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Experimental Validation of an Elastic-Plastic Contact Model

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Component Science and Mechanics

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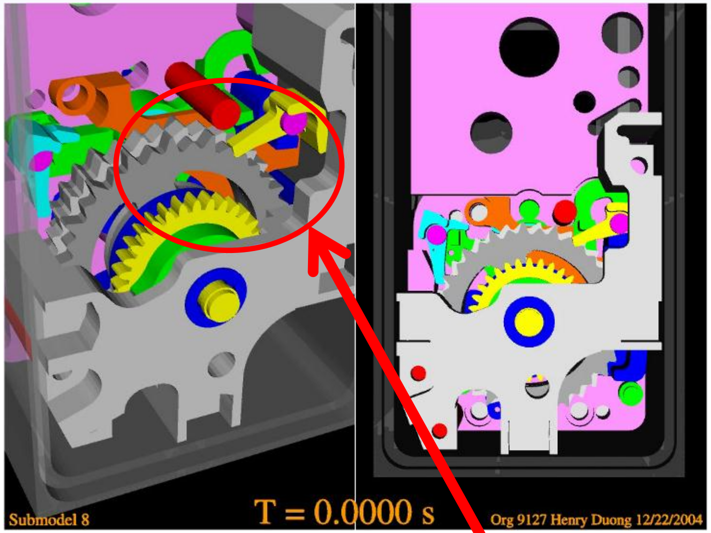
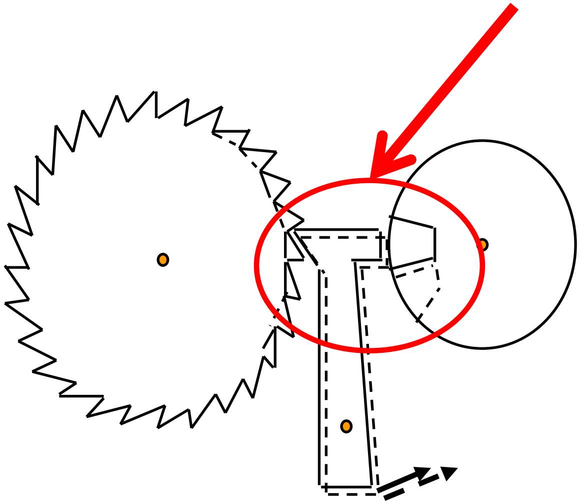
Elastic Plastic Contact Dynamics

- **Project Goals:**
  - Develop a predictive elastic-plastic contact law
  - Develop an experimental method to validate models
- **Motivation**
  - Elastic-plastic contact is often modeled in an ad hoc manner
  - Even using FEA can lead to incorrect results

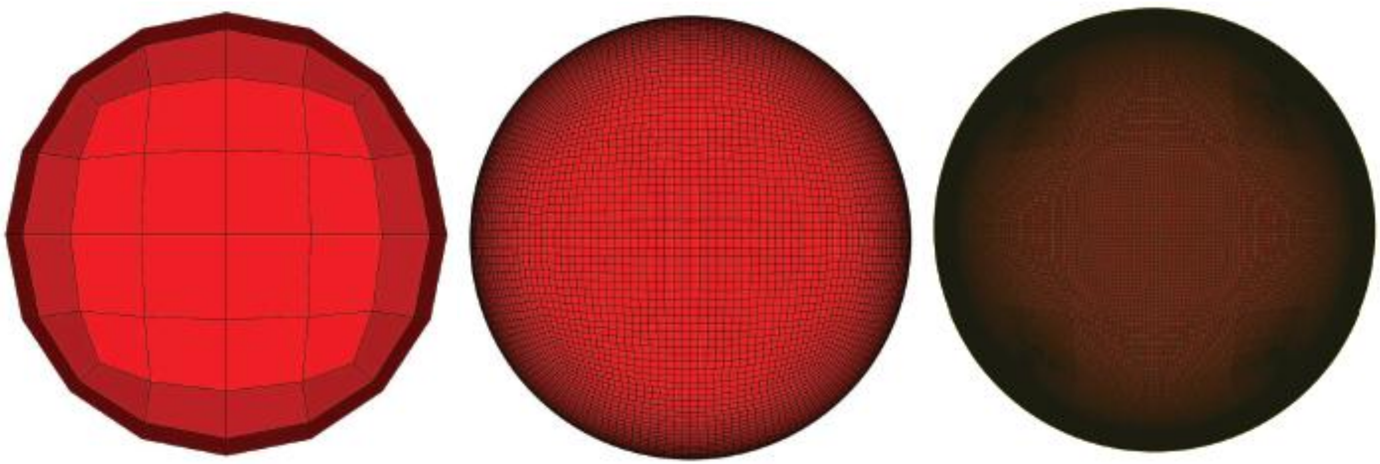


Key impact events



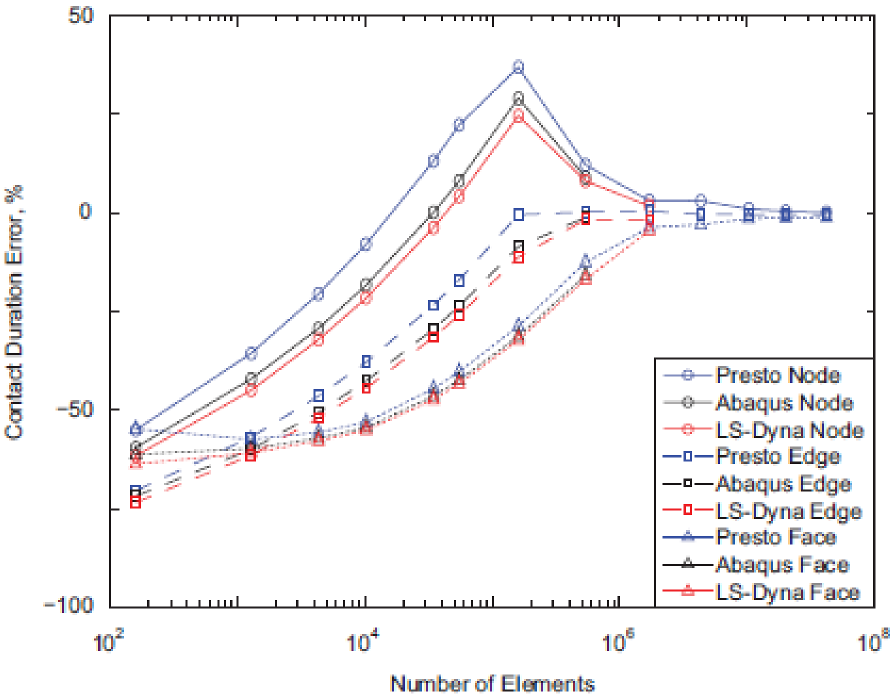
High Fidelity Numerical Modeling Is Impractical For General Problems

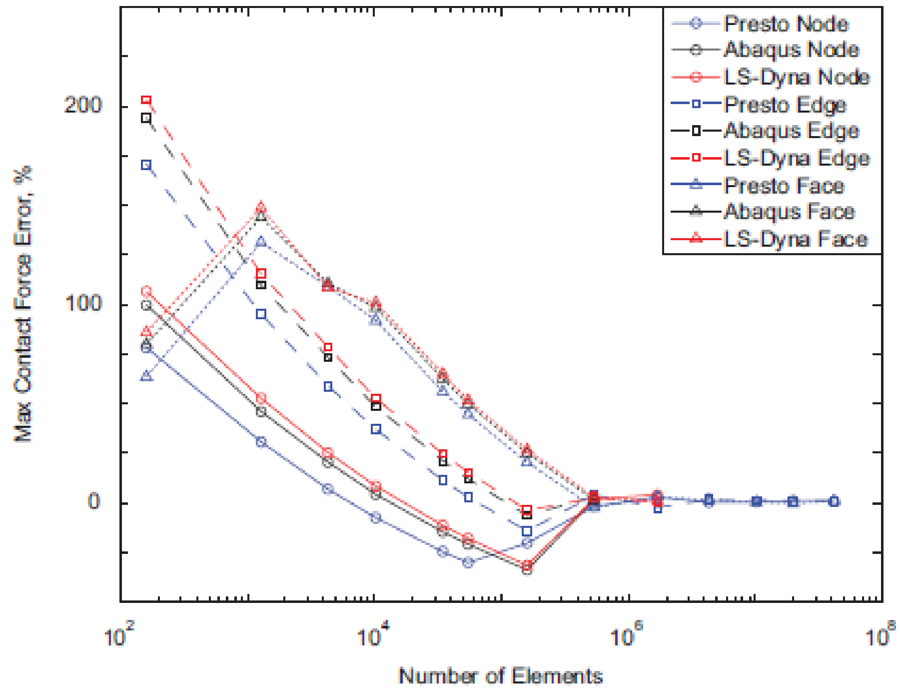
- In real systems, contact can occur at arbitrary locations
- Important for numerical studies to use unbiased meshes for accurate computational estimates
- Coarsest, medium, and finest meshes shown:



Refinement Level	Circumferential Intervals	Element Size, mm	Element Size/Radius, mm	Number of Elements
1	16	9.97	2.5	160
2	32	4.99	5.1	1,280
3	48	3.32	7.6	4,320
4	64	2.49	10.2	10,240
5	96	1.66	15.3	34,560
6	112	1.42	17.8	54,880
7	160	1.00	25.5	160,000
8	240	0.66	38.2	540,000
9	352	0.45	56.0	1,703,680
10	480	0.33	76.4	4,320,000
11	640	0.25	101.9	10,240,000
12	800	0.20	127.3	20,000,000
13	1024	0.16	163.0	41,943,040

High Fidelity Numerical Modeling Is Impractical For General Problems

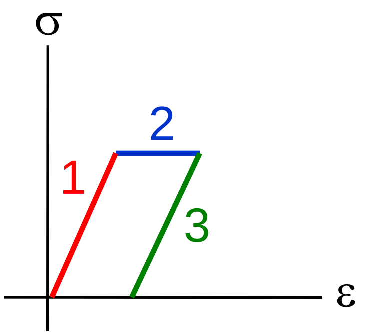


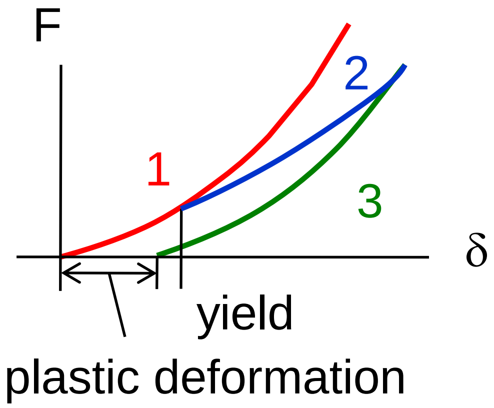


- **Numerical solutions compared to analytical (Hertzian) solution for elastic contact**
- **An impractical number of elements is required to accurately model contact in just the elastic regime**

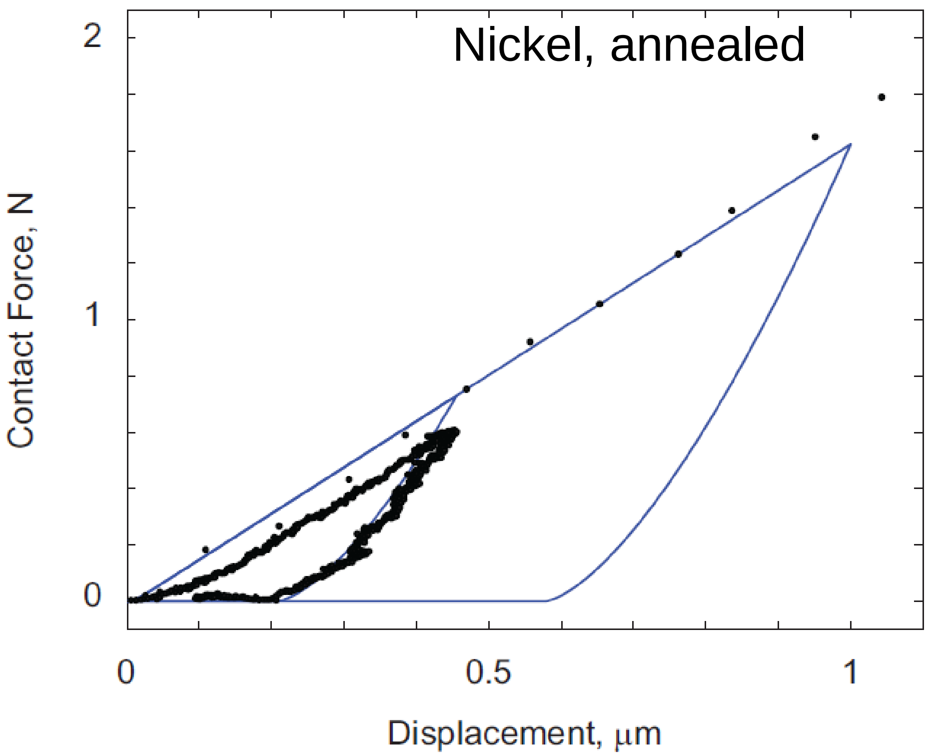
Overview of Our Elastic Plastic Impact Model

- **Deflection divided into three phases:**
  - Elastic loading (1)
    - Hertzian force-deflection relationship
    - Spans from the initial contact until the onset of yielding
  - Mixed Elastic-Plastic and Plastic loading (2)
    - Transition regime from elastic to unconstrained (plastic) flow defined using hardness properties
    - Linear force-deflection relationship in fully plastic regime (elastic-perfectly plastic behavior only…)
    - Strain hardening incorporated using the Meyer's hardness index
  - Elastic unloading (3)
    - Hertzian, but with a different contact radius than for loading
    - A portion of the plastic deflection is unrecoverable

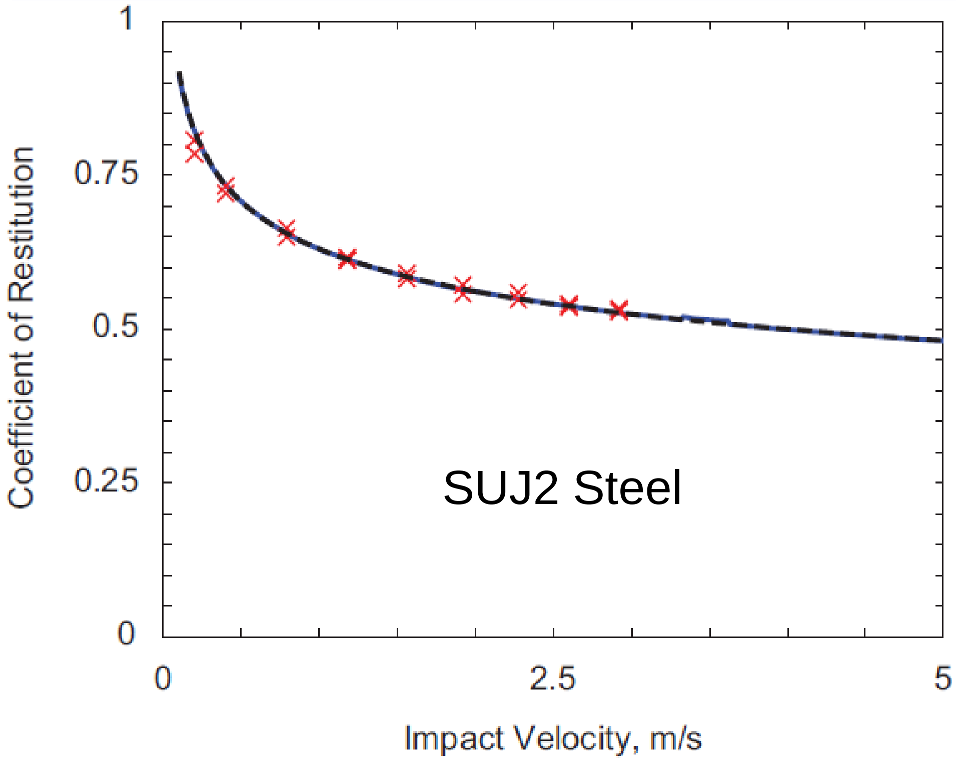




Direct v. Indirect Validation



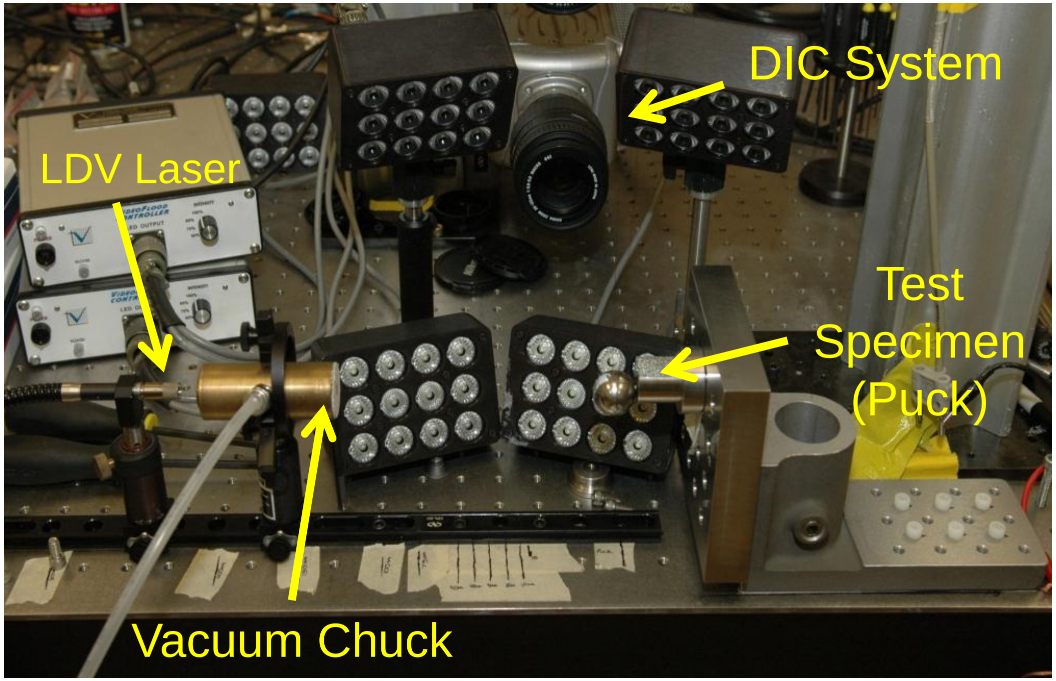
Alcala, Giannakopoulos, and Suresh, “Continuous Measurements of Load-Penetration Curves with Spherical Microindenters and the Estimation of Mechanical Properties,” Journal of Materials Research, 13 (1998), 1390-1400.



Minamoto and Kawamura, “Effects of Material Strain Rate Sensitivity in Low Speed Impact Between Two Identical Spheres,” International Journal of Impact Engineering, 36 (2009), 680-686.

- **Direct validation: compliance tests**
- **Indirect validation: rebound tests**

Experimental Validation
Test Configuration



- **Approximately 2.2 m long pendulum, suspended on a knife edge**

Material Characterization

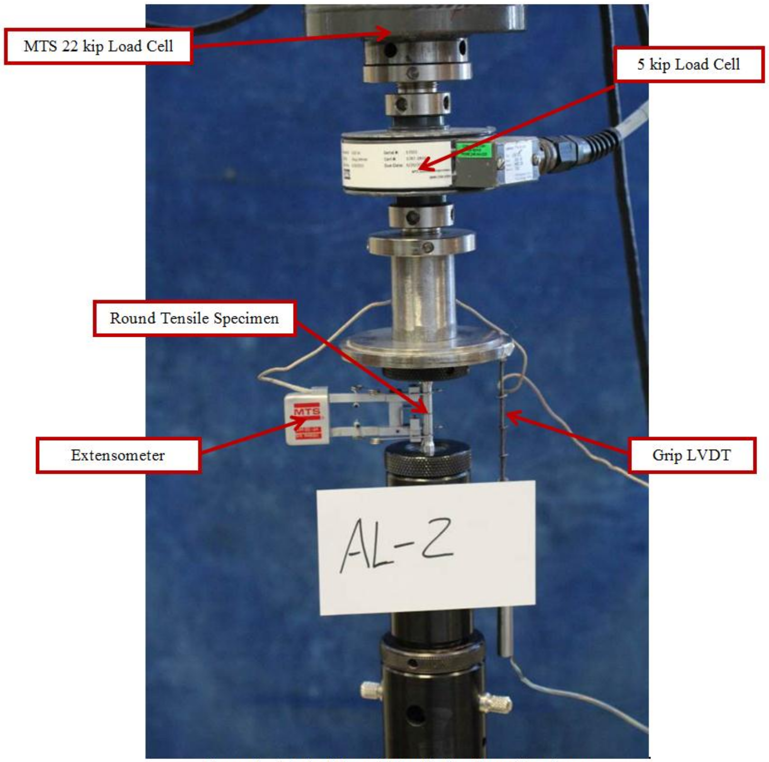
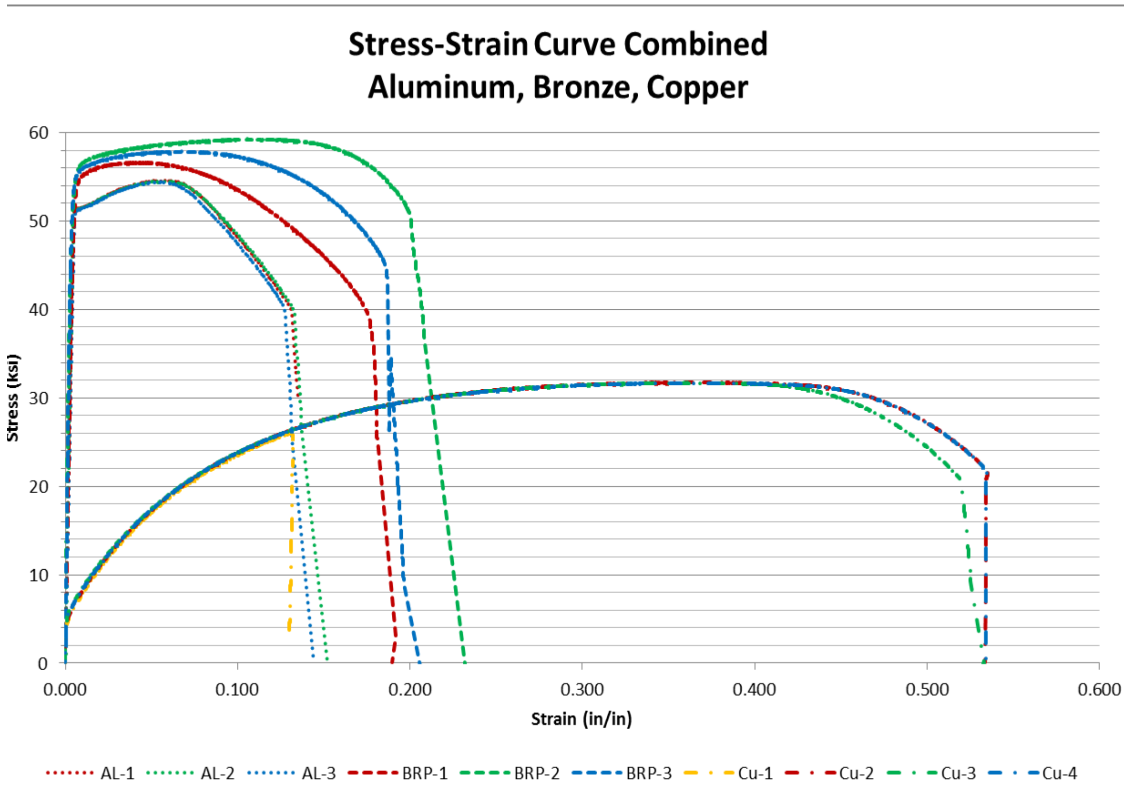
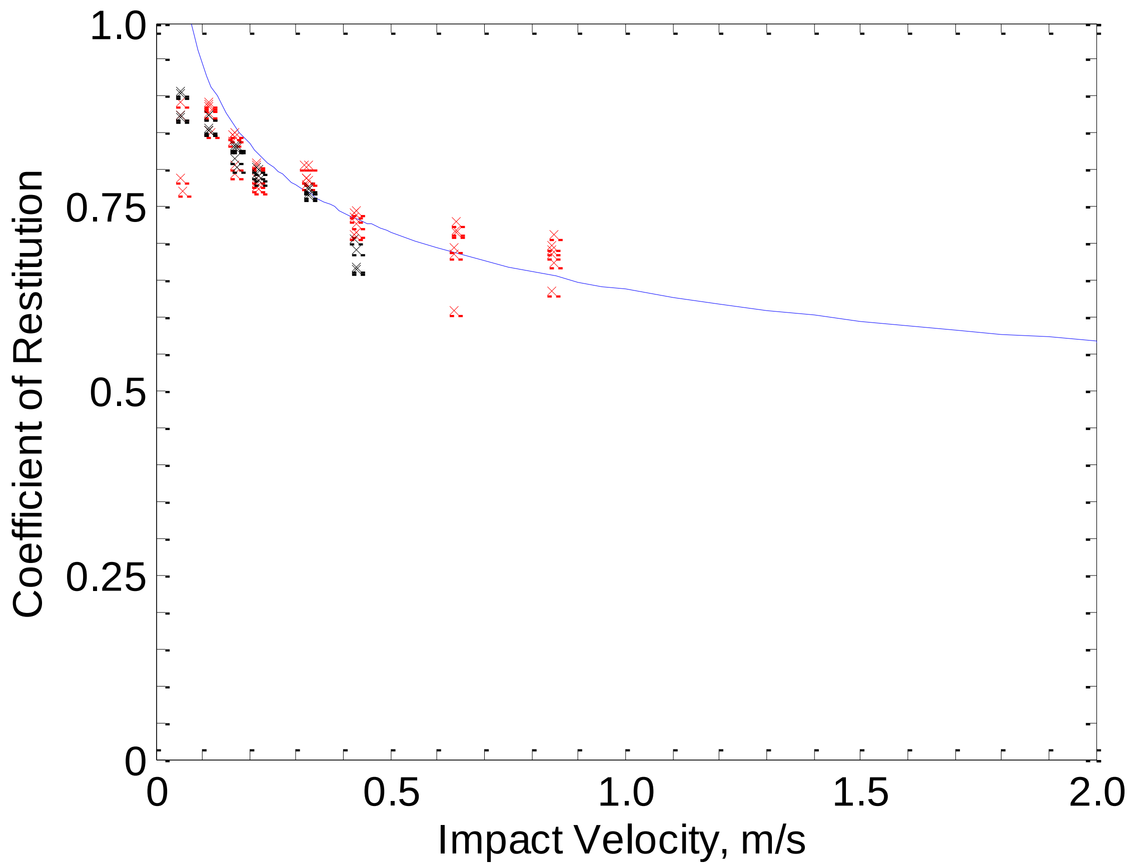


Figure 1 – Typical Round Tensile Specimen Test Setup



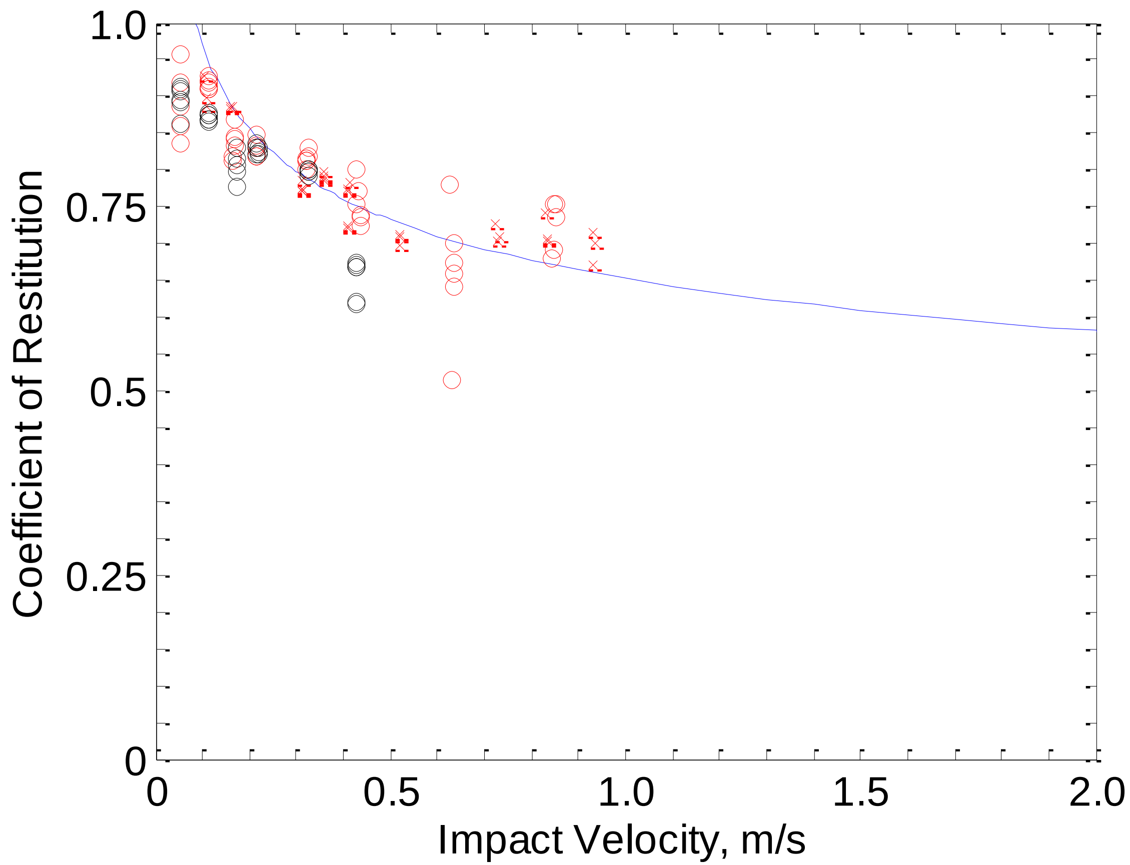
- **Hardness and density measured separately**

Nitronic 60 Measurements



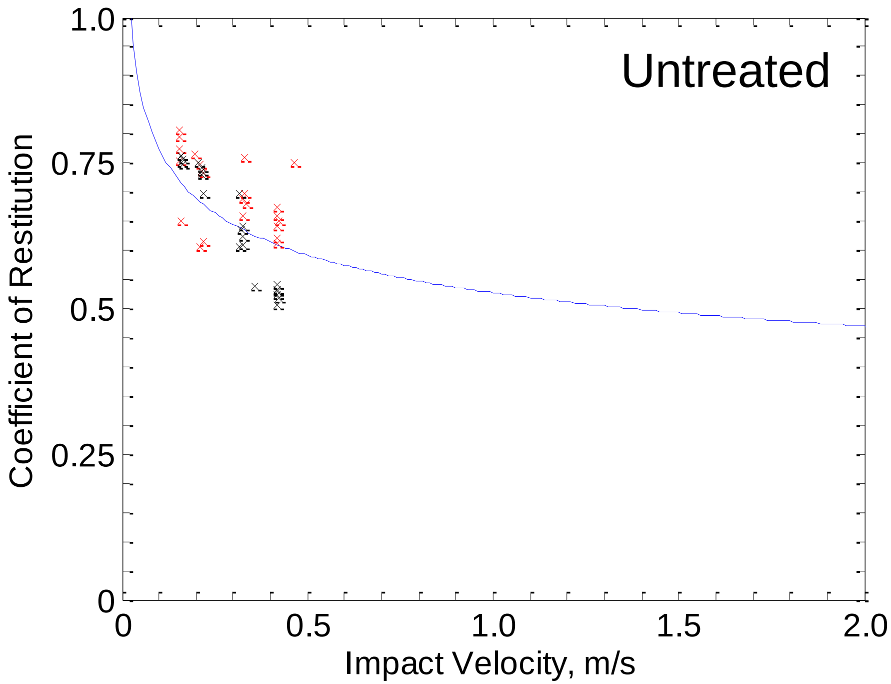
- **Nitronic 60 Impact Plate**
- **440c Grade 100 Wear Resistant Stainless Steel Sphere**
- **x : DIC measurements; x : LDV measurements**

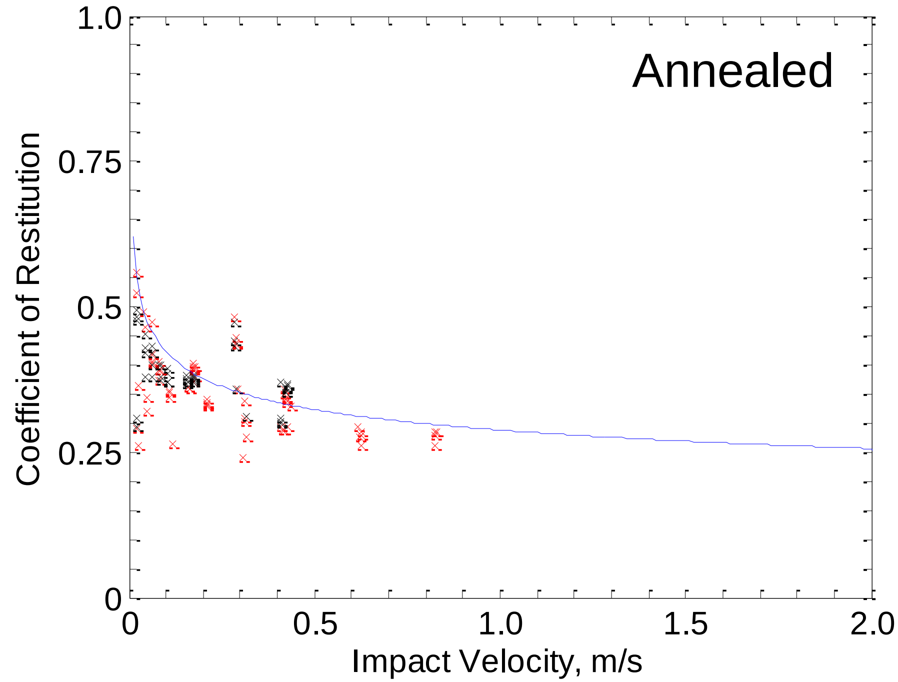
SS304 Measurements



- **AISI 304 Stainless Steel Impact Plate**
- **440c Grade 100 Wear Resistant Stainless Steel Sphere**
- **o : DIC measurements; o : LDV measurements; x : DIC 2011 measurements**

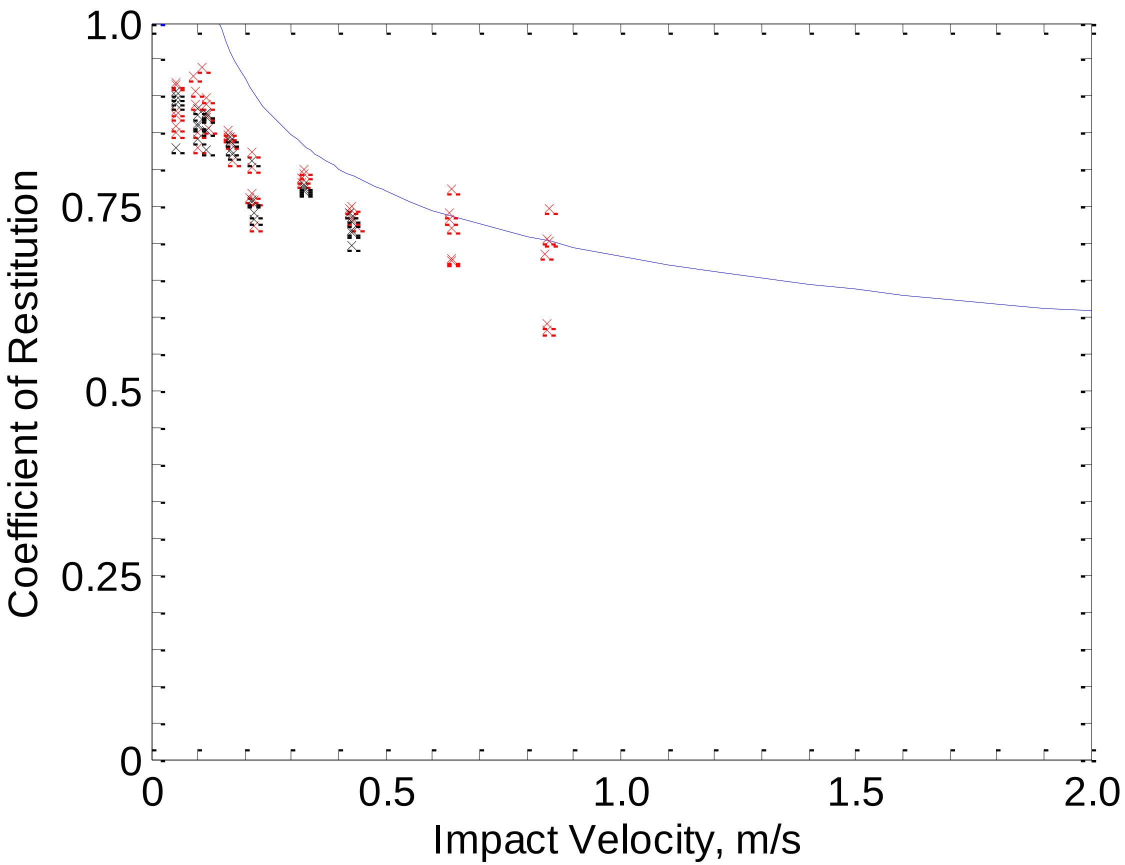
110 Select ETP Copper Measurements





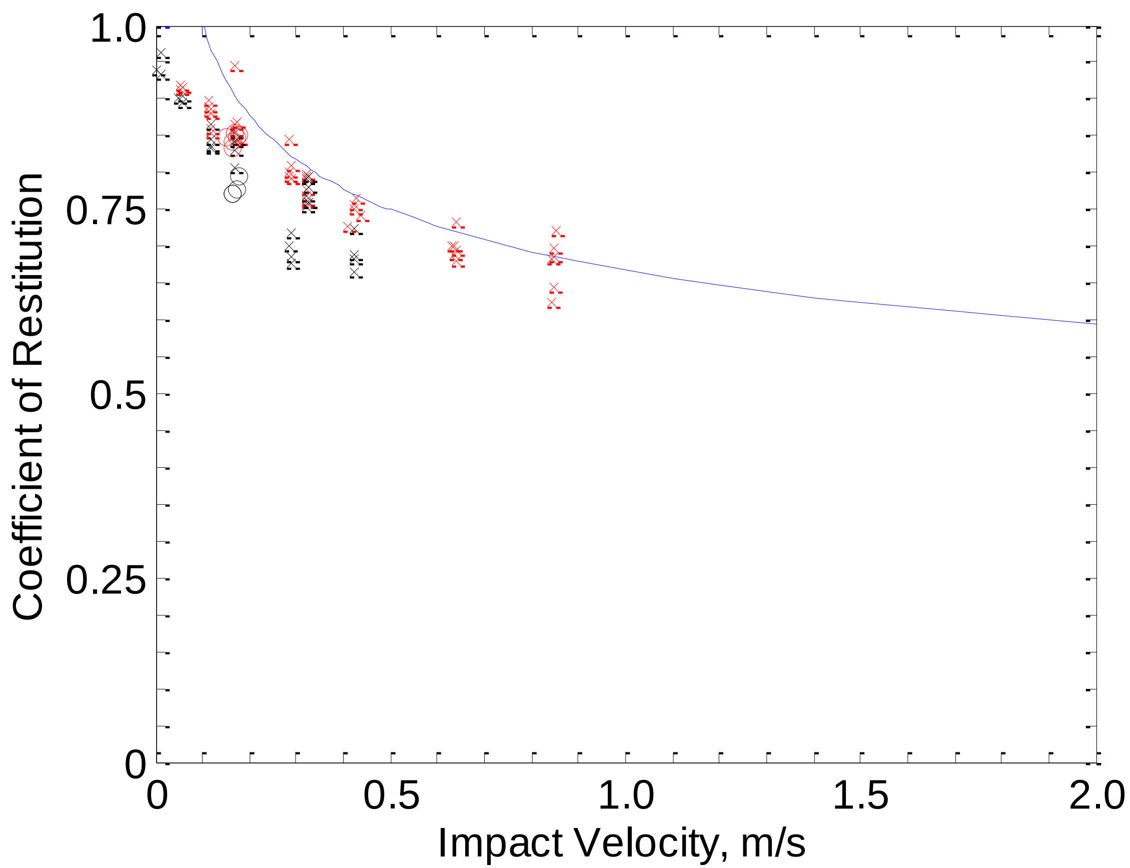
- 110 Select ETP Copper Impact Plate
- 440c Grade 100 Wear Resistant Stainless Steel Sphere
- x : DIC measurements; x : LDV measurements

Aluminum 6061-T6 Measurements



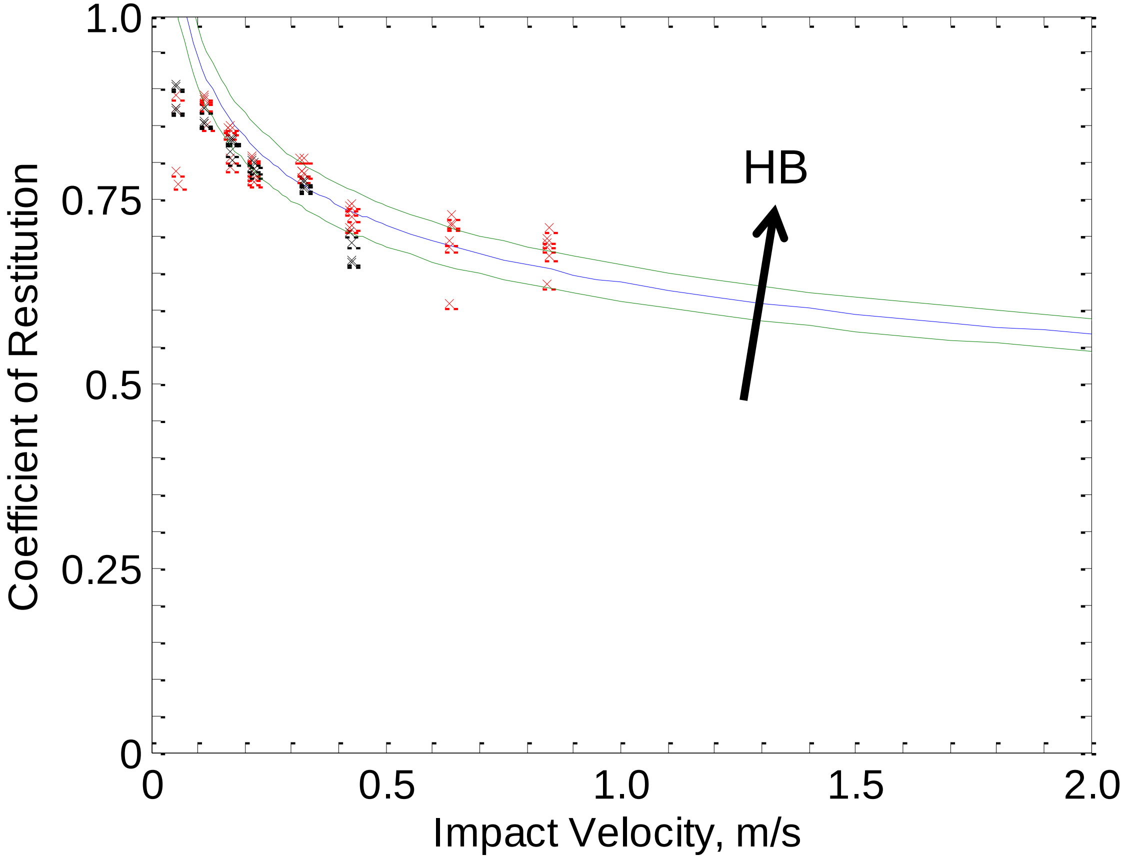
- **Aluminum 6061-T6 Impact Plate**
- **440c Grade 100 Wear Resistant Stainless Steel Sphere**
- **x : DIC measurements; x : LDV measurements**

Phosphor Bronze, Alloy 510 Measurements



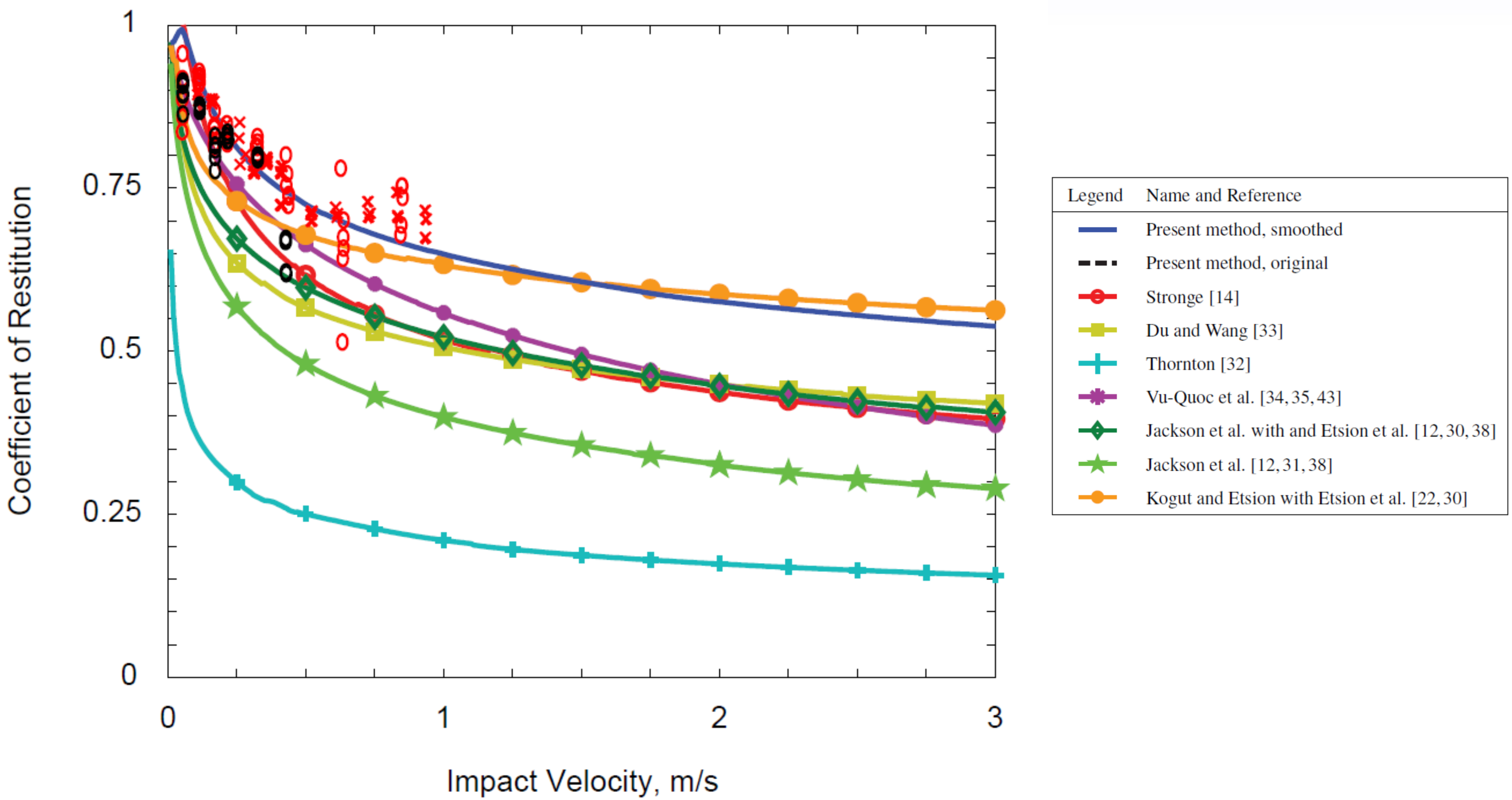
- Phosphor Bronze Alloy 510 Impact Plate
- 440c Grade 100 Wear Resistant Stainless Steel Sphere
- x : DIC measurements; x : LDV measurements
- o : Preliminary measurements for reducing off-axis motion

Effect of Hardness Variation Nitronic 60 Measurements



- **Nitronic 60 Impact Plate**
- **Hardness measurements showed a +/- 10% variation across the specimen**

Comparison to Other Models in the Literature for SS304



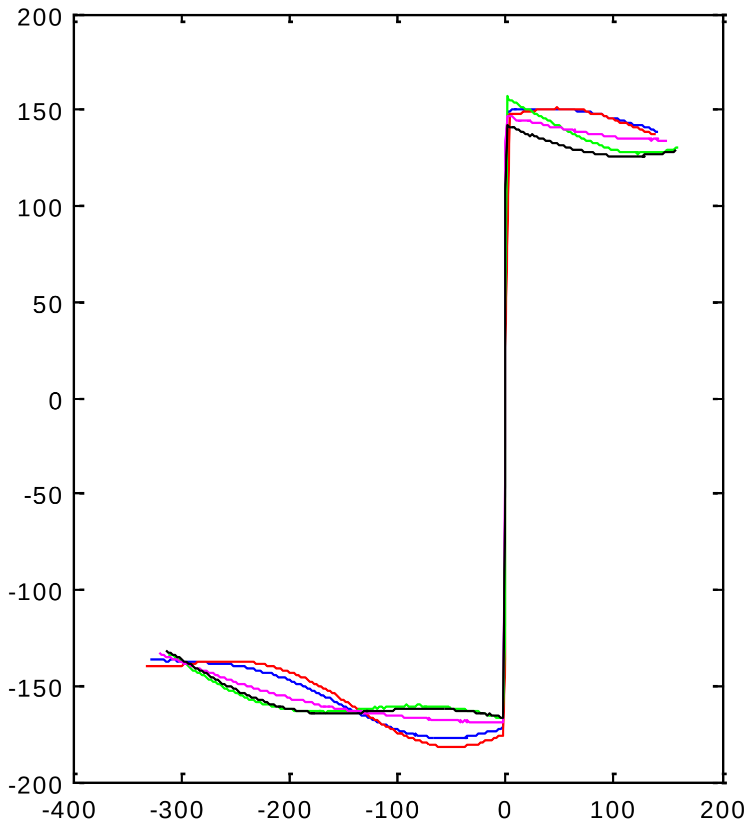
- **Present model shows much higher agreement than other models**

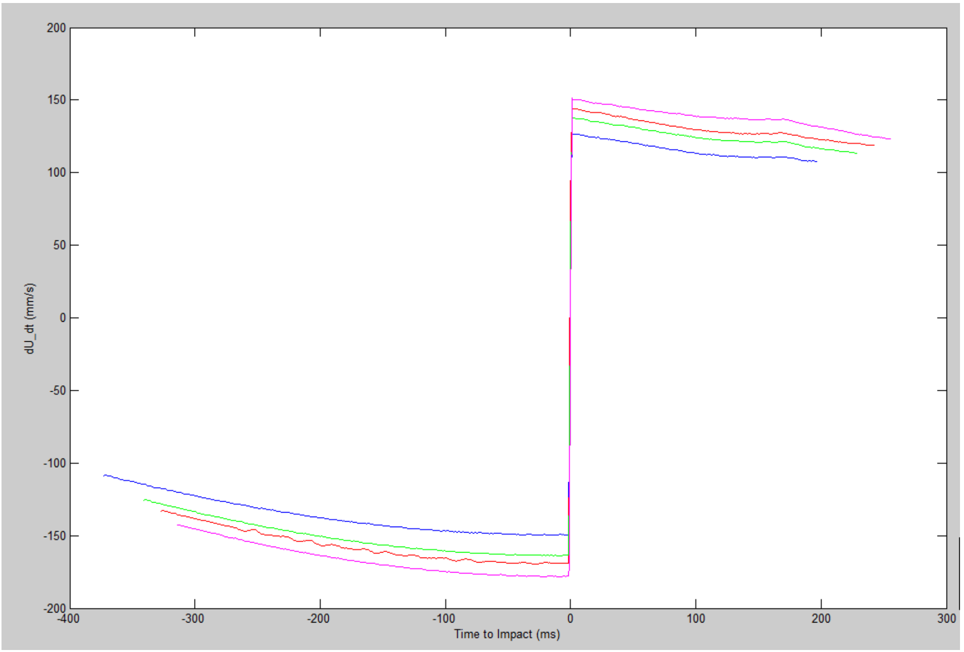
Summary

- **An experimental capability has been developed to study losses that occur during rebound**
- **This experimental capability has been used to validate a newly developed elastic-plastic contact law**
- **The elastic-plastic model is based entirely on material properties, requires no calibration, and is thus easily extended to new materials**
- **Future work is focused on minimizing off-axis motion and oblique (frictional) impacts**

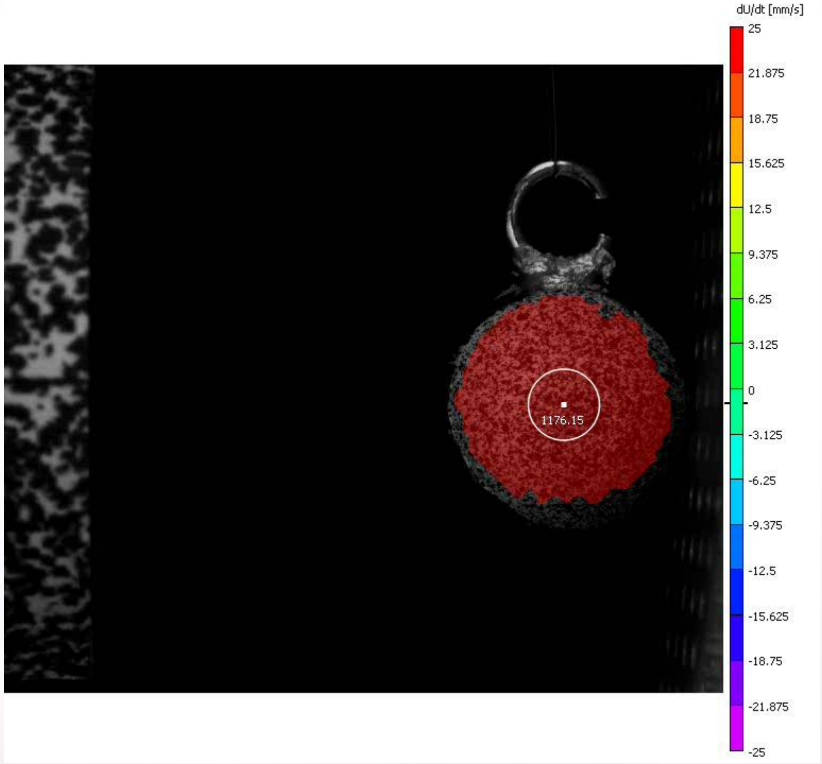
Future Work

- **Minimizing off-axis motion**
  - Bronze Phosphor at 75mm
  - Sphere allowed to swing freely for several minutes before the impact test





Questions?


dU/dt [mm/s]
25
21.875
18.75
15.625
12.5
9.375
6.25
3.125
0
-3.125
-6.25
-9.375
-12.5
-15.625
-18.75
-21.875
-25
1176.15