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TECHNICAL NOTE

Rotation Enhancement of Conical Picks Coupled with Springs

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Highlights

- Effect of the spring on the conical pick rotation was investigated experimentally for the first time.
- The combination of spring and conical picks resulted in higher amounts of rotation especially for 5 mm cutting depth.
- A precise conclusion was not drawn about the effect of the skew angle on rotation.
- 4% of permanent deformation was observed on the spring as a result of 124 cutting tests.

Keywords Rock cutting · Conical picks · Wear · Tool rotation

1 Introduction

Conical picks are widely used cutting tools which find application in underground and open-pit mining, tunnelling, road construction, trenching, and demolition industries. The highlight of the conical picks is their ability to rotate in their tool holders, which provide them ability to wear evenly to have a longer service life. This great characteristic is interrupted when the tool holder is filled with rock material. This leads to the blockage of the pick and eventually resulting in the asymmetrical and pre-mature wear of the pick because of the permanent contact of the one side of the pick with rock. Therefore, machine and tool manufacturing industry and as well as the research community are seeking solutions to sustain the rotation ability to increase service life of picks.

Various parameters can be listed for sustainability of the tool rotation, such as steel quality, clearance between tool shank and tool holder, avoidance of the dirt or dust entrance inside tool holder, skew angle, and torque on tool tip (Myren et al. 1985; Frenyo and Lange 1993; Hekimoglu 2020). Tecen (1982) investigated the high-pressure water jet assisted cutting and imposed skew angles between 0° and 13°. As a result, he could observe no rotation in the course of cutting tests. Myren et al (1985) carried out laboratory-scale rock cutting tests to investigate the conical pick rotation as a function of cutting parameters and they determined that the maximum rotation during cutting tests with – 10° skew angle. Frenyo and Lange (1993) recommended 10° skew angle for smaller tool shank diameters with higher sumping depths and 25° for bigger tool shank diameters with lower sumping depths. Kim (2010) researched conical pick rotation both in linear and rotational cutting test benches under varying experimental conditions, and she could not determine any connection among cutting parameters and rotation amount of conical tools. Hekimoglu (2020) discussed the mechanism of tool rotation and concluded that while the skew angle does not play role in shearer drums, it is crucial for roadheaders to sustain rotation.

In addition to the experimental studies under different skew angle conditions, several companies applied for patents including embodiments coupling conical picks with industrial plate springs to enhance the rotation ability of conical picks (Kamerer 2000; Sollami 2013). Additionally, Kim (2010) investigated the conical pick spring coupling with numerical modelling. However, there has been so far no experimental study showing the effects of springs on the rotation of conical picks.

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On this context, cutting tests with a linear rock cutting testing machine on a concrete sample composed of two different concrete types were executed using conical picks coupled with an industrial plate spring. Different experimental parameters were imposed such as embodiments (without spring|with spring), cutting depth (5 mm|10 mm|15 mm), skew angle (0°|15°) and cutting speed (0.5 m/s|1.5 m/s). Along with the cutting trials, rotation of the picks was measured with a 2D laser scanner. At the end of the experimental campaign, wear of cutting tools and deformation of the spring were analyzed with the aid of a 3D profilometer which scanned the surface of the pick and the spring to compare the profiles of used and unused picks and spring. The results showed that conical pick coupled with the spring showed higher amounts of rotation during cutting. On the other hand, scanning results of the picks suggested that amount of cutting tests is not enough to observe a considerable amount of wear to compare the wear profiles of two embodiments. On the other hand, the spring showed a permanent deformation of approximate 4%.

2 Experimental Studies

Cutting tests were carried out at the Institute of Mining and Special Civil Engineering, TU Bergakademie Freiberg with the linear rock cutting machine (HXS 1000-50) manufactured by ASW-GmbH which has a force capacity of 75 kN with a maximum cutting speed of 1.7 m/s. During rock cutting tests, tool forces in three dimensions were also recorded with piezoelectric force sensors, but the emphasis was given to the rotation. Therefore, the force issue was not discussed within the range of the study. The sample was fixed on a movable table which moves in the direction of the stable cutting tool and force measuring unit. More information about the linear rock cutting test machine (HXS 1000-50) can be found in Yasar et al. (2023). To conduct controlled cutting tests, a concrete block which consisted of two different concrete types (Concrete 1: UCS = 14.68 MPa|Concrete 2: UCS = 22.29 MPa|UCS: Uniaxial compressive strength) was used. Detailed information about the sample preparation was not provided, since the sample preparation procedure does not play a crucial role in results.

Cutting tests were carried out with different experimental conditions, such as cutting depth ($d = 5 \mid 10 \mid 15$ mm), cutting speed ($v = 0.5 \mid 1.5$ m/s), and skew angle ($\lambda = 0° \mid 15°$). On the other hand, angle of attack ($\gamma = 50°$) and cutting spacing ($s = 35$ mm) were kept constant and were not changed in entire study. Each cutting level was replicated two times. Before starting the controlled cutting trials, surface of the block was conditioned with several layers of levelling cuts to create a surface comparable to real-life rock surface. The details of the experimental campaign can be seen in Fig. 1.

The cutting tests were conducted with two different embodiments as seen from Fig. 1. Embodiment 1 is a classical combination of a conical pick (Erkat ER 17/75/70/30 Q) and pick holder. Embodiment 2 includes additionally a plate spring (Sodemann Federn Company with serial number 07016500) whose technical parameters were given in Table 1. Rotation of the picks was measured with a Keyence LJ-V7080 2D profile laser which recorded the rotation of a reference element fixed at the back part of the pick. To transfer the data from the laser, Keyence LJ-8000 control unit was employed. Digitalized signals were recorded with an 8-kHz measuring frequency during cutting using terminal software of Keyence.

At total, two picks were used for the embodiments. These picks and the plate spring were scanned with Keyence VR-5000 3D Profilometer to be able to compare wear conditions of picks and spring after cutting tests. Scanning activity was realized with 12 × magnification with a resolution of 0.1 µm. Scanning was carried out both before and after cutting tests with under same conditions.

3 Results and Discussion

3.1 Effect of the Spring on the Rotation of the Pick

Before discussing the rotation results, rotation term in rock cutting with the conical pick must be defined. Figure 2 shows the results of two rotation measurements from this study, along with the definition of the rotation during the cutting process. Even/symmetrical wearing feature of the conical picks comes into play, provided that they are free to rotate continuously during cutting. Hence, individual jumps as seen from Fig. 2b cannot be recognized or evaluated as rotation. When there is a rotation pattern like the graph in Fig. 2b, it was evaluated as 0° rotation. On the other hand, Fig. 2a is an instructive example to illustrate the continuous rotation (θ_1 is for concrete 1|θ_2 is for concrete 2) of the conical picks which provides the opportunity towards symmetrical wear. It is also worth to note that the end rotation (θ_{End}) must be distinguished from the continuous rotation ($\theta_1|\theta_2$) which has not a significant role on symmetrical wear. Each rotation measurement was evaluated with the above-mentioned procedure and the rotation amounts were therewith calculated. Variation of rotation in different cutting conditions is shown in Fig. 3.

After describing the rotation, variations of the rotation in different cutting conditions which are demonstrated in Fig. 3 must be discussed. A clear-cut difference between the rotational measurement of embodiment 1 (without spring) and embodiment 2 (with one spring) were observed, as shown in Fig. 3. Embodiment 2 was observed to have experienced

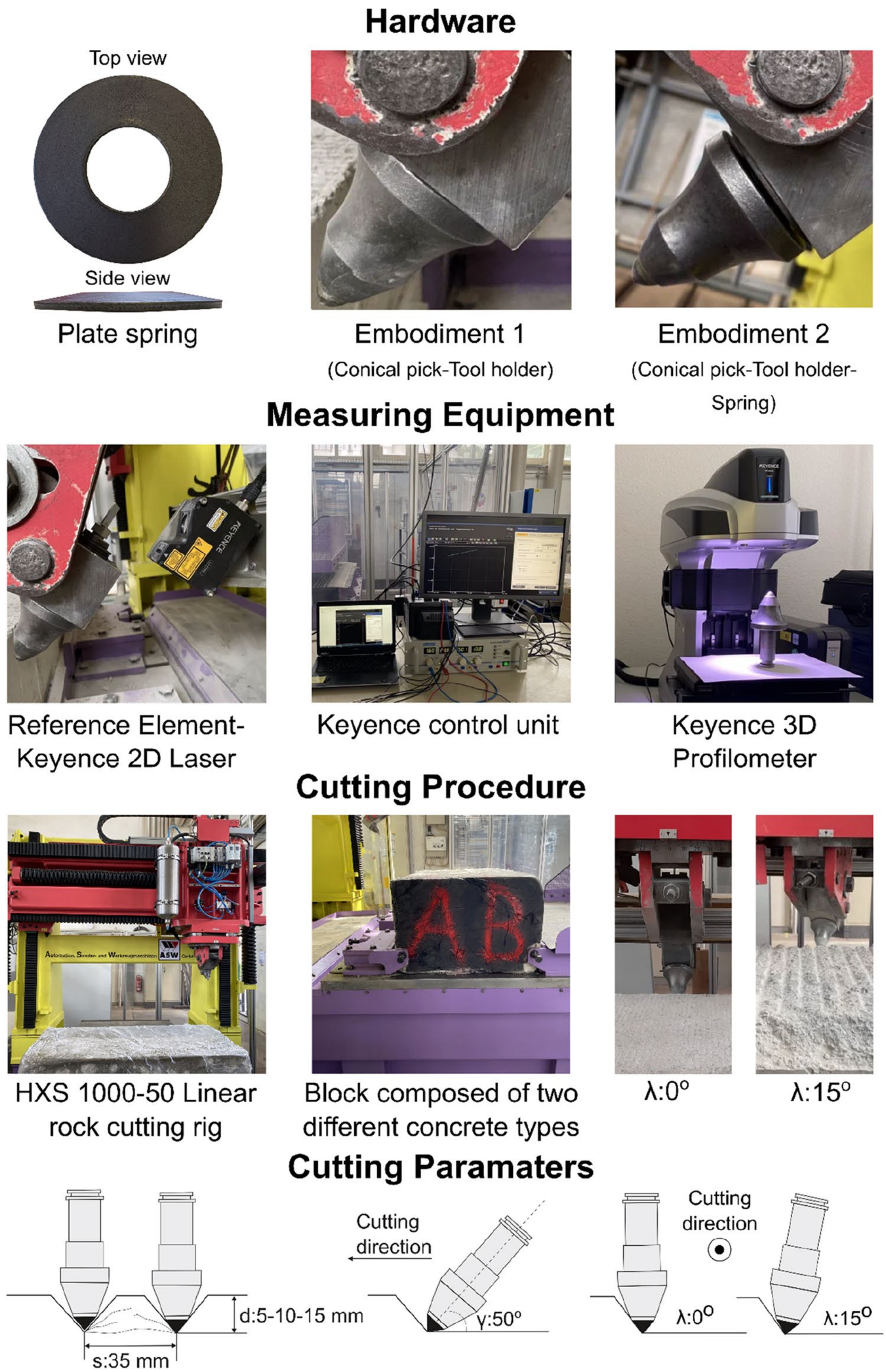

Fig. 1 Experimental campaign at a glance

more rotation when compared with embodiment 1 by means of continuous rotation (θ_1 and θ_2).

In embodiment 1 for concrete 1 and concrete 2, the *d* of 10 mm resulted on the highest average rotations, which was followed by the *d* of 5 mm and 15 mm, respectively. At end rotations in embodiment 1, similar highest rotation output was seen at the *d* of 10 mm. However, this was followed by 15 mm and 5 mm, respectively. In embodiment 1 concrete 1, the 15° λ produced a slightly higher amount of continuous rotation than the λ of 0°. However, the opposite was observed in the same embodiment for the end rotations. In both concrete 1 and 2 for embodiment 1, with the

Table 1 Technical properties of the plate spring employed in this study

Material of the spring	Steel—oiled
Outside diameter (mm)	70.00
Inside diameter (mm)	30.50
Thickness (mm)	2.50
Unloaded length (mm)	4.90
Height at max. load (mm)	3.10
Maximum force (N)	8031
Maximum travel (mm)	1.80

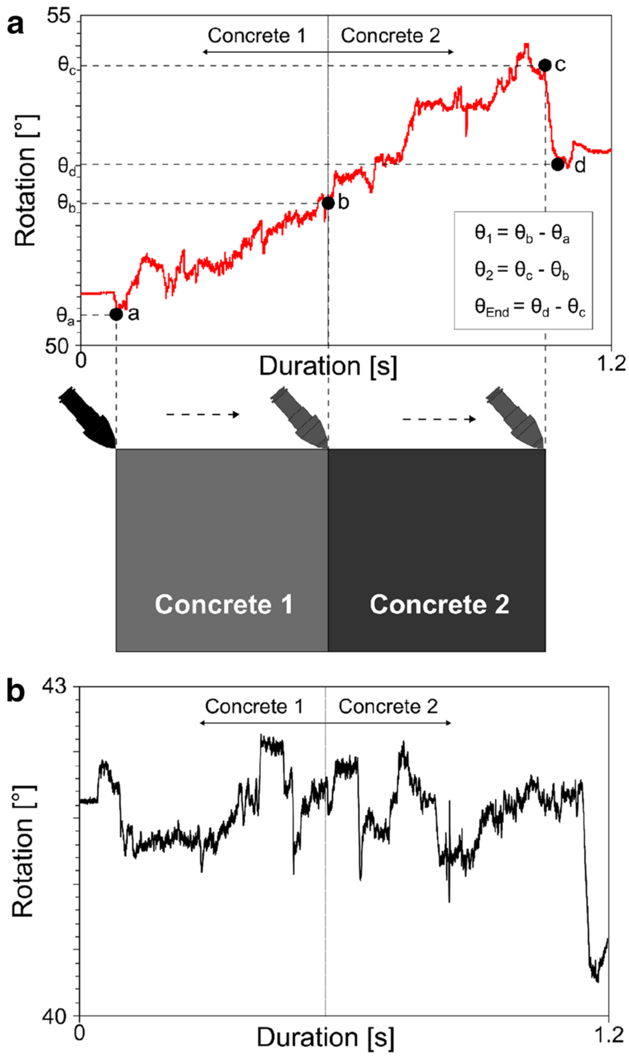

Fig. 2 Demonstration of pick rotations during cutting with example data. **a** Continuous and end rotations ($d = 5$ mm | $v = 0.5$ m/s | Embodiment 2). **b** Individual jumps ($d = 15$ mm | $v = 0.5$ m/s | Embodiment 1)

v of 1.5 m/s resulted in a higher amount of rotation than the v of 0.5 m/s.

Embodiment 2 in continuous rotation in concrete 1 and 2, the d of 5 mm averaged the highest rotation, followed by the d of 10 mm and lastly 15 mm averaging the least amount of rotation. However, the opposite was observed for end rotation. Embodiment 2 at the λ of 0° exhibited higher rotation than the λ of 15°. In both concrete 1 and 2 in embodiment 2 at the v of 0.5 m/s resulted in a higher amount of rotation than the v of 1.5 m/s. It must be also stressed here that end rotation is much higher than continuous rotation for all cutting conditions and embodiments. This supports the statement of Frenyo and Lange (1993) that the rotations occur when the pick leaves the rock rather than during the cutting action.

The increase in continuous rotations in embodiment 2 as compared to embodiment 1 might be attributed to the spring which was used in coupling the pick. In this case, the spring prevented small concrete particles from filling the small gap between the pick and the tool holder and enabled the pick to rotate freely. When the pick without the spring is in the cutting action, there is a big contact area between the pick and the holder that creates friction and makes the rotation more difficult. However, with the presence of spring, there is a very small contact area between the pick and the spring that creates opportunity for a better moveability and eventually better rotatability.

On the other hand, the d of 5 mm averaged the higher rotation, followed by the d of 10 mm, and the lowest was the d of 15 mm; this could result from compression. The deeper the cutting depths, the higher forces; hence, the higher the compression and vice versa. The spring could not therefore truly function, because it might be fully compressed. Nevertheless, this counters in end rotation; the significant rotations in cutting depths of 15 mm could result in high spring force release of the elastic strain energy stored in the spring.

There is not a clear picture of the effect of the λ either for embodiment 1 or for embodiment 2. Concrete 1 in embodiment 1 with the λ of 15° averaged a slightly higher amount of rotation than the λ of 0°. At the λ of 15°, there could be a higher possibility of torque forming as indicated by Frenyo and Lange (1993) that the tool can rotate if pick forces can create torque without acting through the tool axis. However, this trend seen in embodiment 1 concrete 1 is inconsistent with other rotation results.

It is noteworthy that the rotation amount (e.g., 2° for 30 cm cutting length of the semiblock) obtained with spring coupling can be regarded as a small number, but it must be kept in mind that the important mechanism to stimulate is the continuous rotation that helps the symmetrical wear, and it was successfully stimulated with the spring element. Additionally, this study delivers the results of a linear cutting testing, which is sometimes not representative for the real cutting conditions. For an instance, the trajectory of the pick

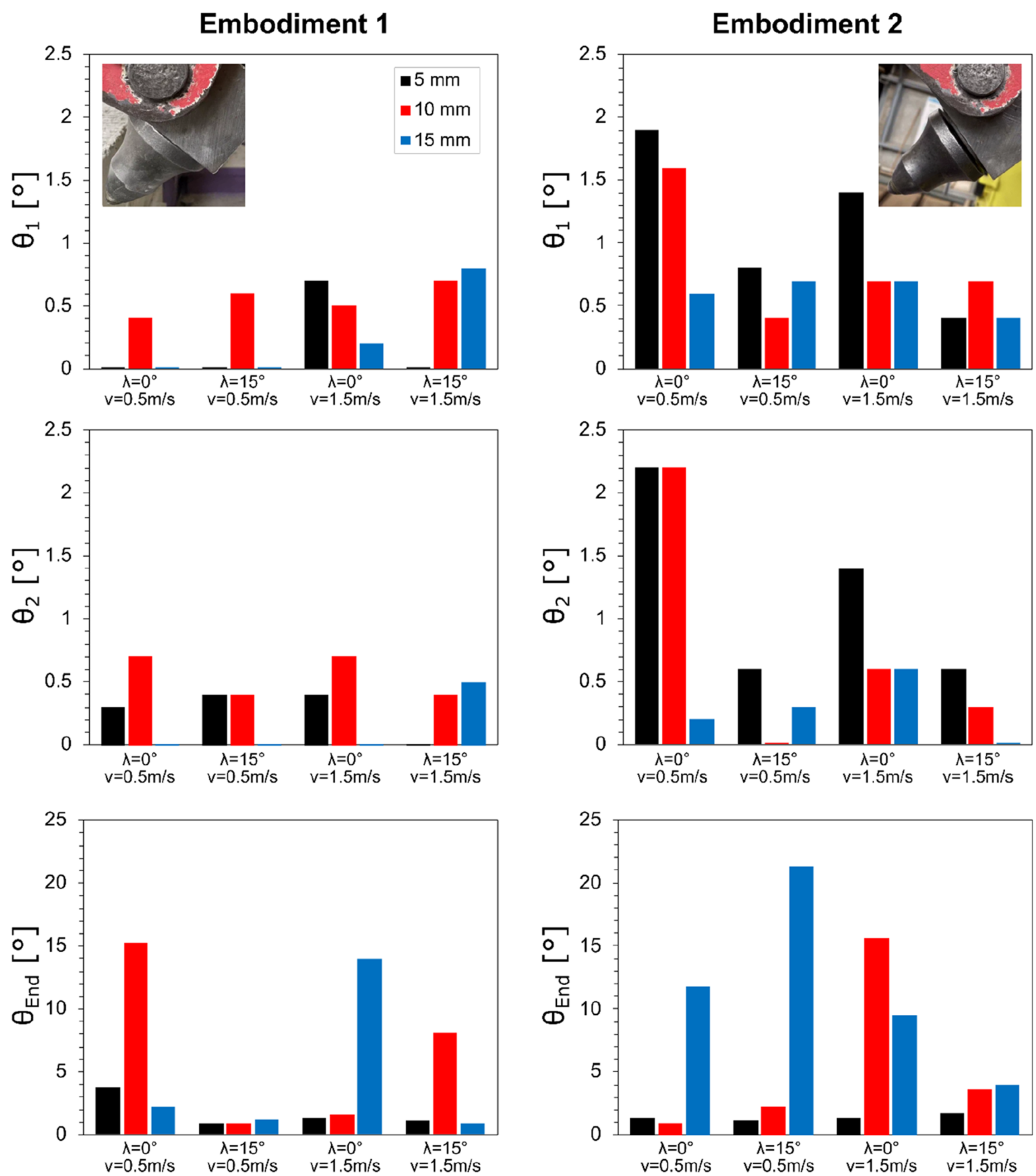

Fig. 3 Averaged overall results of rotation measurements

on a transverse-type roadheader can resemble to the linear setting during sumping and arcing. For traversing, which is the fundamental motion in a transverse-type roadheader excavation, the trajectory of the pick is helical. Therefore, there is more physical opportunity for the pick to rotate.

3.2 Wear of the Picks and the Spring

Wear of the picks were besides investigated with the aid of a Keyence 3D Profilometer as seen from Fig. 4. Cross-sections of the picks before and after cutting tests were overlapped to obtain the amount of pick wear. For each pick, two planes were selected, and cross-sections were produced. The

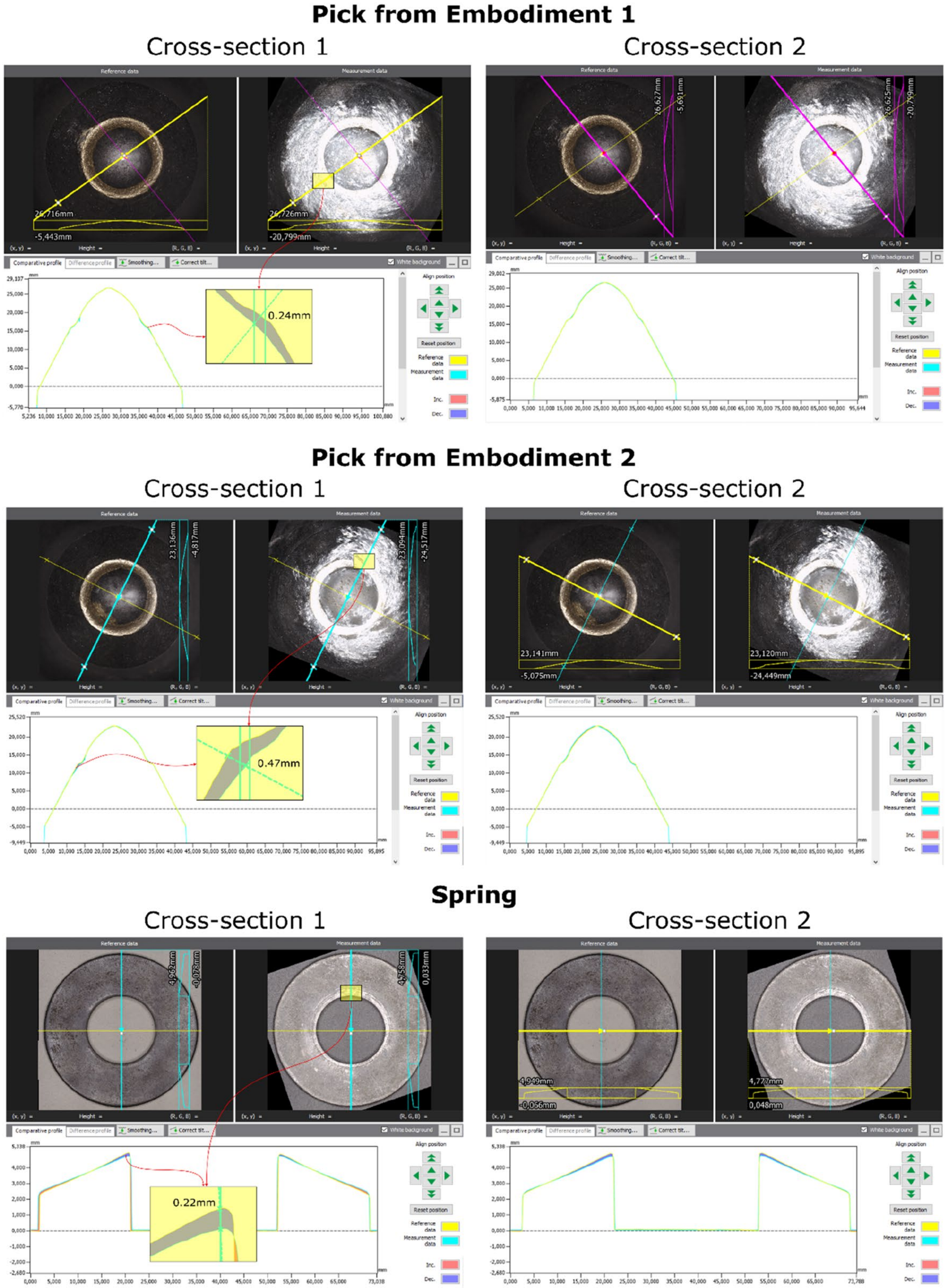

Fig. 4 Scanning of picks and spring before and after cutting tests

amount of wear was therewith calculated. Highest decrease on the cross-section was accepted as the amount of wear, which was 0.24 mm and 0.47 mm for embodiment 1 and embodiment 2, respectively. At the normal experimental program, 24 cutting tests were realized for each embodiment. Additionally, 100 tests were conducted to increase the wear. Nevertheless, these numbers are quite low to draw a certain conclusion about the effect of the spring on the wear. When the measurement photos on the right-hand side of the results are viewed, it is also hard to recognize this effect.

Permanent deformation of the spring is also matter of interest for understanding the robustness of system. It can be seen from Fig. 4 that 0.22 mm (approximately 4% of the original height) of permanent deformation was detected near the inner hole of the spring. This deformation zone also confirms the contact area between the pick and the spring. It must be stressed here that the plastic deformation is the result of 124 cutting trials, no continuous measurement during certain intervals was realized.

4 Conclusions

The effect of the presence of the spring on the rotation of conical picks was for the first time experimentally investigated, even though there were patents related to spring and pick coupling. Following significant conclusions and recommendations were eventually drawn:

- Different rotation cases, such as continuous rotation, individual jumps, and end rotation, were defined.
- It was shown that the spring enhanced the rotation ability (continuous rotation) of the pick, especially for the d of 5 mm. For the case of higher d (e.g., 15 mm), this effect was not completely pronounced. It was due to the complete compression of the spring because of higher forces.
- The end rotation was also found to be more dominant when it was compared with the continuous rotation which is consistent with the previous studies.
- The effect of λ on the rotation was not clear according to the study either with spring or without spring.
- Wear analysis did not glean a satisfactory difference between embodiments, where the necessity of a more cutting experiments for this purpose arose.
- As a result of 124 cutting tests, 0.22 mm of permanent deformation around the inner hole of the spring was determined.
- There arose a necessity of conducting these trials on real machines and natural rocks to have a deeper understanding of the effect of the spring on the rotation ability.

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Data availability statement The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of Interest The authors have no competing interests to declare that are relevant to the content of this article.

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