EFFECT OF COMMINUTION METHOD ON PARTICLE DAMAGE AND BREAKAGE ENERGY

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Outline

- Our Department
- High Pressure Grinding
- Particle Damage Characterization
- Breakage Energy
- Application to Simulant Development

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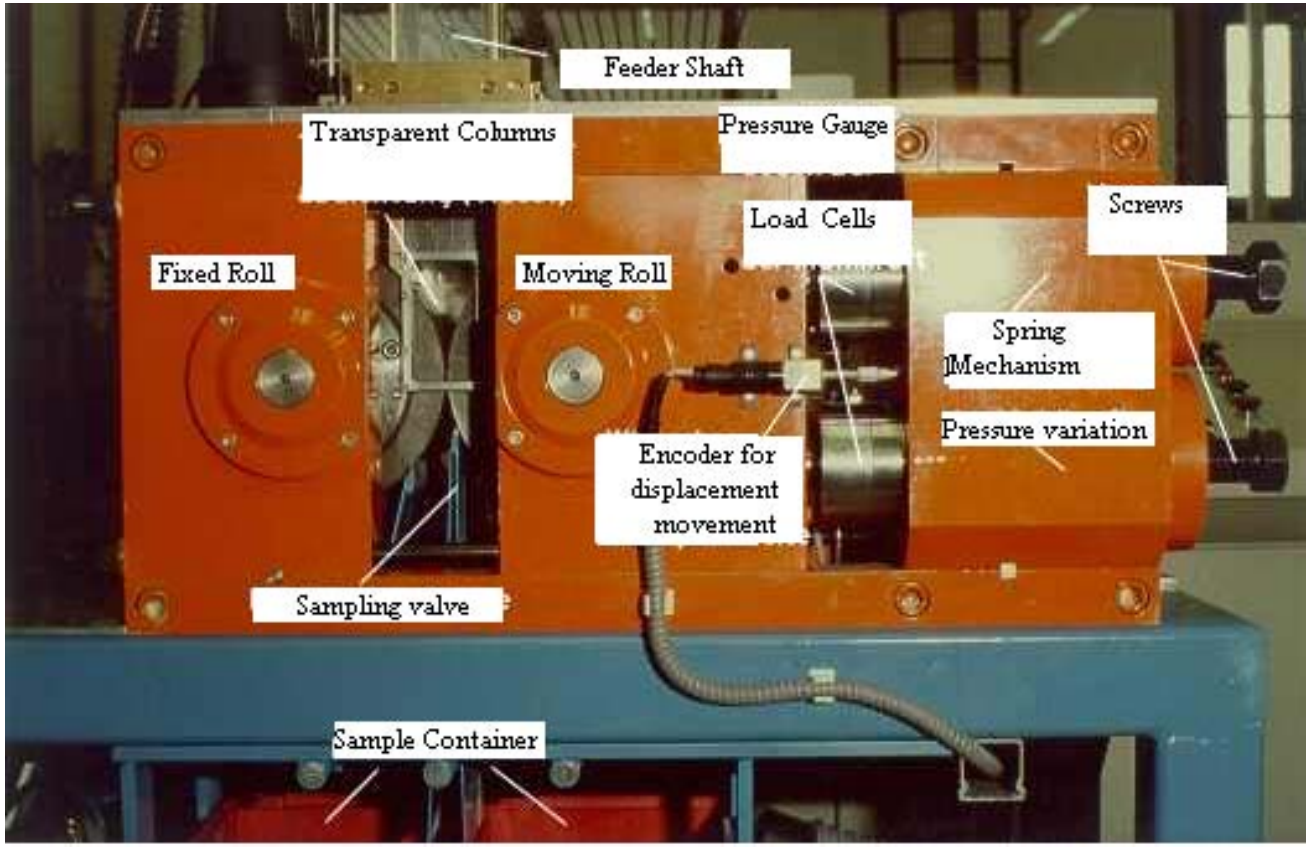
Department of Metallurgical Engineering

- University of Utah is located in Salt Lake City along the Wasatch Mtns.
- Only stand alone Metallurgical Engineering department remaining in the U.S.
- Traditional curriculum with critical mass of professors
  - Mineral Processing
  - Chemical Metallurgy
  - Physical Metallurgy

High Pressure Grinding Rolls (HPGR)

- HPGR consists of a pair of counter rotating rolls, one fixed and the other floating.
- The feed is introduced to the gap in between the rolls and they compress the bed of particles.
- The grinding force applied to the crushing zone is controlled by a hydro-pneumatic spring on the floating roll.
- Speeds of the rolls are also adjustable to obtain optimum grinding conditions.



Comparison of HPGR and AG/SAG Mills

Aspect	HPGR	AG/SAG Mill
Grinding Mechanism	Inter-particle compression	Impact, attrition and compression
Residence Time	Low-single pass	High (feed migrates through length of mill)
Wet/Dry Grinding	Dry-Low moisture	Predominantly wet milling
Availability	>90% -2-4 change outs pa	>90% -1-2 change outs pa
Size regulated feed Required	Yes-strongly affects stud breakage	AG-No, SAG-Sometimes
Critical material size	Not required	Required
Product particle micro-cracking	Yes (beneficial for downstream processes	Negligible
Maximum Throughput	2000tph	4000tph
Footprint	Small	Large
Specific power	1-5kWh/t	5-12kWh/t
Operating cost	Overall plant 20% lower	Overall plant 20% higher
Capital Cost	25% lower	25% higher
Delivery time	Substantially faster	Substantially longer
Variation in feed hardness	Single parameter variable	High losses

•Reference: Koenig, R.L. and Hudson J (2006). "Design Selection for Large-Scale Grinding Operations-AG/SAG or HPGR?", Metallurgical Plant Design and Operating Strategies (MetPlant 2006) 18-19 September 2006, Perth, WA.

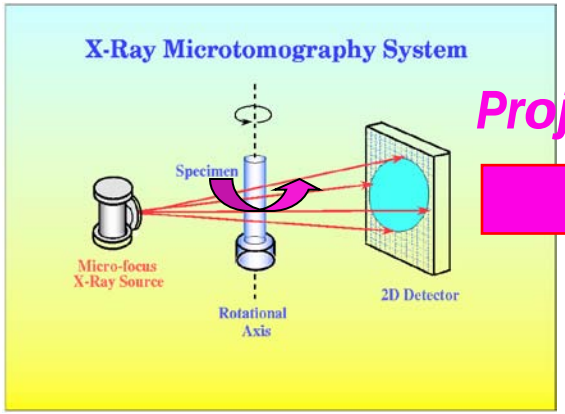
HPGR vs. Jaw Crusher

- Due to the scarcity of water on the lunar surface, dry comminution will be performed.
- HPGR are a likely candidate for to crush and grind regolith material for use in construction and oxygen generation.
- HPGR generate different product particles than conventional crushing

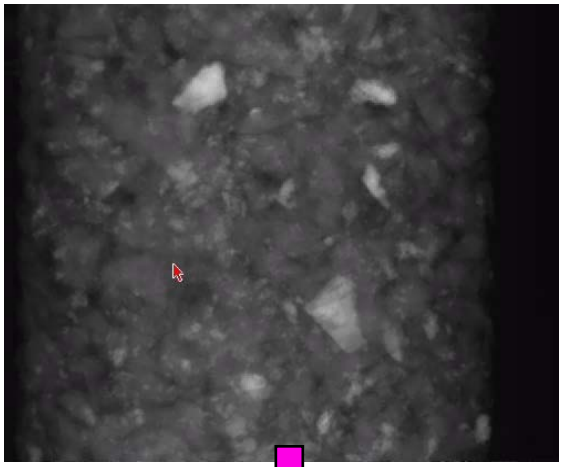
Conventional crushed

HPGR product

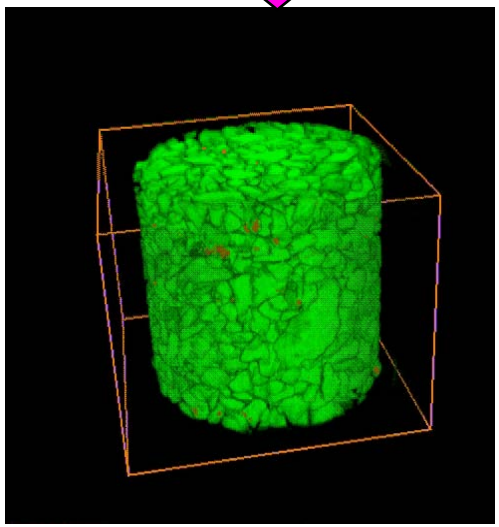
Particle Damage Characterization using XMT



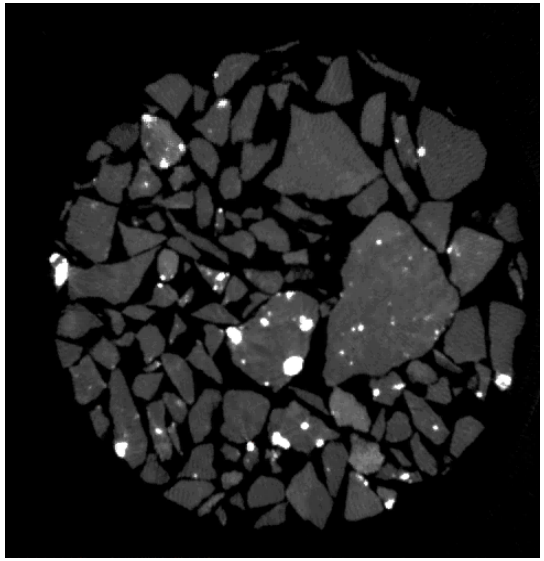
Projection



3D View

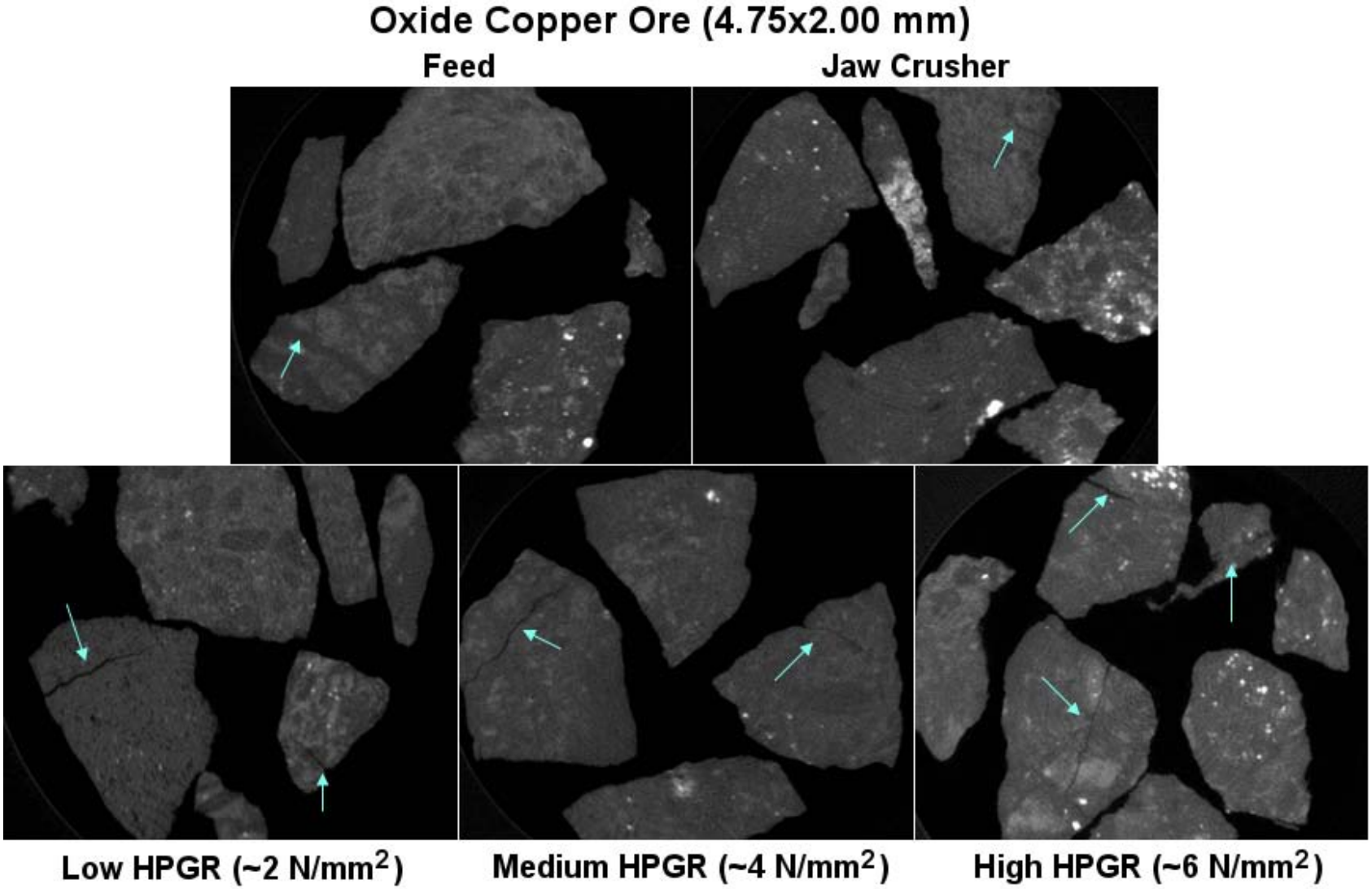


Slice Views



Miller and Lin, Mineral and Metallurgical Processing, 2004

XMT Images of Damage to Oxide Copper Ore Particles



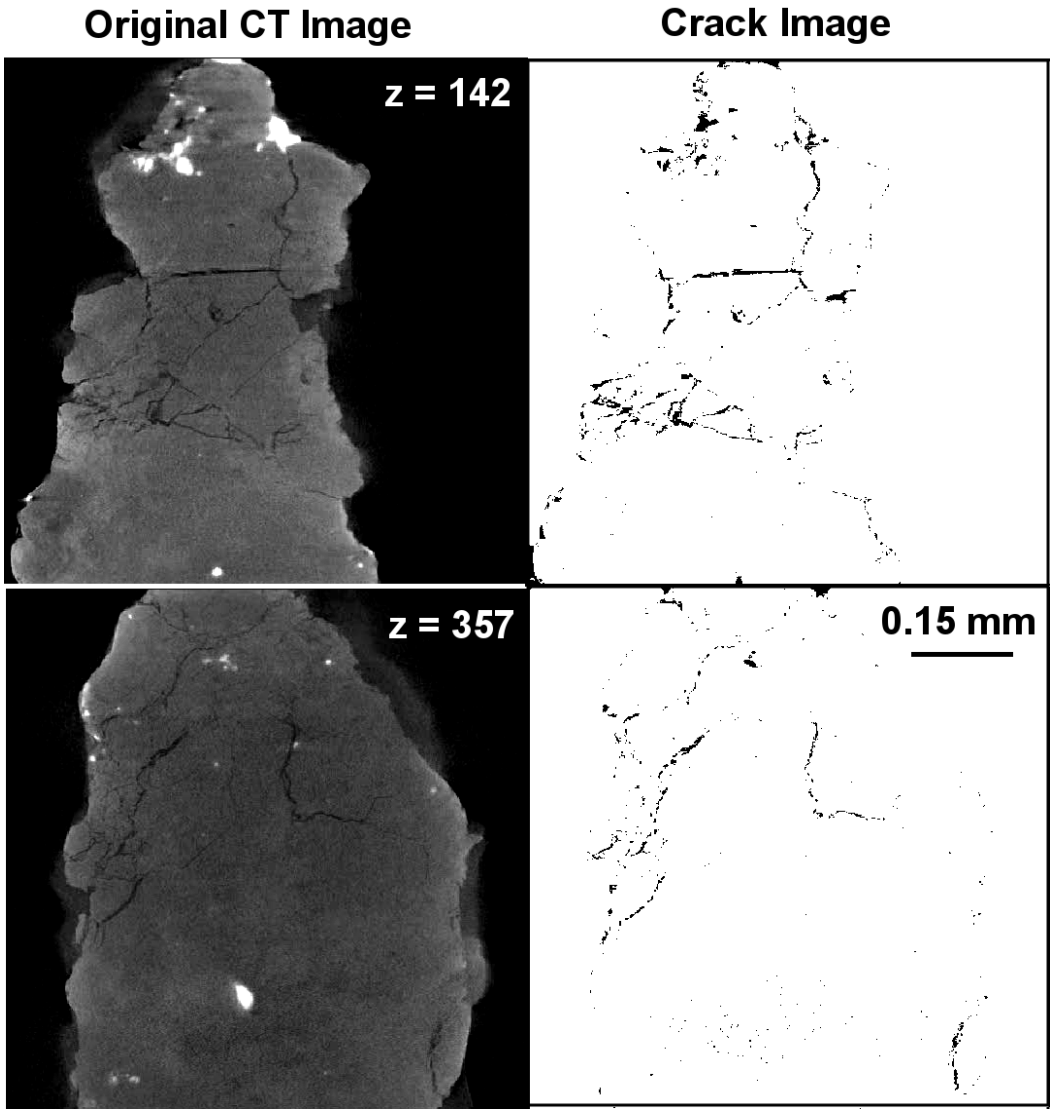
J.D. Miller. “Characterization, Analysis, and Simulation of Multiphase Particulate Systems Using High Resolution X-ray Micro Tomography (HRXMT)” XXV International Mineral Processing Congress (IMPC 2010).

Percent of Damaged Particles for Different Crushing Methods

Crushing Method	Extent of Damage (% of Particles Cracked)	
	Oxide Copper Ore	Sulfide Copper Ore
Feed	14	20
Jaw	14	23
Low HPGR	37	51
Medium HPGR	44	69
High HPGR	79	84

J.D. Miller. “Characterization, Analysis, and Simulation of Multiphase Particulate Systems Using High Resolution X-ray Micro Tomography (HRXMT)” XXV International Mineral Processing Congress (IMPC 2010).

Isolation of Crack Surfaces (Copper Ore , 1.70x0.85 mm)



Miller and Lin, *Recent Advances in Mineral Processing Plant Design*, SME, p.48-59, 2009.

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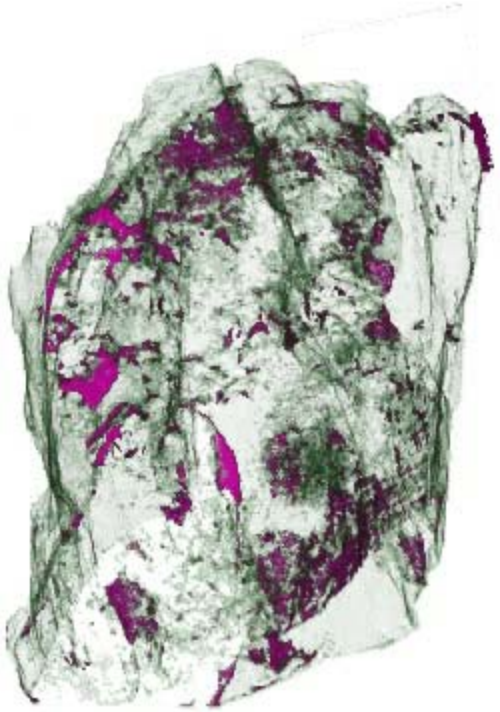


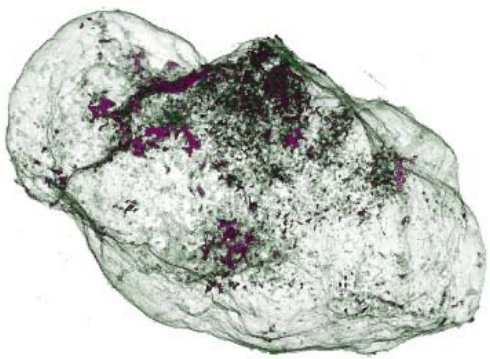
Miller and Lin, *Recent Advances in Mineral Processing Plant Design*, SME, p.48-59, 2009.

Preliminary Crack Information for Damaged Particle of Copper Ore

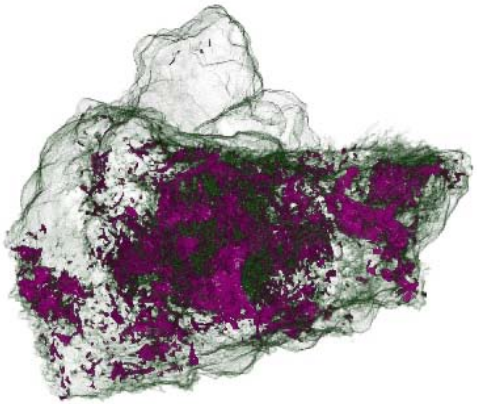
Particle Volume (mm^3)	Total Surface Area of Cracks (mm^2)	Specific crack surface area (mm^2/mm^3)
0.28	2.8	10

HPGR vs. Jaw Crusher

JAW Crusher Product



HPGR Product



The dark areas highlight internal cracks, internal pores, and crack surfaces.

Lin and Miller. SME 2010 Annual Meeting

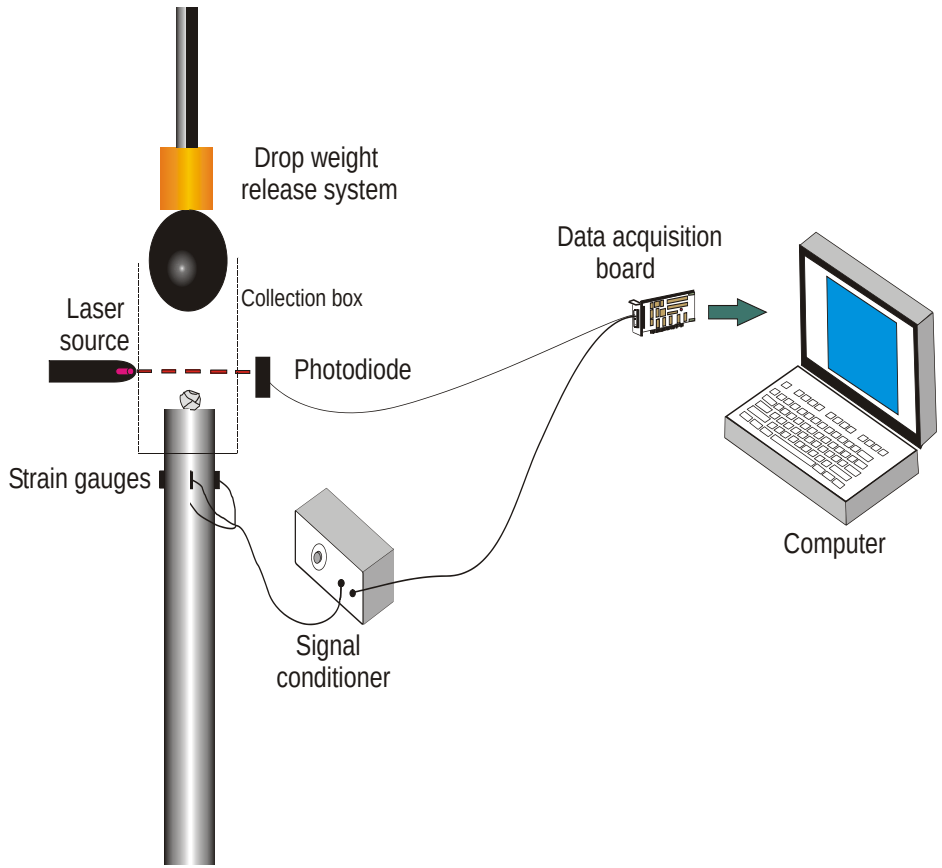
Particle Breakage Energy

- Ultra Fast Load Cell (UFLC)

UFLC is a device supported by electrical equipments to measure the fracture energy of any particle at first fracture under impact loading.

A steel rod of 5 m length is equipped with strain gauges to catch very high resolution signals at the instant of fracture.

Fracture happens in 100 micro-seconds time range



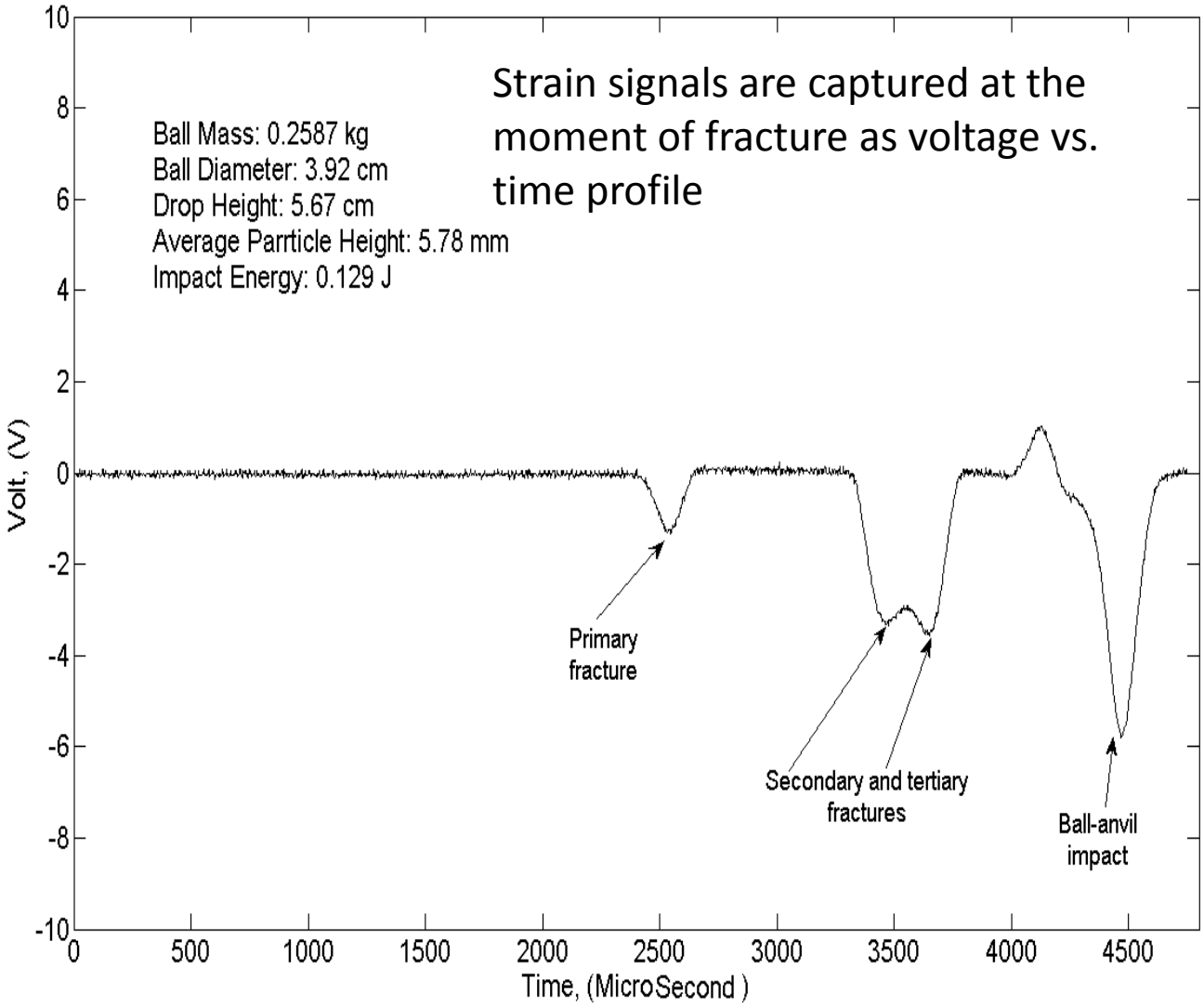
T.Tuzcu, R.Rajamani (2010) “Modeling breakage rates in mills with impact energy spectra and ultra fast load cell data” Minerals Engineering, doi:10.1016/j.mineng.2010.08.017.

Information from UFLC

- UFLC captures high-resolution compressive force signals.
- It provides detailed information about fracture characteristics of the particle under impact loading.
- The measurement of the compressive force at the instant of fracture of the particle allows computation of tensile strength and stiffness of the particle, energy at first fracture, the energy stored by the particle and the residual energy of the falling object after breaking the particle.
- By testing 30 or so particles one can get fracture probability distribution.

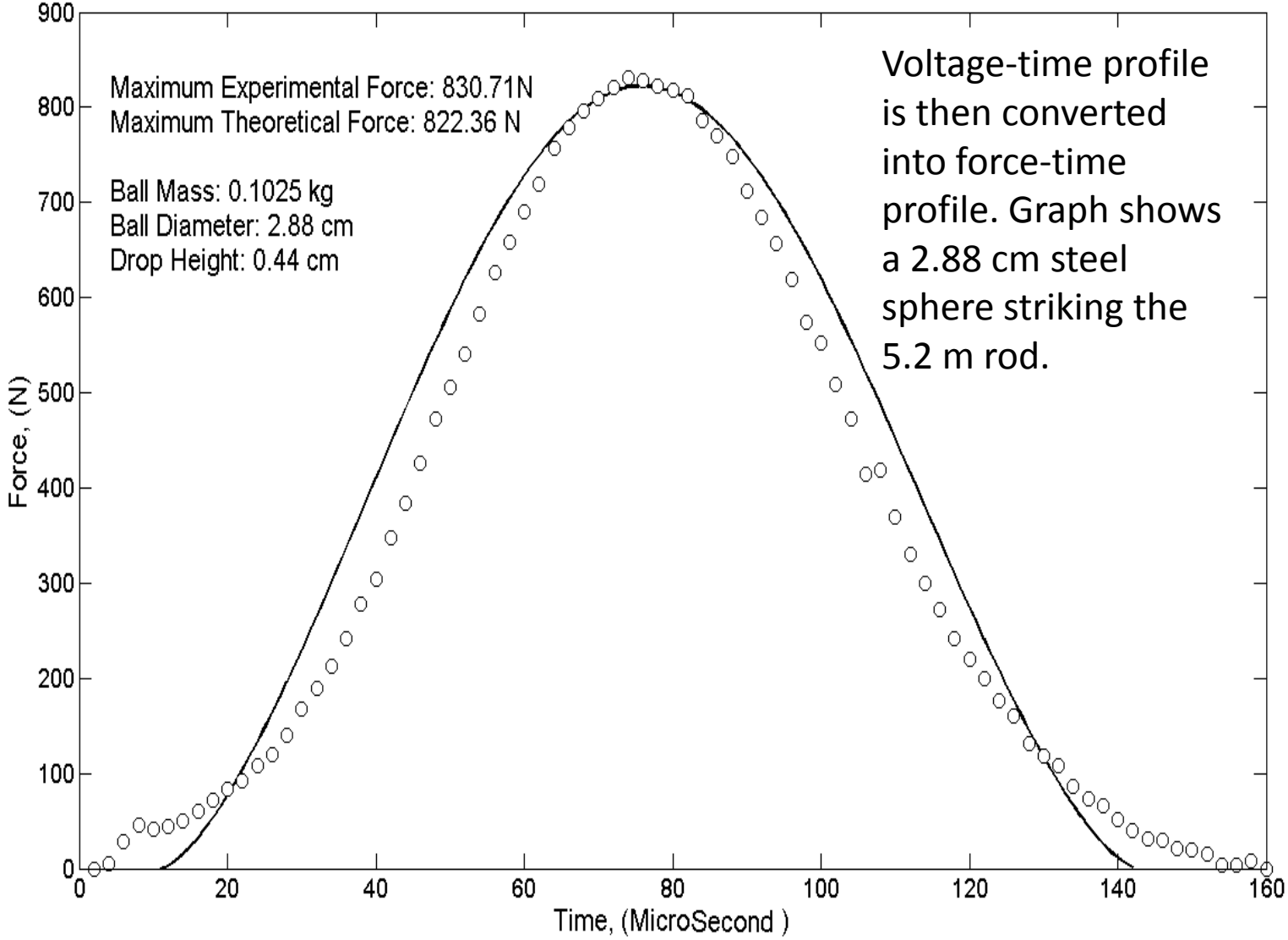
L.M. Tavares and R.P. King, Modeling of particle fracture by repeated impacts using continuum damage mechanics, Powder Technology 123 (2002) 138–146.

Breakage Signature



T. Tuzcu, PhD Dissertation, Univ. Of Utah, 2009

Force – Time Profile



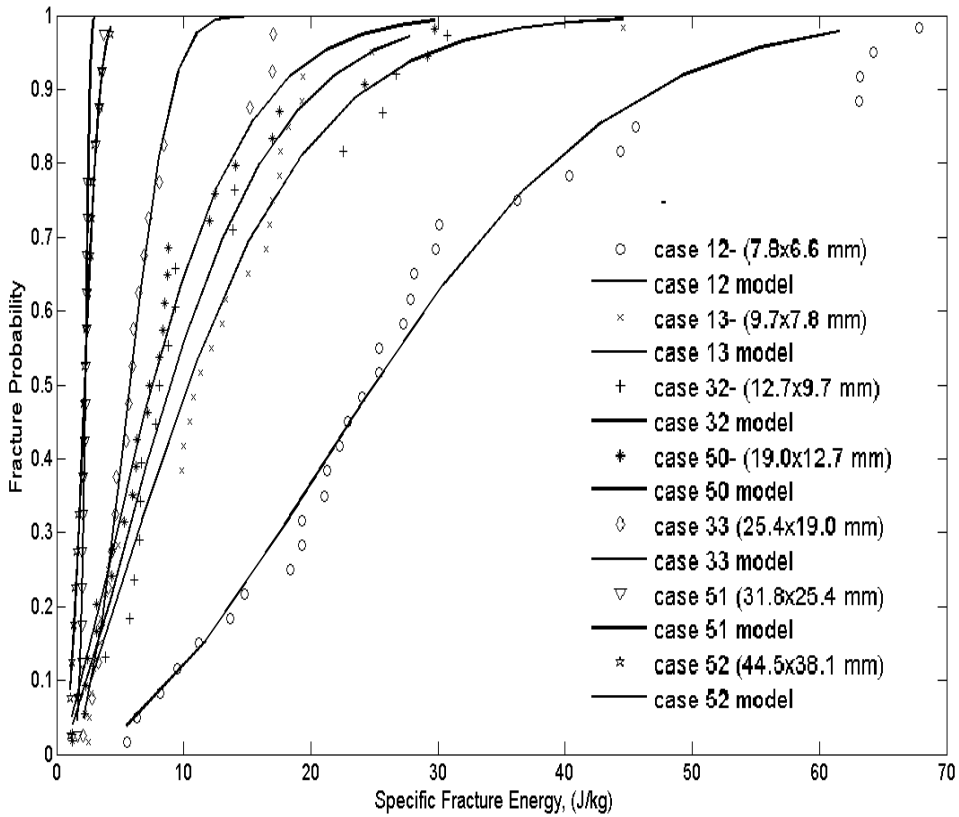
Voltage-time profile is then converted into force-time profile. Graph shows a 2.88 cm steel sphere striking the 5.2 m rod.

T. Tuzcu, PhD Dissertation, Univ. Of Utah, 2010

Probability of Fracture

Particles exhibit different fracture energy due to their random internal flaw size distribution. Graph shows the probability of fracture of a particle at a specified energy. Then, it can be decided whether a particle will break or not under a particular loading.

The probability of breakage also depends on the damage state of the particle. Our research program can integrate information from XMT and UFLC to improve our understanding of particle breakage phenomena.



T. Tuzcu, PhD Dissertation, Univ. Of Utah, 2010

Application to Simulant Development

- Comminution methods affect simulant particles
  - Particle size and shape
  - Internal defects
  - Energy consumption for subsequent breakage
- Internal characterization of lunar regolith and simulant would strength understand of the materials
  - Internal crack/damage specification would be desirable to insure better simulant
- Breakage signature is another way to characterize simulant and evaluate energy needed for comminution on the lunar surface

Thank You for Your Attention
Questions?

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