The Effect of Brush Wear on High Tension Roll Electrostatic Separation Performance

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ABSTRACT

The brush in a High Tension Roll (HTR) separator performs two independent functions: physically sweeping non-conducting particles from the roll surface and providing the earthing path for the roll. Despite being a routine consumable, there is limited published understanding of how brush wear affects separation performance. This study presents a systematic investigation across 11 test campaigns and 27 individual tests using a heavy mineral sands feedstock. Three worn brushes recovered from an operating plant showed that these two functions degrade sequentially. Earthing degrades first: titanium mineral recovery to conductors dropped from 17.7-18.7% for new brushes to 11.1-11.7% for worn brushes, while zircon recovery was maintained. Sweeping degrades second: one brush exhibited a drastic performance drop, with zircon recovery falling from 89-92% to just 58.5%, while titanium recovery rebounded to near new-brush levels as recirculated material was given additional discharge opportunities. These two failure modes were independently validated by single-variable campaigns isolating brush tension and earthing configuration respectively. Brush tension was the most influential single variable, with zircon recovery ranging from 48% at zero applied pressure to 87% at 20 kg of applied pressure. Material and coating variables produced comparatively minor effects. The findings establish titanium recovery as an early indicator of brush degradation and support a shift to more frequent, condition-informed brush replacement in HTR circuits.

Keywords: electrostatic separation; high tension roll; brush wear; mineral sands; zircon; rutile; maintenance

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1. INTRODUCTION

The High Tension Roll (HTR) separator is widely used in mineral sands processing for the separation of conducting minerals such as rutile and ilmenite from non-conducting minerals such as zircon. The separator operates by charging particles on a grounded rotating roll using a corona electrode. Conducting particles rapidly lose their charge to the earthed roll and are flung from the surface by centrifugal force, while non-conducting particles retain their charge, remain pinned to the roll, and must be physically removed by a brush [1, 2].

The brush therefore serves two critical functions: physically sweeping non-conducting particles from the roll surface, and providing the earthing path for the roll itself [3]. Despite the brush being a routine consumable in plant operations, there is limited published understanding of how brush wear affects separation performance, or at what point a worn brush should be replaced. Operators typically rely on visual inspection or fixed time intervals, neither of which is informed by quantified performance data.

This study addresses that gap. Three worn brushes were recovered from an operating heavy mineral sands plant and tested under controlled laboratory conditions alongside new brushes of known specification. To contextualise the wear effect, eight additional test campaigns were conducted to systematically evaluate other brush variables including bristle geometry, different brass alloys, spray coatings, bristle length, applied tension and earthing configuration. In total, 11 campaigns comprising 27 individual tests were completed.

2. EXPERIMENTAL

All tests were conducted on a single laboratory-scale Carrara HTR 270 separator using a consistent heavy mineral sands feedstock at a feed temperature of 110-120°C. Electrode positions were fixed and unchanged throughout the programme, with the corona wire positioned 60 mm from the roll surface and the electrode 40 mm away. All tests were completed by the same operator to keep variables as constant as possible. The primary performance metrics recorded were zircon grade and recovery to the non-conductor stream, titanium mineral (rutile and ilmenite) grade and recovery to the conductor stream, zircon misplacement to the conductor stream, and total middlings.

The test programme was structured into 11 campaigns, each isolating a single variable. Baseline brushes of known specification were included in each campaign to enable direct comparison. The campaigns and variables investigated are summarised in Table 1.

Table 1. *Summary of test campaigns and variables investigated.*

Campaign	Variable	Tests
C1	Supplier comparison	T11 (Brush A, S1), T12 (Brush B, S2)
C2	Brass alloy composition	T12, T13
C3	Coating types	T12, T19, T14, T15
C4	Straight vs crimped bristles	T11, T12, T13, T17
C5	Tampico vs brass	T11, T12, T13, T20
C6	New vs worn brushes	T11, T12, T13, T33, T21, T22, T23
C7	Bristle length	T29 (28 mm), T30 (20 mm), T31 (15 mm), T32 (10 mm)
C8	Bristle consistency	T11, T12, T13, T16
C9	Brush tension	T24 (0 kg), T25 (10 kg), T26 (20 kg), T27 (30 kg), T28 (2 kg)
C10	Earthing configuration	T34, T35, T36, T37
C11	Lab standards vs new	T11, T12, T16, T18

Figure 1. A selection of the brushes tested, showing variation in bristle type, length, and condition.

3. RESULTS AND DISCUSSION

3.1 Brush Wear (C6)

The worn brush campaign produced the most operationally significant findings of the study. Table 2 presents the key metrics for new and worn brushes, with zircon recovery to non-conductors and titanium recovery to conductors as the primary indicators.

Table 2. *Separation performance of new vs worn brushes.*

Brush	Zr Rec. (%)	Zr Grade (%)	Ti Rec. (%)	Ti Grade (%)
A (New, S1)	89.4	21.2	17.7	37.4
B (New, S2)	92.0	23.6	18.0	37.8
C (New, S2-Gold)	89.3	24.9	18.7	37.0
P (Worn - sample from site)	91.4	23.0	11.1	37.3
Q (Worn - sample from site)	93.6	24.0	11.7	35.1
R (Worn - sample from site)	58.5	21.6	17.3	33.7

New brushes achieved zircon recovery of 89-92% and titanium recovery to conductors of 17.7-18.7%.

The brush serves two independent functions, and the data indicates these degrade sequentially. Earthing degrades first: brushes P and Q maintained zircon recovery at 91-94%, but titanium recovery to conductors dropped from 17.7-18.7% to 11.1-11.7%, a reduction of approximately 37%. This indicates that the worn bristles reduced in effective earthing of the roll, so conductors retain their charge and remain pinned to the roll surface rather than being discharged to the conductor stream. Zircon recovery appears unaffected because the physical sweeping function is still intact.

Sweeping degrades second: brush R exhibited a drastic performance drop, with zircon recovery falling from 89-92% to 58.5%. The non-conducting particles that should be swept from the roll instead ride around it and are misplaced to the conductor and middling streams. Notably, titanium recovery for brush R rebounded to 17.3%, close to new-brush levels. This is explained by recirculation: material that remains on the roll is carried back around the roll, giving conductors additional opportunities to discharge and report to the conductor stream.

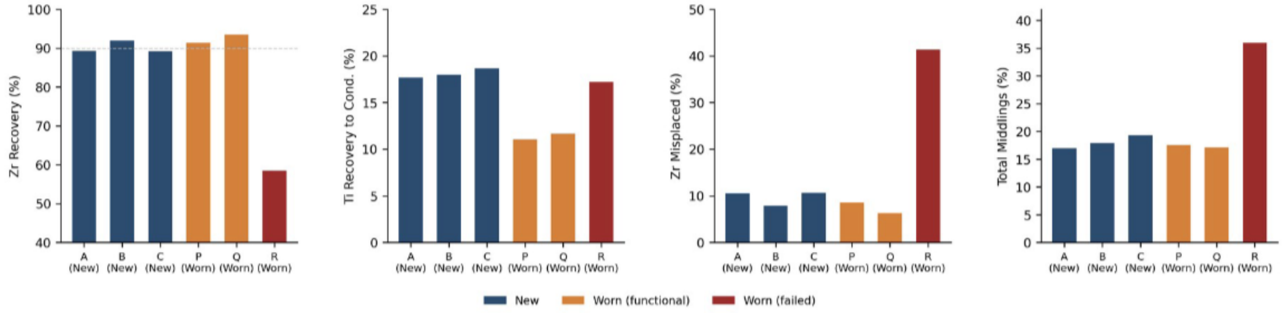

Figure 2. Zircon recovery and titanium recovery for new and worn brushes (Campaign C6). P and Q show earthing degradation (Ti recovery drops, Zr recovery maintained). R shows sweeping failure (Zr recovery collapses, Ti recovery rebounds via recirculation).

Table 3 summarises the proposed degradation sequence and the distinct metallurgical signature associated with each stage

Table 3. *Brush degradation sequence and metallurgical signatures.*

Stage	Earthing	Sweeping	Zr Rec.	Ti Rec.	Indicator
1 - New	Intact	Intact	89–92%	17.7–18.7%	Normal operation
2 - Worn	Compromised	Intact	91–94% (maintained)	11.1–11.7% (↓ 37%)	Ti recovery decline is the early warning
3 - Failed	Compromised	Compromised	58.5% (↓ drastic)	17.3% (↑ rebounds)	Zr collapse with Ti rebound confirms recirculation. Replace immediately

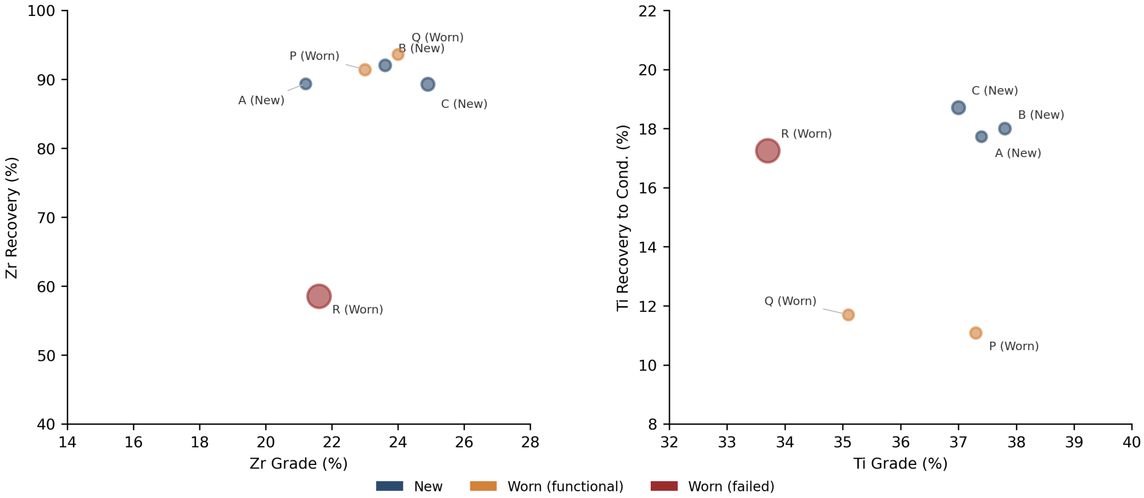

Figure 2. Grade-recovery plots for new vs worn brushes (Campaign C6). Bubble size represents total middlings. New brushes cluster together while Brush R is an extreme outlier, confirming the drastic separation loss when sweeping fails.

3.2 Brush Tension (C9)

Brush tension was the most influential single variable in the study and independently validates the sweeping-failure mechanism. At zero applied pressure (but still brush contact on roller), zircon recovery was just 48.3% while titanium recovery was the highest recorded at 25.2%, mirroring the signature of Brush R. As tension increased, zircon recovery climbed to 87.4% at 30 kg while titanium recovery fell to 12.8%. A clear plateau was observed between 20 and 30 kg of applied pressure. The zero-tension condition effectively simulates sweeping failure with earthing intact, producing the same inverse relationship between zircon and titanium recovery observed in the worn brush data.

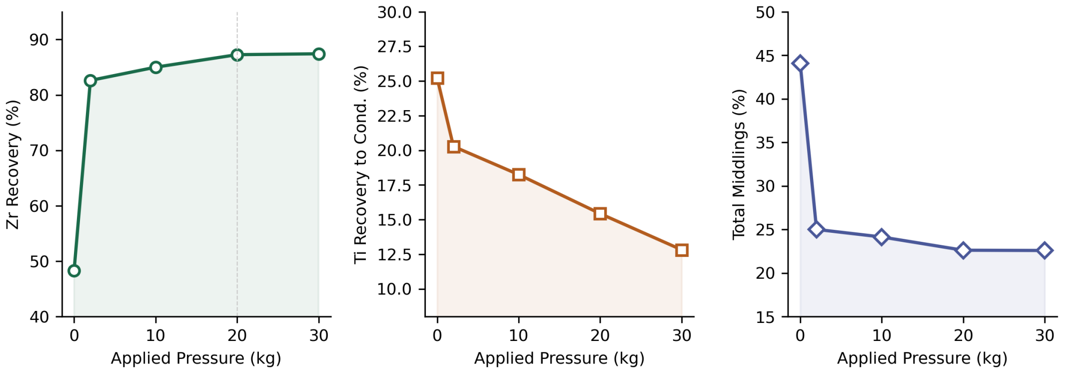

Figure 5. Effect of brush tension on separation performance (Campaign C9). At zero tension (simulated sweeping failure), Zr recovery is lowest and Ti recovery highest, mirroring the worn Brush R signature. Performance plateaus above 20 kg of applied pressure.

3.3 Earthing Configuration (C10)

The earthing campaign independently validates the earthing-failure mechanism. Progressively removing earthing connections caused titanium recovery to drop from 24.0% to 16.8%, while zircon recovery increased from 77.8% to 85.1%. This mirrors the P/Q worn brush signature: reduced earthing quality means fewer particles lose charge to the roll, so conductors remain pinned and report to non-conductors. Crucially, no titanium recovery rebound was observed because the brush was physically intact and sweeping normally, confirming that recirculation only occurs when sweeping is compromised.

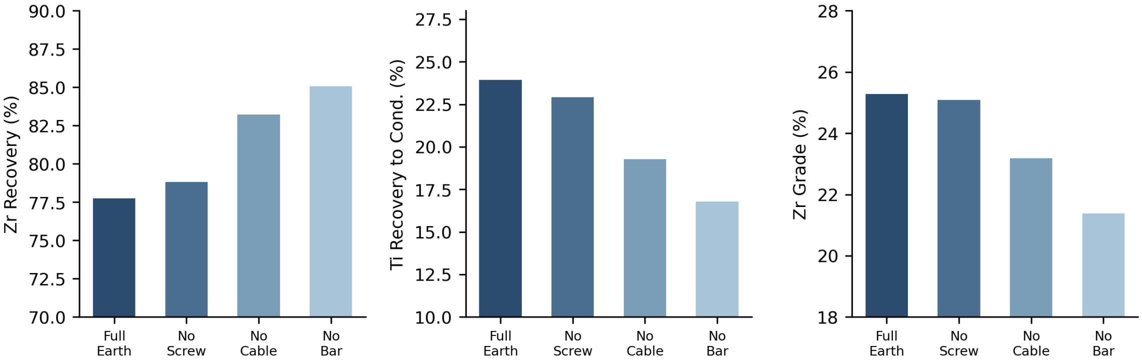

Figure 6. Effect of earthing configuration on separation performance (Campaign C10). Ti recovery falls as earthing is removed, with no rebound, confirming that recirculation requires sweeping failure.

3.4 Other Variables

Of the remaining variables, bristle geometry produced the most notable result: a straight wire brush achieved zircon recovery of 92.7% and titanium recovery of 16.5%, matching or exceeding crimped wire performance. Bristle length exhibited an optimum at 15 mm, with shorter and longer bristles both degrading zircon recovery. Spray coatings and brass alloy composition all produced comparatively minor effects.

4. CONCLUSIONS

This study demonstrates that the brush's two functions, sweeping and earthing, degrade sequentially and produce distinct metallurgical signatures. Earthing degradation is characterised by a decline in titanium recovery while zircon recovery is maintained. Sweeping failure produces a drastic drop in zircon recovery accompanied by a rebound in titanium recovery driven by material recirculation. These two mechanisms were independently validated by single-variable campaigns isolating brush tension (C9) and earthing configuration (C10) respectively.

A decrease in titanium recovery to the conductor stream should be monitored as an early indicator of brush degradation. A decline in conductor recovery, even when non-conductor recovery appears stable, signals that earthing is compromised and sweeping failure may follow.

Brush tension was the most influential single variable, with a 40-percentage-point swing in zircon recovery between zero and 20 kg of applied pressure. Bristle geometry and length offer secondary optimisation opportunities, while brass alloy and coating selection have comparatively limited influence.

The overarching finding is that plants seeking to improve HTR circuit performance should prioritise brush condition monitoring. Conductor recovery should be tracked as an early indicator of degradation: a decline in conductor recovery, even when non-conductor recovery appears stable, signals that earthing is compromised and the brush is approaching end of life. Where conductor recovery is a priority, brushes should be replaced at the first sign of decline. If there is evidence of material recirculation due to sweeping failure, the brush must be replaced immediately.

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