Imparting Residual Stresses in Ceramics via High Speed Impact

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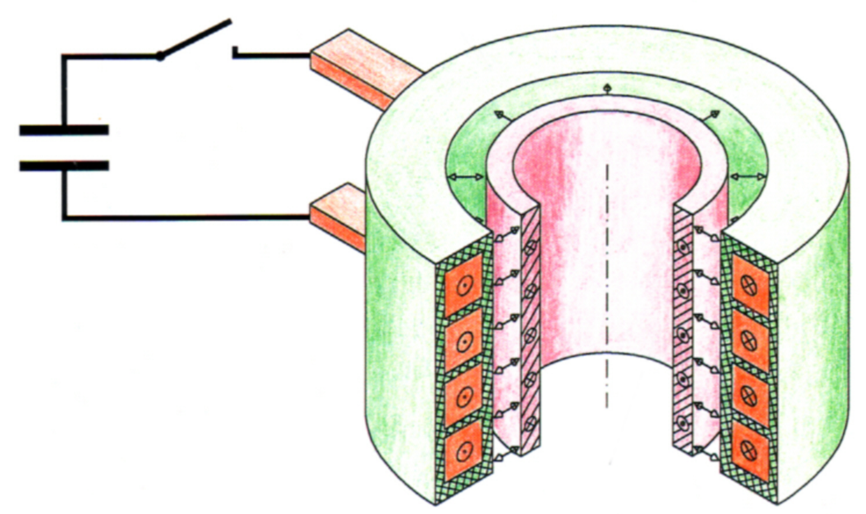
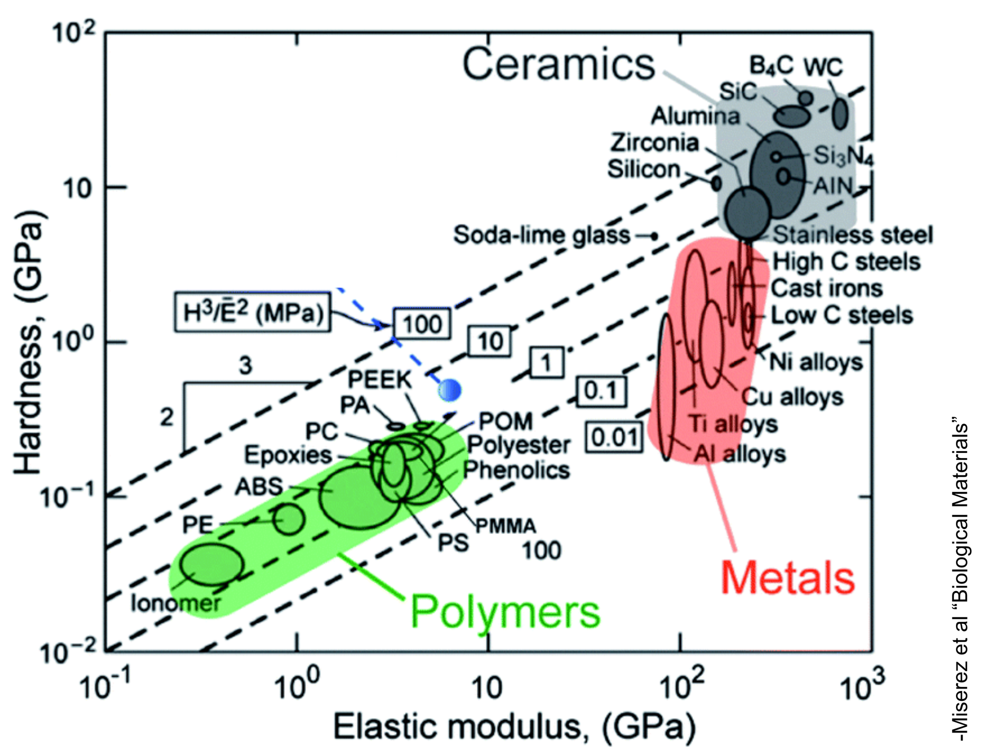
Project Objective: To perform a feasibility study of imparting residual stress in Alumina ceramics through high-speed impacts in a controlled Electromagnetic (EM) environment.

Absract



- Residual Stress can change material properties.
- Tempered Glass is an excellent example, with the glass pressed in one direction allows an increased resistance to shattering in another direction.
- EM Forming can allow for a highly controlled stress application. Potentially allowing for solid state welds between very dissimilar substances.

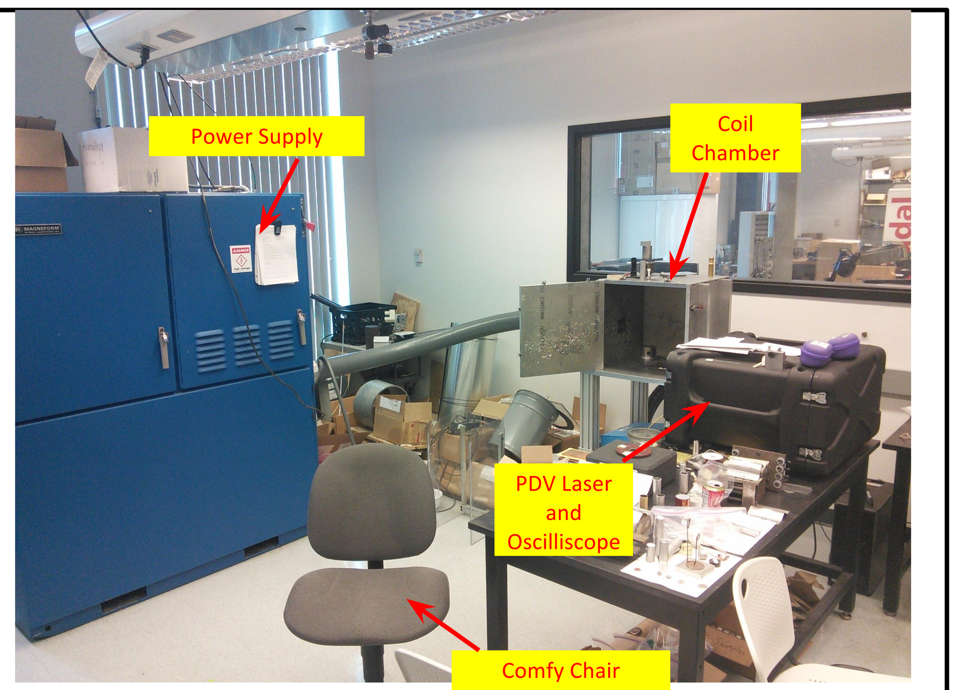
Background



- The zone in which ceramic deforms without failing is very small and at very high pressure.
- Ceramic varies in its response to EM fields but when centered can be impacted by a metal tube.
- Ceramics are traditionally hard, brittle, stiff and fail abruptly at high pressure. Controlled impact may affect these properties.

Impacted metal samples on the left, unimpacted ceramic samples on the right.

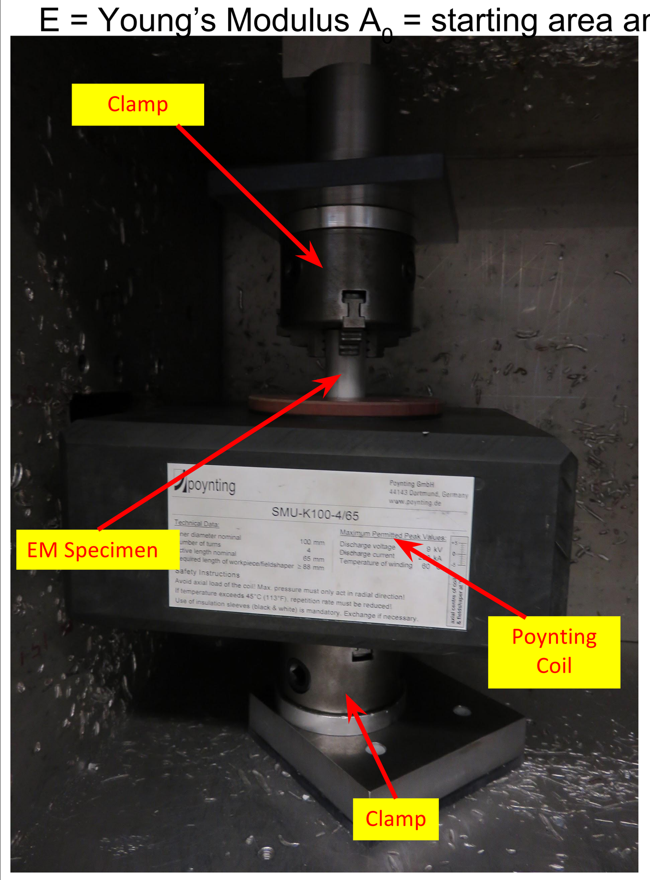
Methods



- A Photon Doppler Velocimetry (PDV) system was used to find exact high velocities of deforming metal tubes at different field strengths.
- The laser for the PDV was placed inside the tubes to avoid interacting with the field shaper.
- With accurate velocity and time measurement, calculations of pressure, kinetic energy and optimal gap distance could be predicted.

$$dx = v\,dt \qquad KE = \frac{1}{2}mv^2 \qquad F = \frac{EA_0\Delta L}{L_0}$$

Where x is position, v is velocity, KE is Kinetic Energy, m is mass, F is force E = Young's Modulus A_0 = starting area and L is tube wall position.

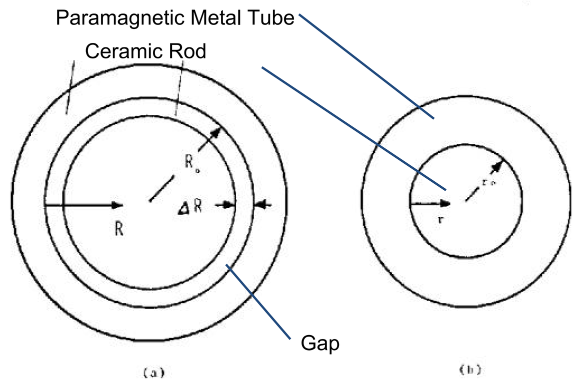


EM Deformation Chamber: Poynting Coil & Sample Control

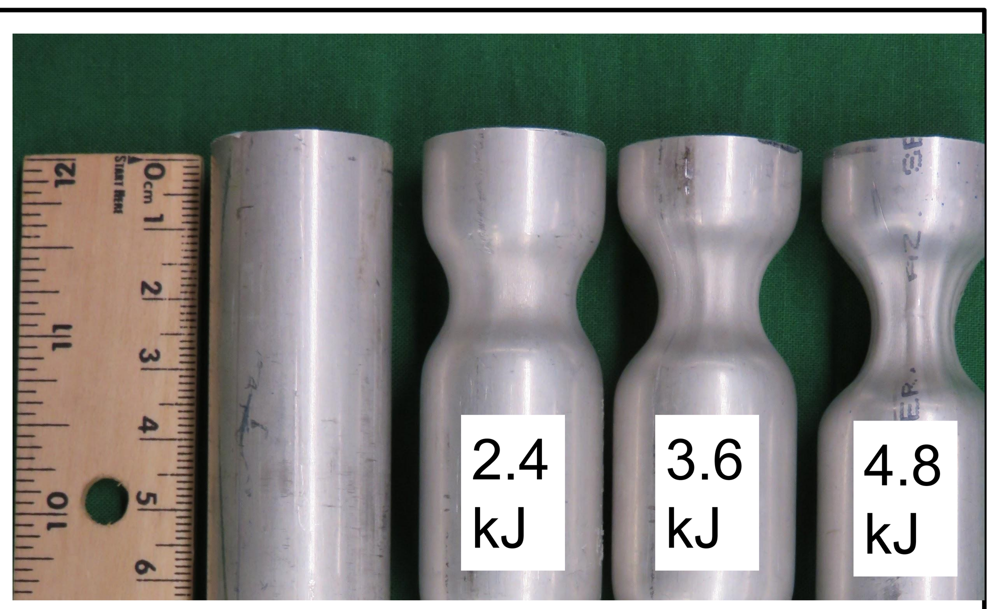
Poynting Coil Specifications

Machine Specifications	Value	Units
Inner Diameter	100	*mm*
Coil Turns	4	*turns*
Max Field Length	65	*mm*
Max Voltage	9	*kV*
Max Amperage	200	*kA*

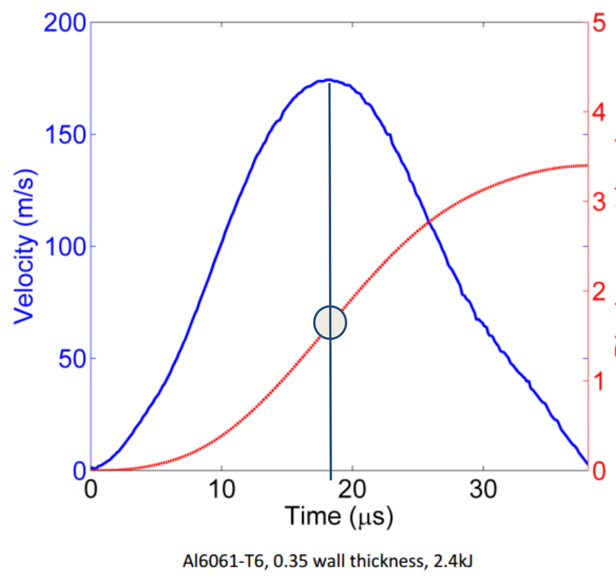
Cross section of a ceramic rod inside a metal tube before (a) and after (b) EM deformation.
Delta R is the acceleration gap.



Experimental Results



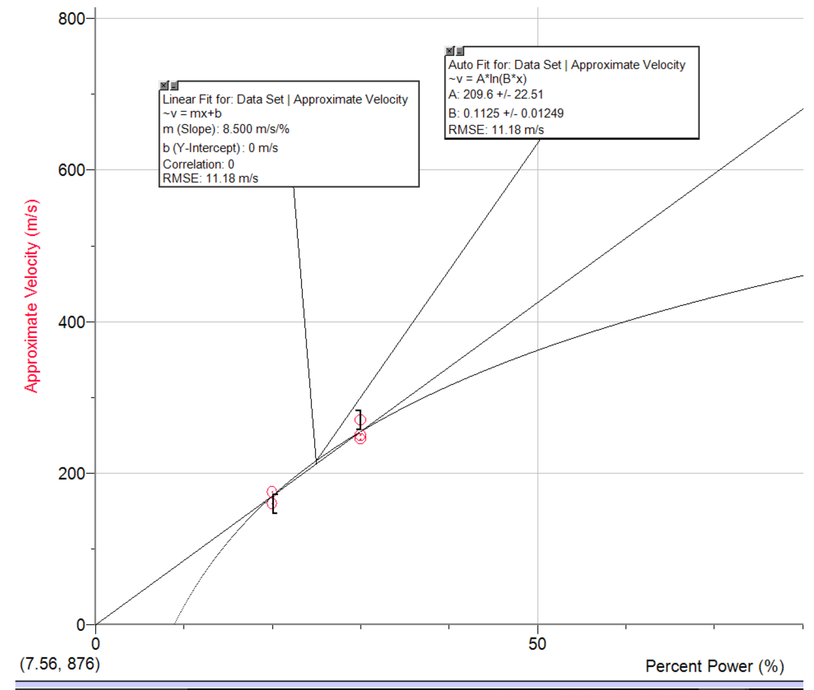
Samples of Al 6061-T6 deformed by increasing energy



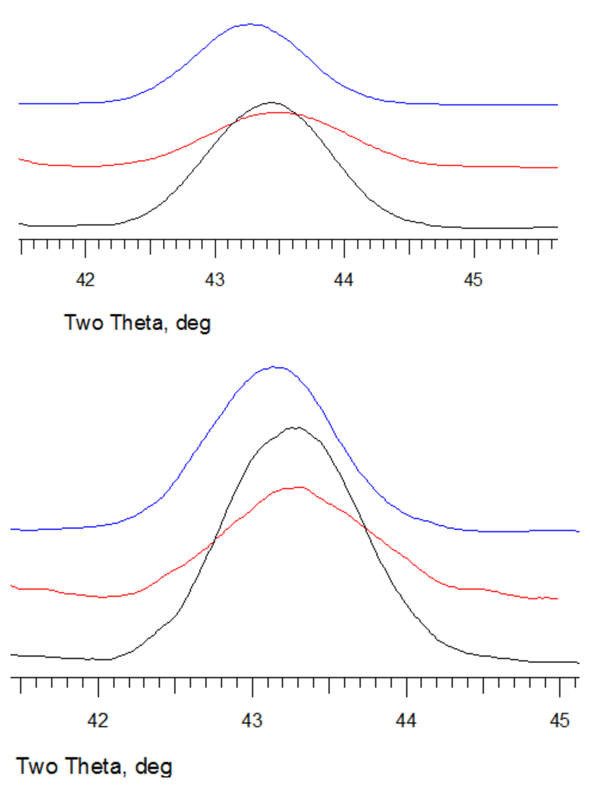
- Velocity measurements suggest that the optimal spacing (gap) between the rod and tube is around 2 mm for a 2.4 kJ trial to allow the tube to achieve maximum velocity.

- The pressure at which Alumina will fail via cracking is somewhat variable but well known.
- To impart maximum stress without cracking, the ideal velocity will impart a pressure below this.
- Alumina can usually withstand shock loading at 2.06 GPa. This data suggests that EM Forming setup can generate a maximum impact pressure of 2.2 GPa. at 12 kJ.

By modelling the amount of velocity produced at different EM field energy levels, the ideal impact velocity can be determined.



Impacted Alumina Rod



- X-Ray Diffraction was used to assess residual stresses in the ceramic.
- The top graph is unimpacted Alumina the bottom is impacted at 2.4 kJ.
- An imparted stress should cause these peaks to become either more or less aligned.
- We would expect a pressure of 1 GPa at this energy.

Alumina fragment showing telltale tube impact markings.
The gap is from a seam in the EM Field shaper.

Conclusions

- At this point it is hard to be certain whether permanent induced stress in Alumina can be induced.
- The strength of the EM formation field and the (as of now) lack of a thorough basis of stressed Alumina in x-ray diffraction makes a definitive answer to this question not obtainable.
- It should be possible to obtain a measurement of residual stress using these methods.

Works Cited

V. Psyk, D. Risch, B.L. Kinsey, A.E. Tekkaya, M. Kleiner "Electromagnetic Forming" Journal of Materials Processing Technology 211 (2011) 787–829
M.W.Chen, J.W.McCauley,D.P.Dandekar,N.K.Bourne "Dynamic plasticity and failure of high-purity alumina under shock loading" *Nature Materials* 5, 614 - 618 (2006)

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