables with an R squared of 0.932 for cavity length (Figure 5), 0.980 for distance of the start point (Figure 6) and 0.977 for distance of the end point (Figure 7).

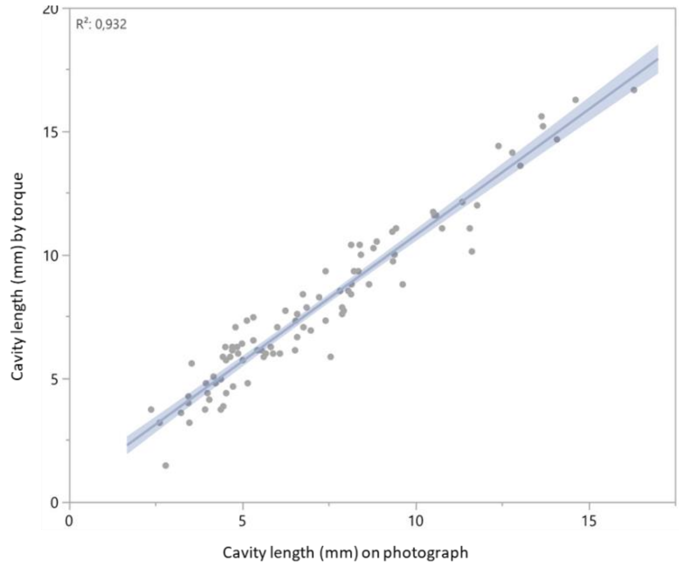

Figure 5: *Correlation graph for cavity length determined by photographic and torque evaluation*

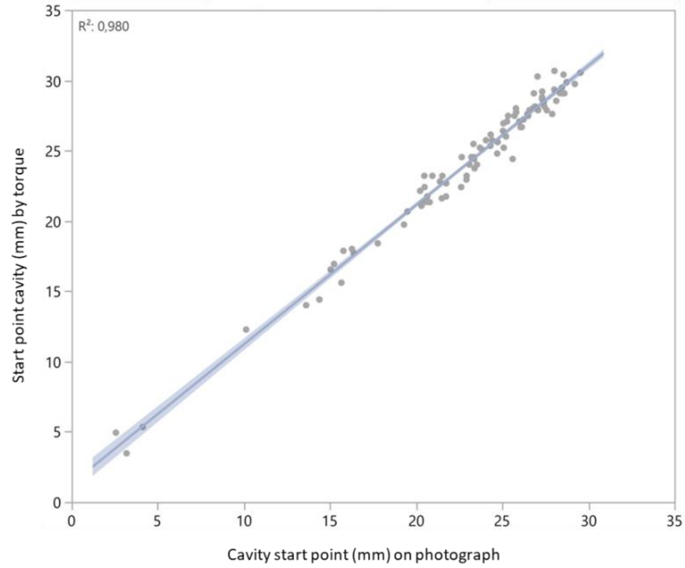

Figure 6: *Correlation graph for cavity start point determined by photographic and torque evaluation*

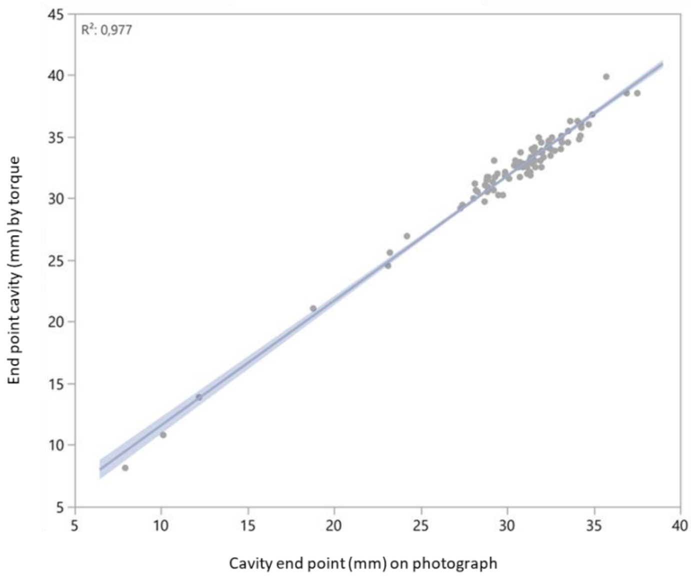

Figure 7: *Correlation graph for cavity end point determined by photographic and torque evaluation*

Discussion

This study shows that spindle torque evaluation is a reliable method to determine extension and localization of the cavity on the length axis of the sample. The values determined by this approach are identical to values measured by photographic evaluation of the sample surface.

The implications of this finding are various. First, torque evaluation during milling can be used as a screening method for cavities. In case that no cavities are identified in the torque curve, the vision inspection can be skipped and the sample can be directly transferred to the spectrometer. This might save only little time for the single sample (less than 1 s) but has impact on the global laboratory performance as majority of samples do not show cavities.

Second, torque measurement can be used as a complementary method to vision inspection. It potentially increases accuracy and reliability of surface inspection especially in the case of cavities with little optical contrast. Third, in some applications, it might completely replace vision systems. Drawbacks of this approach are that it can only determine cavity location on the length axis. The position cross to the length axis cannot be determined. Therefore, the complete sample segments containing the cavity has to be excluded from analysis. Furthermore, the method is not able to identify very small inclusion on the sample surface.

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