Experimental Investigation of Pick Body Bending Failure

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***Abstract*—Modern excavation machines that are used in civil and mining industries typically use picks as cutting tools, and thus the reliability of picks is critical to the productivity of these machines. Picks suffer from different failures in production. Among the various failure modes, pick body bending is a common one. A series of experiments were conducted in Commonwealth Scientific and Industrial Research Organisation's (CSIRO) Rock Cutting Laboratory to investigate the mechanism of pick body bending failures. The tests showed that the bending failure of a pick can be caused by a single strike of an excessive force or multiple strikes of small forces. The results can be used for better selection of picks and optimal operation of excavating machines to maximize productivity and profit.**

***Index Terms*—tool testing, rock cutting, cutting tools, tool failures, mechanical properties.**

I. Introduction

Picks are a kind of rock-cutting tools that have been widely used in excavating machines such as continuous miners, longwall shearers, and roadheaders to cut rocks in mining and construction industries. Improving the performance and reducing the failure rate of picks of excavation machines in production are important to the machine operators and owners. Pick failures during production not only incur a direct cost due to the consumption of picks but also result in some significant indirect cost due to machine shutdown and production interruption. In addition, failed picks can pose an increased risk to personnel and production if not replaced in time, for example, causing frictional ignition in underground coal mining production.

Various researches regarding picks and cutterheads with picks have been carried out from different aspects, including the calculation of pick attack and tilt angles during the cutterhead manufacturing process [1], the analysis of the cutting force and its influencing parameters [2–4], the investigation of rock breakout patterns and cutterhead design [5], and the improvement of depth of cut calculation accuracy [6]. As pick failures adversely influence the productivity and cost of mining and construction, understanding and reducing pick failures have also attracted the attention of researchers for a long time. For example, McNider et al. [7] studied the influence of the geometry of pick cutting tips on pick failures and found that the application of capped tips could prolong the picks' life. Li and Boland [8] investigated the wear characteristics of cutting tips made of thermally stable diamond composite (TSDC) and suggested that replacing existing tungsten carbide (WC) with TSDC as cutting tips could significantly delay wear-caused pick failures, especially in hard rock cutting. Sun and Li [9] investigated typical pick failure modes based on the observations of the used picks collected from the mining industry and indicated that ineffective rock breakout was a common cause that can result in all of these typical failure modes. According to [9], pick body bending is one of the typical pick failure modes.

Bent picks will change the balance of a cutterhead, add additional loading to their cutting tips and adjacent picks, and reduce their depths of cut. Therefore, a bent pick will adversely affect the pick's cutting performance and life and consequently the cutting performance and life of the cutterhead equipped with the pick. In order to minimize or eliminate pick bending failures, it is desired to have a sound understanding of the mechanism of pick bending during production. Due to the complex shape of the pick body, it is difficult to analyze the pick body bending theoretically. In order to address this issue, a series of experiments were conducted in Commonwealth Scientific and Industrial Research Organisation's (CSIRO) Rock Cutting Laboratory to investigate the mechanism of pick bending failures.

The first goal of this experimental study was to investigate whether pick bending was caused by a single strike with an excessive force or could be a cumulative effect of a number of small bending forces, because the force acting on a pick during a cutting process in production often varies to a large extent. Some preliminary outcomes of this experimental study are reported in this paper.

II. Test Rig and Method

A. Test Rig and Picks

The tests were carried out in an Instron machine (Instron Model #1342 servo-controlled uniaxial test machine). This Instron machine has a 150 mm stroke hydraulic ram with a 250 kN load cell.

Figure 1 shows the Instron machine with a test pick sample (a in Fig. 1) inside a purposely made tool holder (b in Fig. 1) installed on the machine.

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Figure 1. Instron testing machine.

The picks used for the tests were a kind of heavy-duty commercial WC rock-cutting picks which were the same as failed picks collected from a mining site. This type of picks has been widely used in some Australian underground coal mines for roadway development. The major profile and dimensions of the picks are shown in Fig. 2.

B. *Setup of the Test Pick*

The load generated by the loading part of the Instron machine was used to simulate the resultant force exerted on the pick tip during a rock-cutting process in mining production. Ideally, the angle between the loading direction and the axis of the test pick should be equal to that between the resultant force and the axis of the pick in most mining production, which is generally between 5 and 25 °.

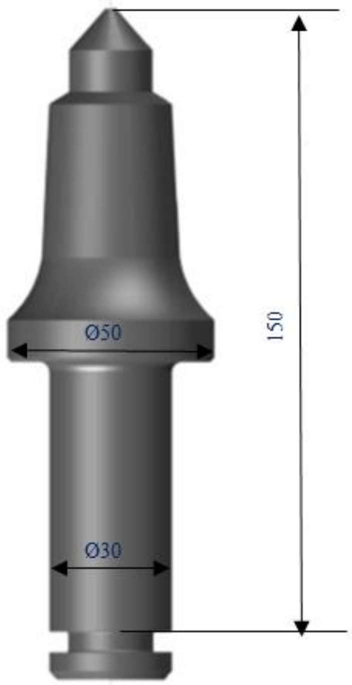

Figure 2. The major profile of the picks used in tests.

However, as the test picks had a tip angle of 82 °, good contact between the loading part and the tip surface of the test pick would be difficult to achieve if the angle between the loading direction and the axis of the pick was set to a value within the range of 5–25 °. To address this issue, the angle between the loading direction and the axis of the test pick was set to 49 °, much larger than the angles between the resultant force and the axis of the pick in most mining production. The setup of the test pick is shown in Fig. 3. As a result, the ratio between the compressive force and the bending force during the tests was smaller than that during mining production. Nevertheless, this reduced ratio could give a safer assessment of the yield bending force because the reduced compressive force in the axial direction of the pick can decrease the bending resistance of the pick.

C. *Testing Method*

The experiments were basically conducted in two stages. The bending tests in the first stage aimed to investigate the yield bending forces of pick bodies and the force that could cause pick body bending similar to the bending value of picks in the field in a single loading cycle. For this purpose, in each test, the load was increased continuously until the pick body yielded (namely, one-go loading test). The tests in the second stage were carried out to investigate the cumulative effects of small plastic residual bending displacements under a small force. For this purpose, cyclic loading was applied to new picks (namely, cyclic loading test). The loading value in each cycle could only cause the test pick body to have a small plastic bending deformation, but this deformation is much smaller than the observed plastic residual bending displacement of the picks from the field. This experiment was designed to investigate whether the large observed residual bending displacement of the picks from the field could be caused by many such small residual bending displacements.

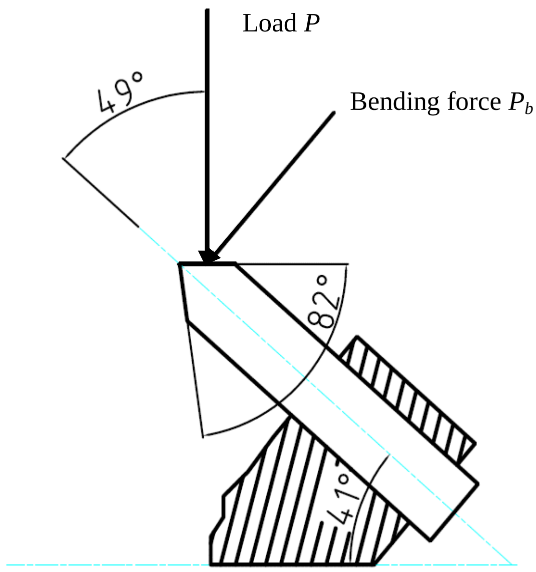

Figure 3. Schematic diagram of the pick setup.

In each test, a new test pick was held by the pick holder (new picks were used because this was a type of comparative study). Then, a required loading that was controlled by a hydraulic system was applied on the tip of the pick through the loading part of the machine (c in Fig. 1) in a designed angle. The test data were recorded by the National Instruments logging hardware and LabVIEW software. A Linear Variable Displacement Transducer (LVDT, Solartron Ax/5/S), which does not appear in Fig. 1, was installed at a location close to the bottom of the cutting tip and perpendicular to the axis of the pick body. The LVDT had a measurement range of −5 mm to +5 mm and was used to monitor the bending of the pick by measuring the lateral displacement of the location of the pick body.

III. Results and Discussions

Figure 4 illustrates an example of the relationship between vertical load applied by the Instron machine and lateral displacement recorded by the LVDT in a one-go loading test.

From Fig. 4, it can be seen that, after the load was released, the pick body had a residual lateral displacement of about 3.6 mm.

Figure 5 shows an example of the relationship between the vertical load applied by the Instron machine and the lateral displacement recorded for a cyclic loading test. This figure clearly indicates that the pick body had a small residual lateral displacement after each loading cycle and the small residual lateral displacements could be accumulated.

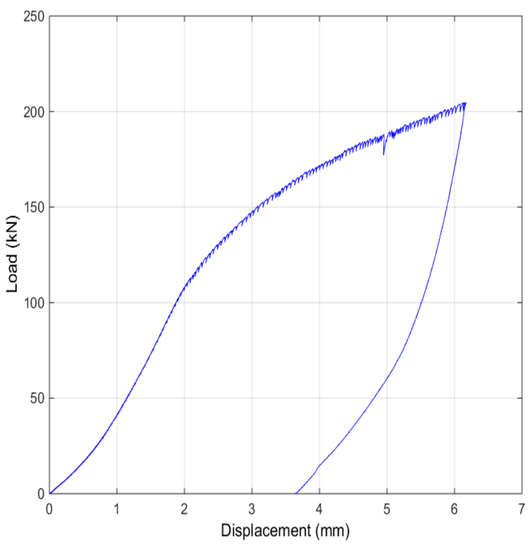

Figure 4. Load versus bending displacement for a one-go loading test.

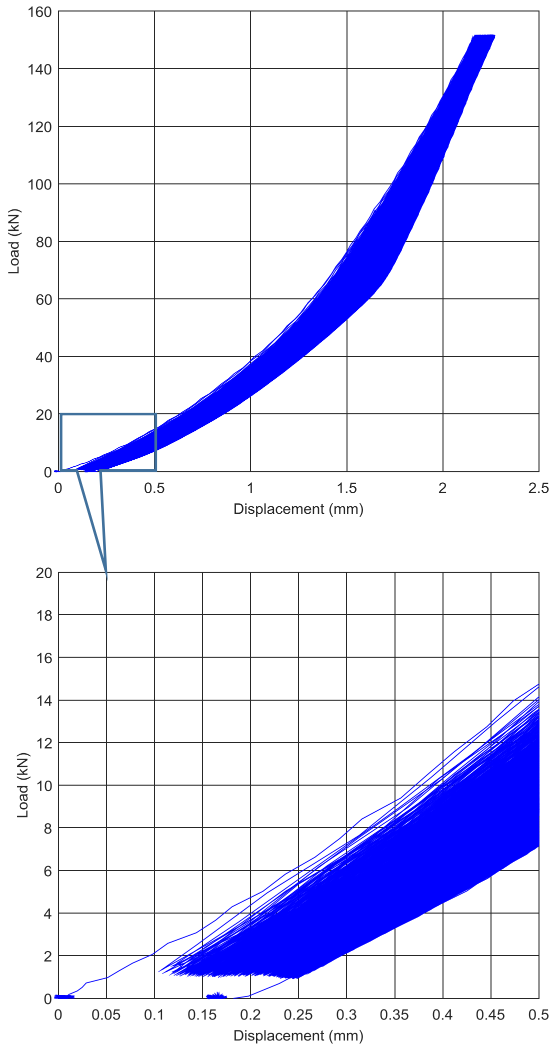

Figure 5. Load versus bending displacement for a cyclic loading test.

Part of the cyclic load is shown in Fig. 6.

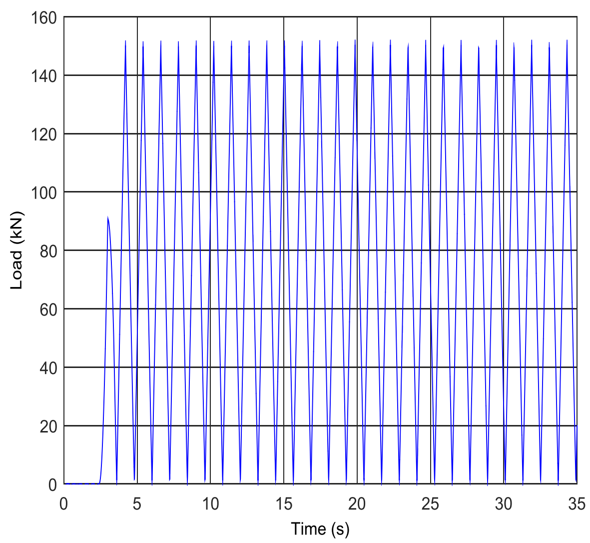

Figure 6. Part of the cyclic load.

Due to the complexity of the pick body shape and for practical applications, yield bending force, instead of yield bending stress, was assessed in this study. The yield bending force is the minimum force that causes the pick body to have a nonreversible bending deformation. Figure 4 indicates that the test pick yielded when the load was about 100 kN. On the other hand, from Fig. 3, it can be seen that the relationship between the bending force exerted on the test pick, P_b, and the load applied by the Instron machine, P, is given by

$$P_b = P\,sin\,49°. \tag{1}$$

Using Eq. (1), it can be found that the bending yield force of the pick body was about 75.5 kN.

In mining production, the bending force acting on the tip of a pick is

$$F_b = F\,sin(\alpha - \theta), \tag{2}$$

where F_b and F are the bending force (kN) and resultant force (kN), respectively, and α and θ are the attack angle (degrees) and resultant angle (degrees), respectively.

The cutting force from the cutting process, F_c, is

$$F_c = F\,cos\,\theta. \tag{3}$$

Figure 7 demonstrates the resultant force, bending force, cutting force, attack angle, and resultant angle in a rock-cutting process. The definitions of attack and resultant angles can be found in [10].

If the attack angle is 45° and resultant angle is 60°, a bending force of 75.5 kN means a resultant force of 291.7 kN based on Eq. (2). Operators should investigate what kind of operation conditions would cause this large force acting on a pick. Furthermore, from Fig. 3, it can be seen that, even with a loading force above 200 kN, the residual lateral displacement was only a little higher than 3.5 mm, which is still smaller than some pick bending deformations that occurred in the mining production. This result indicates that some pick bending failures should not have been caused by a single loading cycle in normal mining operation.

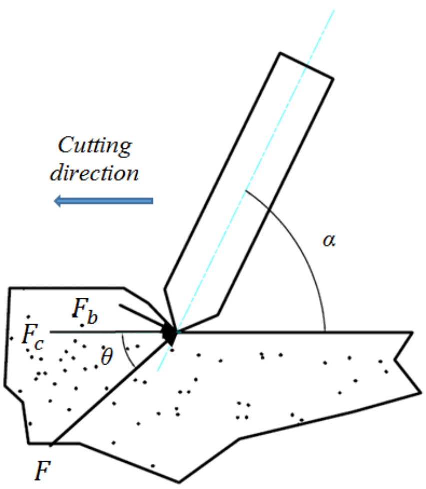

Figure 7. Resultant force F, bending force F_b, cutting force F_c, attack angle α, and resultant angle θ during a rock-cutting process.

On the other hand, from Fig. 5, it can be found that pick body bending has a cumulative effect; that is, a number of small residual body bending displacements can result in a large residual body bending displacement. Note that, in these cyclic loading tests, for simplicity, the loading in each cycle was the same and exceeded the yielding value as shown in Fig. 6. This simplified loading scenario was different from the scenarios in reality where the resultant force acting on a pick generally varies from time to time and may not be always exceeding the yielding value of the pick body. Therefore, further studies are needed to investigate whether the pick body bending values are also dependent on the loading order if a varied cyclic loading is adopted.

IV. Summary

Picks are a critical component in modern excavating machines. Their failures directly affect the productivity and reliability of the machines. Understanding the failure mechanism of picks during production is important. In this study, a series of tests were conducted to investigate the mechanism of a typical pick failure mode, pick body bending. The testing results revealed the following.

- The tested picks had a yield bending force of about 75.5 kN. When the attack angle is 45° and the resultant angle is 60°, the resultant force needs to exceed 291.7 kN to make the pick body bend. If this resultant force is caused by rock cutting, then the cutting force would be greater than 145.9 kN.
- A number of small body bending displacements can result in a large body bending displacement. Therefore, carefully operating excavating machines to prevent the bending force on a pick from exceeding its yield value is important.

As this experimental study was carried out using new picks and the load of each cycle in a cyclic loading test was the same, further studies are needed to investigate the following issues:

- Does the body bending value of a pick also depend on the loading order if a varied load is applied to the pick?
- How will the body wear of a pick influence the yield bending force of the pick?

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