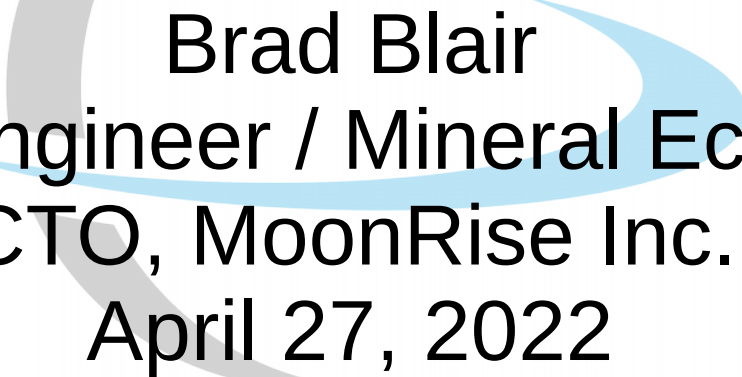


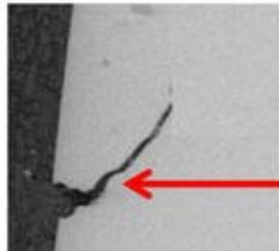
Dust, Wear & Abrasion in Mining



Brad Blair
Mining Engineer / Mineral Economist
CTO, MoonRise Inc.
April 27, 2022

moonrise

Classifying Wear



Pitting failure in gear

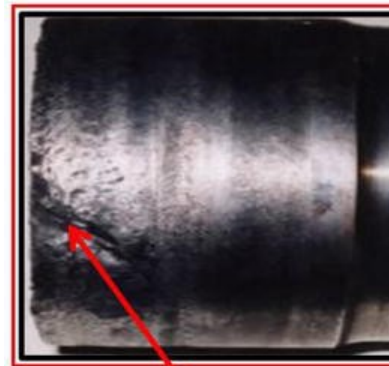


Adhesive wear in industrial parts



Abrasive wear in industrial parts

Gas turbine blade surface eroded by solid particle erosion wear



Fretting wear

Surface damage due to corrosion and oxidation



- Abrasion
- Adhesion
- Fatigue
(pitting)
- Fretting
- Erosion
- Corrosion
- Oxidation

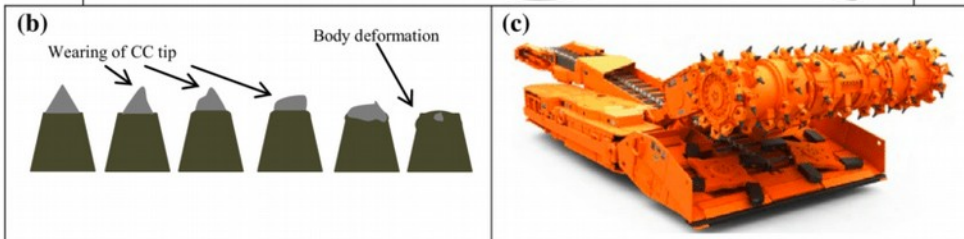
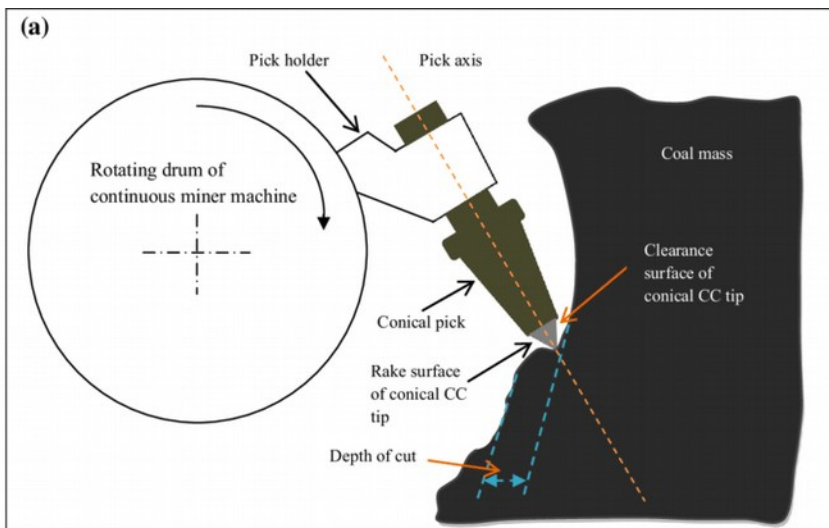
Wear of Tools by Excavation Forces 1/2



<https://alpinecutter.com/rock-grinding-with-a-cutterhead-how-many-picks-will-i-need.html>

- Gradual, steady wear is common in most rock and many soil conditions
- Hardfacing and adding ripping 'teeth' and/or carbide button cutter inserts are common solutions to increasing the service life of excavation systems
- Note mineral-tool interaction is different in cold, under vacuum and based on water content (quartz is particularly abrasive)

Failure of ductile iron can be sudden and catastrophic when wear protection is lost



Wear of Tools by Excavation Forces 2/2



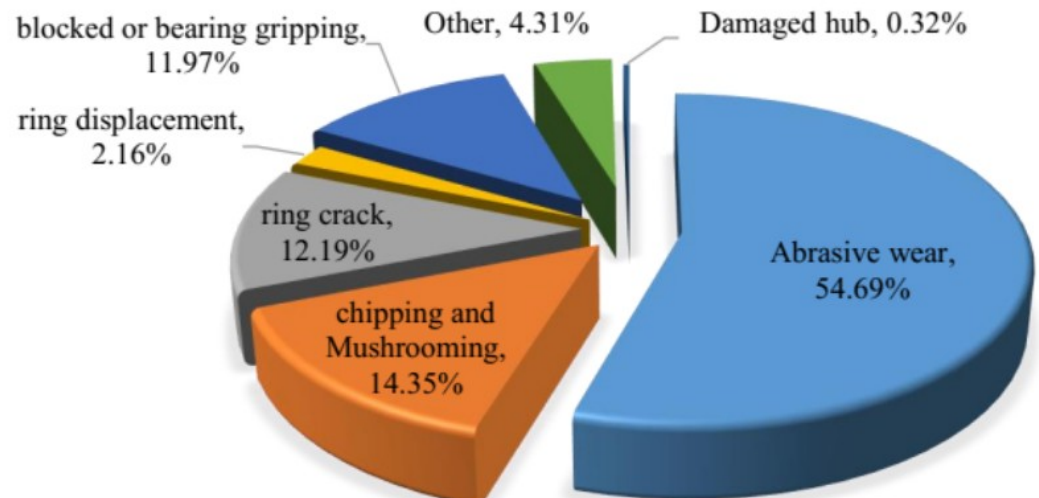
<https://www.robbinstbm.com/products/tunnel-boring-machines/single-shield/>



https://www.tunnel-online.info/en/artikel/tunnel_The_Next_Revolution_in_EPB_Cutters_New_Cutter_Designs_make_an_Impression_1734178.html



- Tunnel boring machines are in common use around the world
- Disc cutters enable rapid advance in a wide variety of ground conditions
- The key to maximizing the tunneling rate is to know when to change the disc cutters
- Failure to address tool wear can lead to cascading failure of the cutterhead – a domino effect



http://jme.shahroodut.ac.ir/article_1881_29024cbca4d55b2e6070dddeef021ba4.pdf

Accident-induced wear

<http://www.miningmayhem.com/>



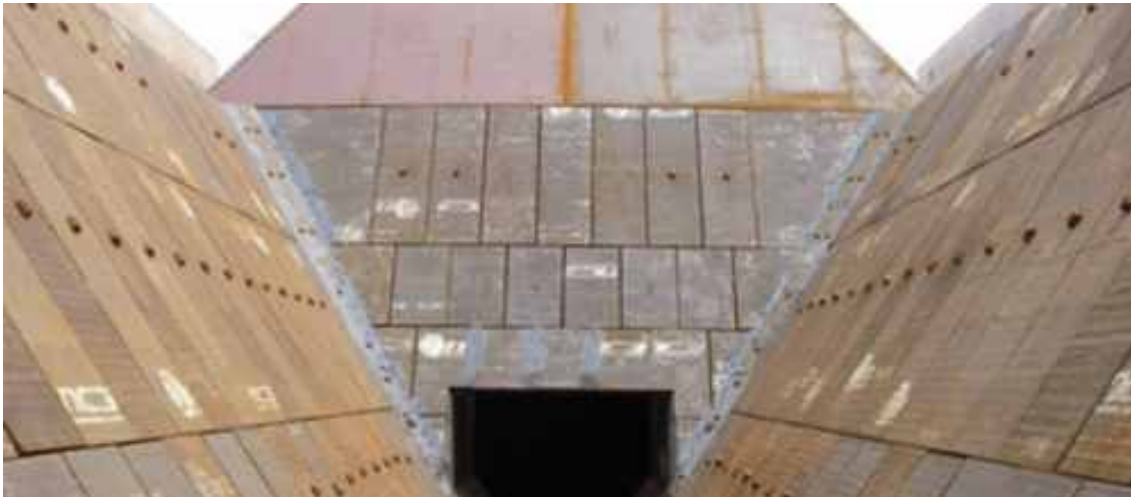
Armored Support Equipment



<http://rdlinings.com/industrial-refurbishment/screw-conveyor-refurbishment/>



<https://www.technogenia.com/en/industries/tunneling/>



<https://www.indiamart.com/proddetail/wear-plate-14126500997.html>

- Loaders, haulers, hoppers, chutes, grizzlies, screw and chain conveyors can experience secondary wear and abrasion
- Wear rates are measurable, and can be predicted as a function of material choice and fabrication method
- Novel solutions often follow a design gradient, or can be discovered by serendipity as conditions change (e.g., cryogenic hardening)

Dust Effects 1/3 - combustion



<https://skybrary.aero/articles/volcanic-ash>



<https://www.mining-technology.com/contractors/transportation/ghh-fahrzeuge/>

- Entrainment of dust into combustion engine airflow can cause erosion of components and rapid buildup of contaminants
- Note damage at left to a NASA DC-8 Turbine Engine from a high-altitude encounter with diffuse volcanic ash

Dust Effects 2/3 – Linear and rotary seals



<https://www.cogentindustries.co.za/causes-fork-stanchion-wear-avoid/>

- Linear actuator scoring degrade seal performance, enabling fluid loss
- Rotary joint erosion creates grooving
- Lubrication fluids mitigate dust and are a major consumable in mining, civil engineering and transportation
- Dry lubricants preferred for spacecraft are more susceptible to dust attack

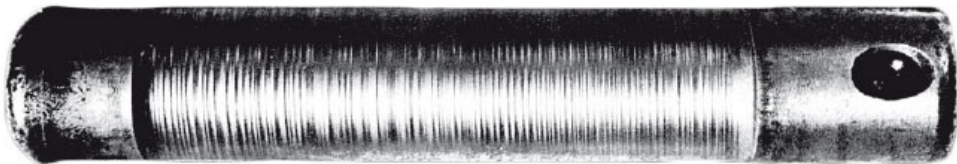


<https://www.machinerylubrication.com/Read/30391/lip-seals-importance>

Dust Effects 3/3 – (dry) bushings & pins



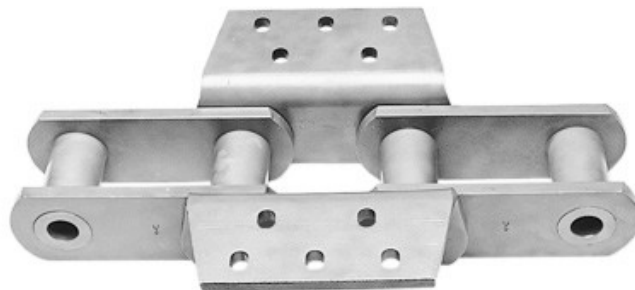
<https://www.powermotiontech.com/hydraulics/hydraulic-filters/article/21882787/hydraulic-filtration>



<https://www.johnkingchains.com/technical-data/analysis-of-damage-cause-and-remedies/21-2-pin-wear-from-abrasion/>

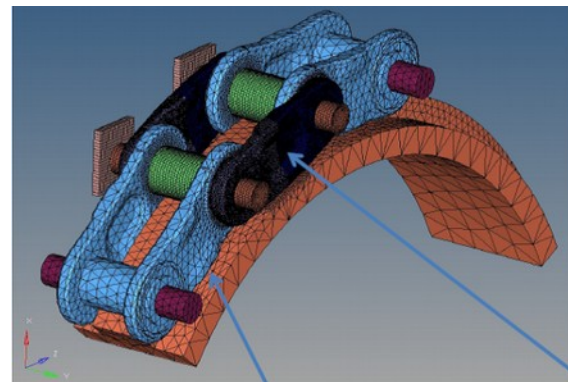


<https://www.mdpi.com/1996-1944/15/8/2709/htm>

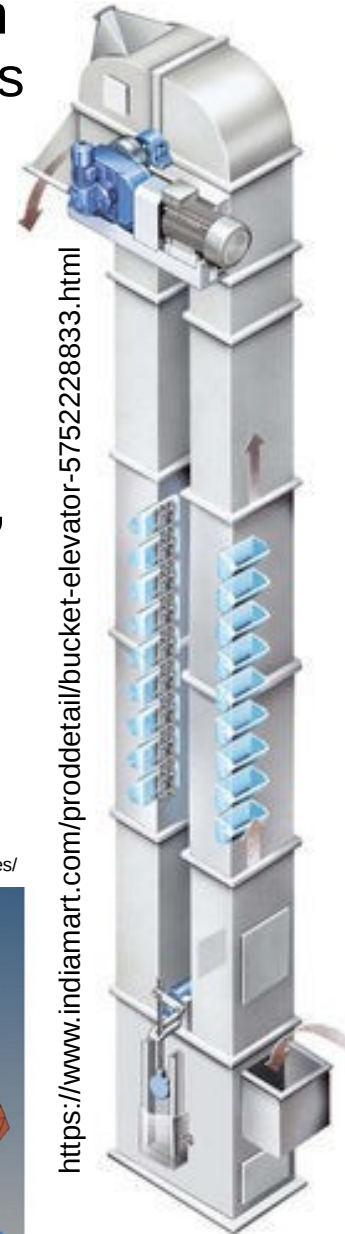


<http://www.tsubaki.ca/products/engineered-chain/bucket-elevator-chain/>

<https://aumund.com/en/editorials/aumund-chains-for-aumund-machines/>

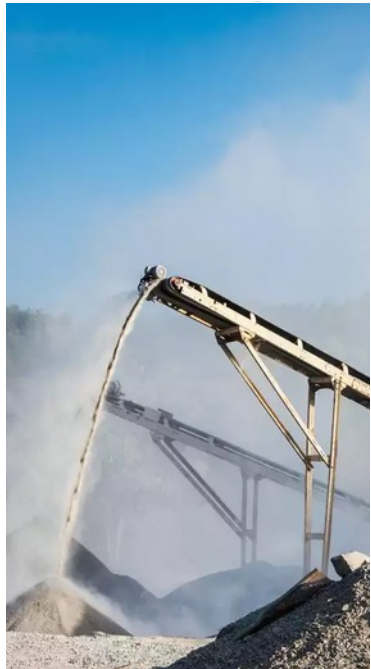


- Bucket elevators operate in extreme-wear environments
- Service life is limited by hub, pin & bushing wear, with MTBF measured in months to years (although notable exceptions exist)
- Materials science + design, test and engineering is maximizing wear life
- These methods can be adapted to lunar systems



<https://www.indiamart.com/proddetail/bucket-elevator-5752228833.html>

Dust Control in Mining



<https://www.robovent.com/industrial-dust-collection/mining/>



<https://www.chansenmachinery.com/product-detail/ub3000v/>



<https://www.cdc.gov/niosh/mining/features/cpdmhelpsminersavoiddust.html>



<https://news.arizona.edu/story/startup-seeks-control-dust-dry-world>

- Active removal of dust is most effective at the source (water guns and cannons, filters, cyclones, scrubbers and *electrostatic precipitators*)
- Passivation of adhesive forces (lubricating oils, films, and coatings)
- Inhibit formation and lifting of dust is another common strategy (add polymers, surfactants & foams to reduce water use for mine roads, ore blending & stockpiles)
- Dust ventilation for mining and mineral processing (wind fences, industrial fans and blowers for airflow management)
- Real-time dust monitoring saves lives
- Also see publications below

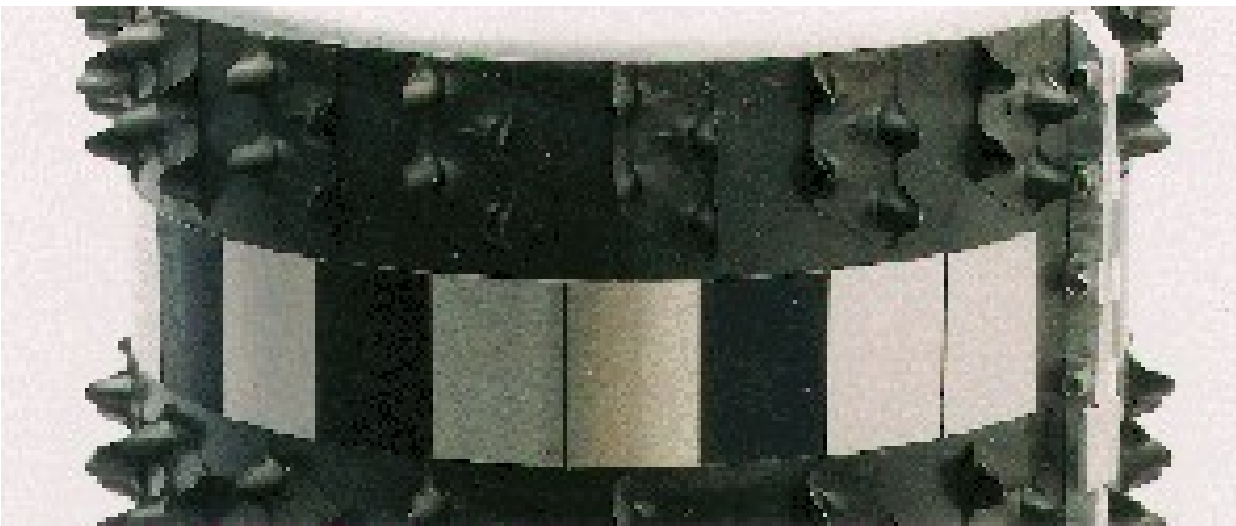
https://www.state.nj.us/health/workplacehealthandsafety/documents/silicosis/mining/mining_bestpractices_full.pdf

<https://www.cdc.gov/niosh/mining/UserFiles/s/works/pdfs/2003-147.pdf>

Lunar Test & Measurement 1/2



<https://www.universetoday.com/146047/better-tires-to-drive-on-mars/>



<https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/98JE02249>

- Curiosity rover wheel failure is well documented (however, note significant difference between a 6 week design life and 2yrs of actual performance)
- Mars Pathfinder Sojourner had an onboard **Wheel Abrasion Experiment (WAE)** which was designed to measure abrasion characteristics of Martian dust on strips of pure metals.
- Ground tests using environmental simulations showed static charging levels of 100-300V. To mitigate Paschen discharge, dissipation points were added to Sojourner.
- Dust accumulations on Sojourner wheels was interpreted as evidence for electrostatic charging

<https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/98JE02249>

Lunar Test & Measurement 2/2



<https://www.rocketstem.org/2015/07/06/construction-of-the-lunar-rover-changed-exploration-of-the-moon/>



<https://www.universetoday.com/146047/better-tires-to-drive-on-mars/>

- Apollo LRV wheels are a case study in wear & abrasion
- GRC has been testing rover wheels made of woven shape memory alloy wires for Artemis
- The wires will rub against each other under cyclical loading, entraining adhesive dust and abrasive minerals into a wear surface
- The (weakest) first fiber to fail will limit wheel life, creating a *space suit puncture hazard*
- Given the ply and density of intersections shown in these images, thousands of wear connection points are estimated (creating a notable analogy to bucket ladder physics)

Common ASTM Abrasion Testing Standards

Note: Numerous application-specific tests are not mention here

TABLE 4.—SUMMARY OF RELEVANT ASTM STANDARDS
FOR ABRASION TESTING

Test name (abbreviated)	ASTM standard	Degree
Loop abrasion test	G 174 (replace G 65)	Two-body
Drum abrasion test	G 132	Two-body
Scratch test	G 171	Two-body
Plastic abrasion test (withdrawn)	D 1242	Two-body
Taber abraser	D 4060	Two-body
Abrasion by particle movement	Nonstandard Tests	Two-body
Printer ribbon test	G 56	Two-body
Yarn test	D 3108	Two-body
Magnetic tape abrasivity test	-----	Two-body
Rock abrasiveness by CERCHAR Method	D 7625	Two-body
Gouging abrasion with jaw crusher	G 81	Three-body
Dry-sand, rubber, wheel abrasion	G 65	Three-body
Wet-sand abrasion	G 105	Three-body
Taber with ancillary grit feeder	F 510	Three-body
Disk versus disk	-----	Three-body
High abrasion test	-----	Three-body
Wet high-stress abrasion test	B 611	Three-body
Chemo-mechanical planarizing	-----	Three-body
Ball cratering test	VAMAS	Three-body
Gas jet erosion test	G 76	Three-body
Abrasion resistance of textile fabrics	D 3884	Three-body

Source: <https://commons.erau.edu/cgi/viewcontent.cgi?article=1606&context=publication>

Lunar Abrasion Experiment at CSM-EMI

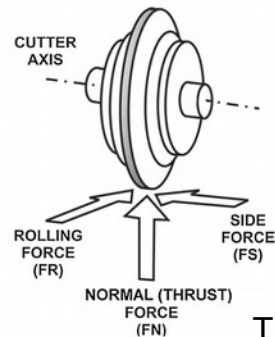
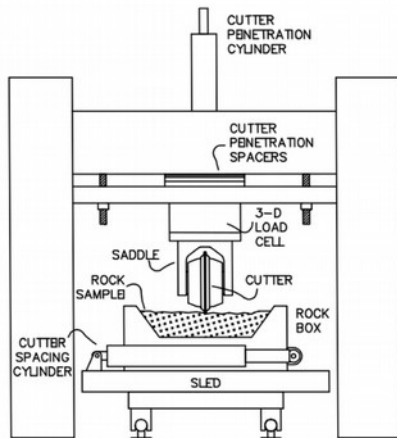


- The CSM Earth Mechanics Institute has been measuring wear of disc and pick cutters, drill bits and specialty metals for the mining and mechanical excavation industry for over 30 years (see final slide)
- The test apparatus shown here measures accelerated wear on tooling and machine components including hardened steels under variable working conditions – *note adaptability to cryogenic and vacuum testing*
- Grain size distribution is a major contributor to the wear of target material – other factors affecting soil abrasivity include mineralogy of the soil / rock, grain shape and roundness, water content, working pressure, and presence of chemical components
- Measurements of wear *in basaltic and anorthositic lunar simulant* are underway, enabling comparison to terrestrial rock and soil (see video)
- Contact <emi@mines.edu> for more info

CSM Earth Mechanics Institute



A unique test fixture at EMI is the **Laboratory Tunnel Boring Machine (LTBM)**. A six-foot diameter, computer-controlled rotary cutting machine with removable cutters and cutterhead performs tunnel, raise and shaft boring investigations. The machine is pivoted on an anchor frame so that it can be tilted to any desired direction. The machine is used in laboratory studies to develop design guidelines to optimize tunnel, raise and shaft boring performance. The capacity is one million pounds of thrust and 200,000 foot-pounds torque with cutterhead speed variable up to 55 rpm.



Linear cutting tests provide a direct measure of rock cuttability under simulated field conditions. The LCM measures the forces acting on an individual cutter while cutting actual rock. Data from this test provides input for performance prediction, machine specification, cutterhead balancing and optimization for cutting geometry. These full-scale tests eliminate the uncertainties of the rock, which may not be identified by physical property testing.



Figure 16. Linear Cutting Machine.

Contact: emi@mines.edu