PENNSTATE 1855

CISP

Center for Innovative Sintered Products

SUMMER 2012 NEWSLETTER / 814-865-2121 / CISP@PSU.EDU / WWW.CISP.PSU.EDU

Director's Message

CISP has closely watched the development of additive manufacturing processes for metal powders over the last ten to fifteen years. Using these techniques, components are built layer by layer in an additive fashion from 3-D solid CAD models. We spent a significant amount of time evaluating the early technologies and although they showed promise, they suffered from issues such as poor surface finish and poor dimensional control. Today these further refined technologies offer a viable alternative to conventional metal working techniques. There has been significant interest in these technologies due to the aging infrastructure of government owned property and the use of these technologies for the fabrication of metallic components to treat trauma victims requiring reconstructive orthopedic components. Powder methods such as laser bonding of organic binders to hold powders together, print head deposition of organic binders onto powders to hold them together, and direct laser sintering or melting exist. Each technique has its strengths and weaknesses and each has its place in application. *For more information on these technologies and how CISP is working with them, please contact us at cisp@psu.edu.*

Figure 1.1: Netshape bronze propeller. Photo courtesy of Ex-One Corporation

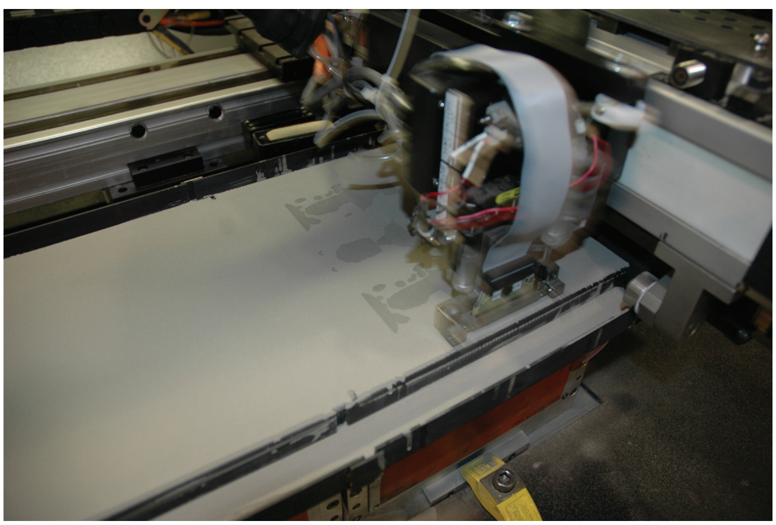

Figure 1.2: Additive manufacturing 3-D printing example. Photo courtesy of Ex-One Corporation

Inside This Edition

Equipment Highlight: Instrumented Press

CISP has a 60 ton Gasbarre instrumented press with various die sets. These die conform to the MPIF standards 10 and 55 that produce tensile bars and crush rings, respectively. In addition to creating the testing specimens, the die is instrumented to track the movements and forces during sample creation. The press utilizes LVDTs which monitor the top ram displacement and the die plate movement. Pressure transducers are mounted on both the top and bottom rams to monitor compression and ejection forces. The instrumentation helps provide a complete picture of how a cycle proceeds. Figure 4.1 shows a standard compression/ejection cycle of the press. First, the top ram compresses the powder and moves the die wall slightly in the process. After the compression cycle, the die wall is moved down causing a force on the bottom ram which corresponds to the ejection force. This exposes the part, which is then removed and the cycle can begin again.

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Upcoming Events

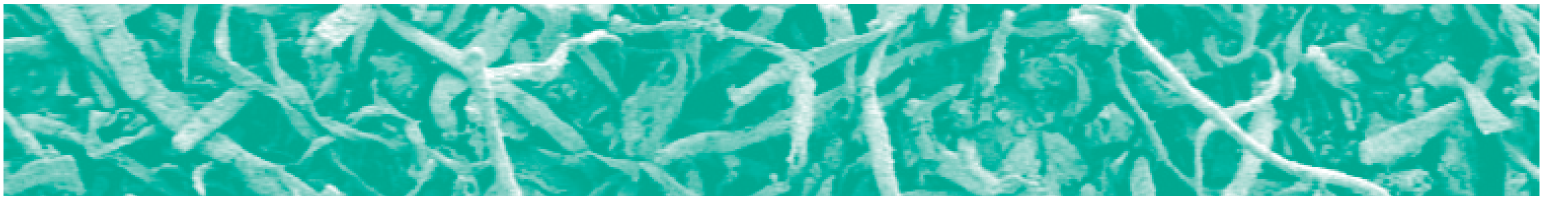
July 23-25, 2012
Metal Powder Industries Federation Short Course
State College, PA
www.mpif.org

September 16-19, 2012
EuroPM2012 International Conference and Exhibition
Basel, Switzerland
www.epma.com

October 7-11, 2012
Materials Science & Technology Conference and Exhibitions (MS&T'12)
Pittsburgh, PA
www.matscitech.org

October 14-18, 2012
Powder Metallurgy World Congress & Exhibition (PM2012)
Yokohama, Japan
www.pm2012.jp

March 4-6, 2013
International Conference on Injection Molding of Metals, Ceramics and Carbides (MIM2013)
Orlando, FL
www.mpif.org



Composite Ni-Encapsulated Hexagonal Boron-Nitride Particles for Self-Lubricating Coatings via Cold-Spray

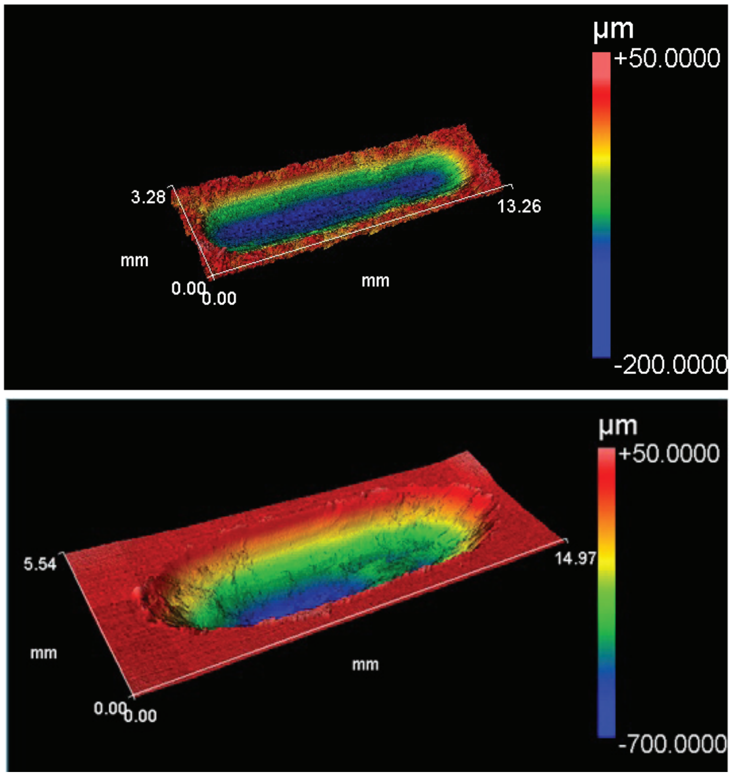


Figure 2.1: Profilometer analysis results. Top: Aluminum substrate coated with hBN encapsulated with Nickel. Bottom: Uncoated Aluminum

Table 2.2: Wear volume of coated and uncoated aluminum substrates

Material	Wear Volume
Uncoated Aluminum	13.91 mm^3
Aluminum substrate coated with hBN encapsulated with nickel	2.13 mm^3

A self-lubricating coating is a new technique to improve the performance of contacting surfaces. This method can extend component lifetimes, by increasing wear resistance, and significantly reducing the coefficient of friction (COF). In this study hexagonal-boron-nitride particles encapsulated by nickel were used for coating Aluminum 6061 substrates, mainly to improve the wear resistance and to reduce the COF. In this approach, nickel played the role of lubricant matrix. Relatively thick nickel encapsulation was required to aid bonding and layer uniformity. This was achieved by electroless Ni plating. To apply the coating material on the aluminum substrates, High Velocity Consolidation or Cold-Spray was employed. Cold-Spray is a relatively new coating technique that applies a coating by accelerating solid-phase particles with different types of gas, such as helium or nitrogen, toward a substrate. Moreover, cold-spray in comparison with other coating techniques is more flexible in use. It is a portable coating method and can be carried out at atmospheric pressure.

Once deposited on aluminum substrates, the coatings are analyzed for bond-strength, micro-hardness, coefficient of friction, and reciprocating wear behavior. The results showed improved wear resistance, low friction, and high adhesive strengths. As an example, to examine the wear resistance of coated and uncoated substrates, reciprocating tests were performed. Profilometry was then used to measure the volume of the removed material from the surface of the un-coated aluminum samples and the aluminum samples coated with hexagonal boron nitride (hBN) encapsulated with nickel. Some representative analysis results are shown in figure 2.1. Also, table 2.2 compares the wear volume for the coated and uncoated samples. As observed in these results, the volume of the wear scar for aluminum surface coated with hBN-encapsulated-with-nickel is much less than that in the uncoated sample. This indicates significant improvement in the wear resistance. *For more information, contact Ivi Smid at 814-863-8208 or smid@psu.edu.*

Maryam Neshastehriz, Ivi Smid, Albert Segall, Timothy Eden

Solid Oxide Fuel Cells

Solid oxide fuel cells are a promising form of alternative energy for the future. They are capable of running on hydrogen, which allows it to have very clean emissions. Solid oxide fuel cells are electrochemical cells, much like batteries. They contain two electrodes separated by an electrolyte membrane. As can be seen in Figure 4.2, the fuel penetrates into the anode and oxygen from air penetrates into the cathode. Where the electrodes meet the electrolyte, the hydrogen and oxygen undergo oxidation and reduction reactions. Electrons leave the hydrogen, oxidizing them, and travel through the external circuit to the oxygen, which becomes reduced to O^{2-}. The oxygen ions then travel through the solid oxide electrolyte to the anode, where they combine with the hydrogen to create water, the waste product. Having only water as a waste product makes these fuel cells particularly desirable for their very clean emissions.

Unfortunately, solid oxide fuel cell technology is currently hindered by high operation temperatures and high fabrication costs. Electrolytes currently being used are incapable of conducting oxygen ions at low temperatures. These fuel cells need to be heated to 500°C or more just to begin working. This heating causes several difficulties such as the need for accommodating thermal stress, more energy input needed to start up the fuel cell, longer start-up times for the devices, and the need for high cost ceramic materials, rather than metals, for major fuel cell components. By using electrolytes that operate at lower temperatures, these complications will be eliminated.

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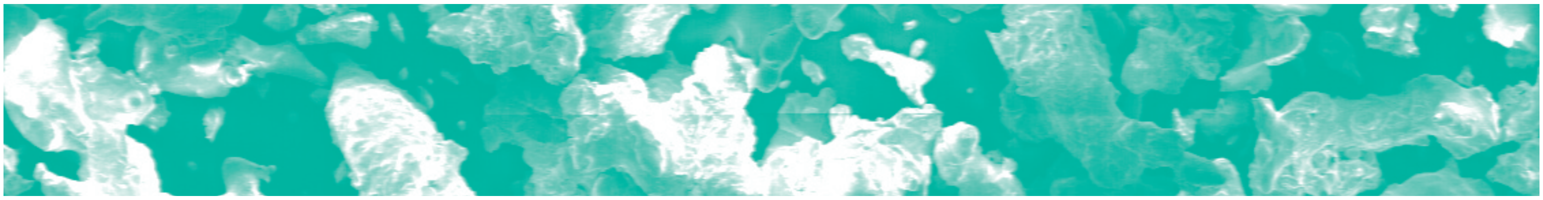

Brittle Failure of Ductile Metals—FE Modeling of High-Strain-Rate Deformation

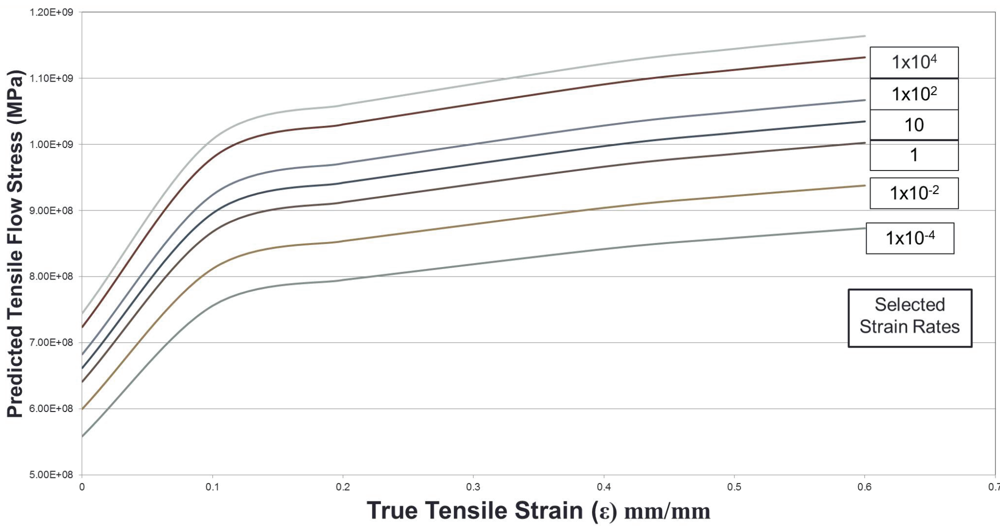

Figure 3.1: Predicted tensile flow stress with respect to true strain and strain rate found using Johnson-Cook parameters

There is a great deal of interest in the behavior of metallic materials under high strain rate loading. Finite element analysis can be used to model these materials with a reduction in the amount of experimentation needed for characterization. In a novel approach, a finite element model of a metallic ring under high strain rate loading was developed using the Johnson-Cook failure model in Abaqus (see figure 3.1). The ring was modeled both axisymmetrically and in 3-D to help ensure accuracy in results. Failure was assumed to occur when the failure strain was exceeded, causing element deletion. Based on this approach, and comparing with experimental data, a failure strain of $1x10^{-4}$ is predicted. Results of both axisymmetric and 3-D were found to be within 3% of each other with respect to maximum stresses, and failure modes were identical. The effects of material changes and different loading conditions on microstructure and fragmentation are compared.

Conclusions: Three dimensional and axisymmetric computer models of an AISI 4340 steel ring were created using the finite element solver Abaqus. These models were used to examine the behavior of the material under high strain rate loading. The Johnson-Cook failure model was used. The conclusions from this work are:

- Using dynamic, explicit modeling, a three dimensional material model was created, and results were supported by an axisymmetric model
- Mesh refinement is necessary to achieve optimal results
- 3D model with full rotational symmetry produced somewhat unrealistic results
- Adding a defect such as eccentricity increases likelihood of realistic failure
- Axisymmetric modeling is consistent with three dimensional results
- A damage initiation value (or fracture strain) of $1x10^{-4}$ was found
- Disintegration predicted to start at 45µs, with a strain rate of $1x10^{4}$ (see figure 3.2)
- Failure is dependent on strain rate, element size, and damage initiation value

For more information, contact Ivi Smid at 814-863-8208 or smid@psu.edu.

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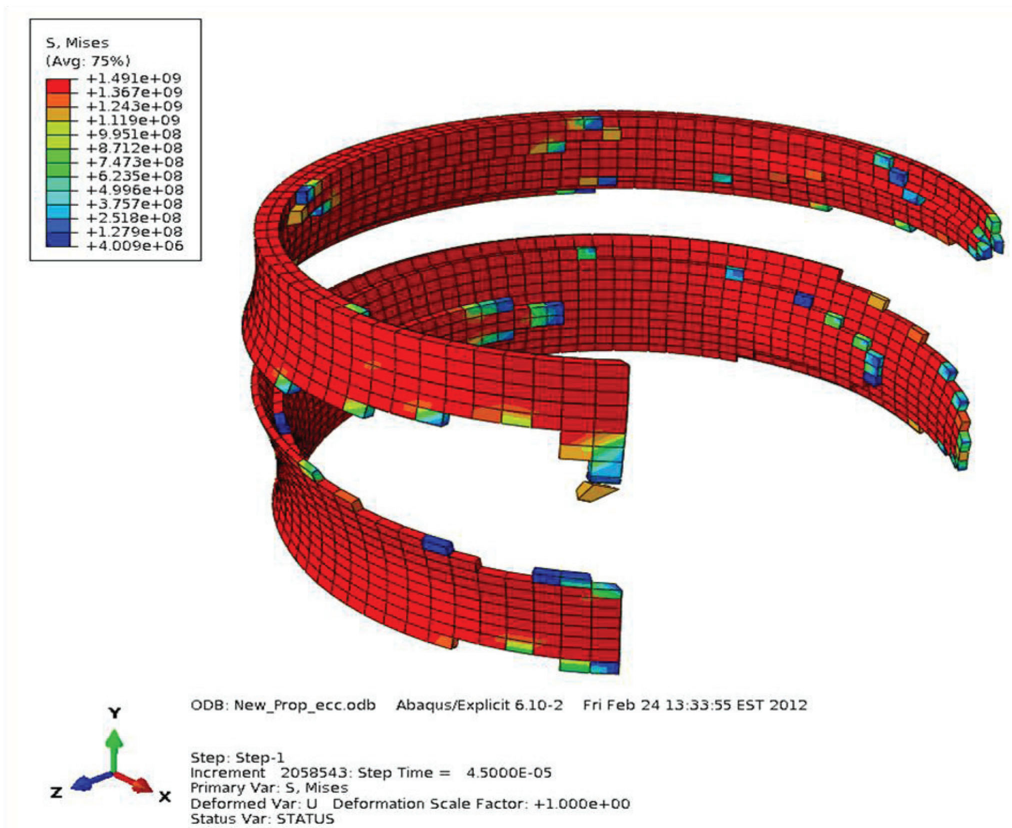
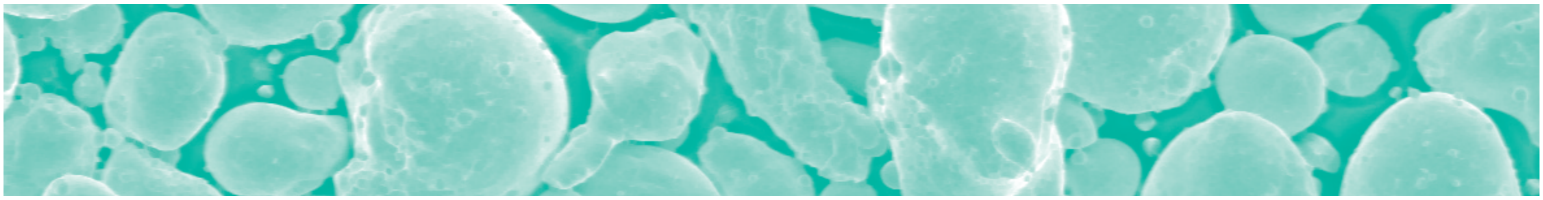


Figure 3.2: Predicted failure behavior of defective 4340 steel ring (t=45µs)



Equipment Highlight: Instrumented Press

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Considering the shape and area of the die allows for comparisons between different powders and lubricants. Just how well a powder compressed and how hard it was to remove from the die provides valuable information on what to expect in a large production run. This information combined with testing of green and sintered parts allows for a complete picture to be generated that balances part properties with the minimizing wear on the press and die. *For more information on this technique or characterization of your materials, please contact Michael Disabb-Miller at 814-865-1393 or mjd39@engr.psu.edu. You can also visit our testing services price list at http://www.cisp.psu.edu/testserv/pricelist.htm.*

Michael Disabb-Miller

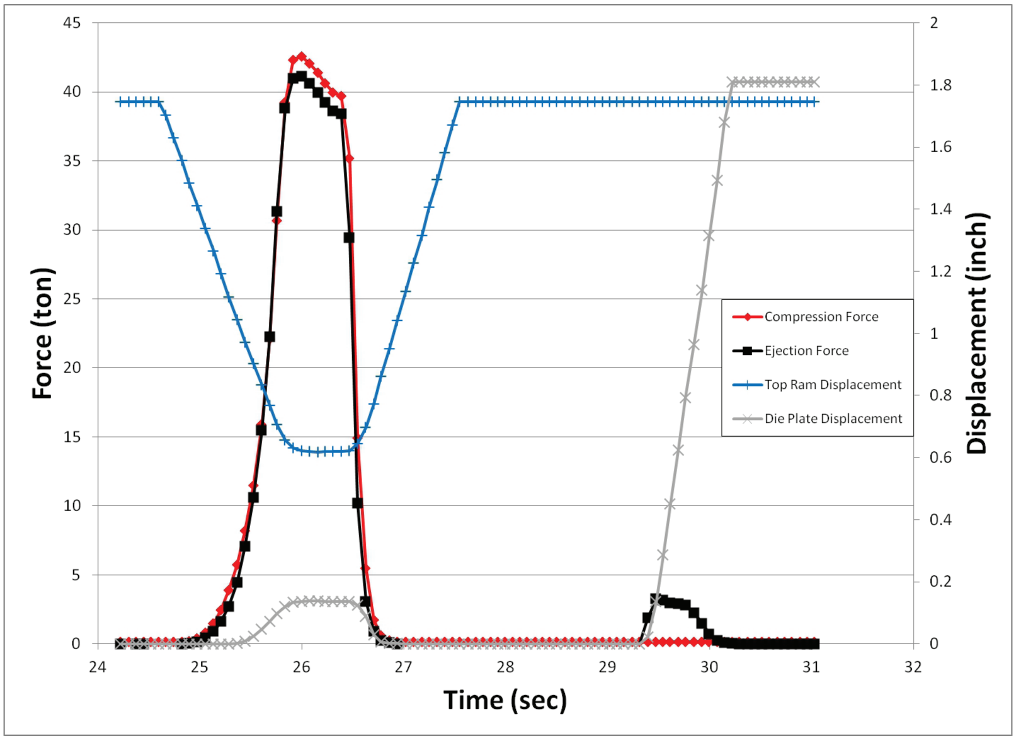

Figure 4.1: Standard compresion/ejection cycle of the Gasbarre instrumented press.

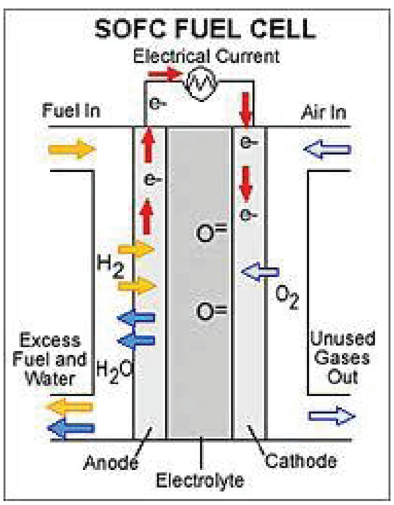

Figure 4.2: Diagram of a solid oxide fuel cell

Solid Oxide Fuel Cells

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Because the fuel and the oxygen need to penetrate all the way through the electrodes, electrodes that have open pores increase the efficiency of the fuel cell. Electrodes with porosities ranging between 22 and 41 percent were created using various cold compaction pressures and sintering temperatures. While it was known that lower compaction pressures and lower sintering temperatures yield higher porosity electrodes, it was found that the width of the pores increased overall with increasing pressure and temperature. The increase in pore size was not very significant and is not expected to provide an advantage that outweighs the decrease in overall porosity. However, the study also analyzed the effects of cold compaction on the porosity near faces of the electrode. It was found that due to the immediate presence of the ram, there were regions of lower porosity near the edges. The maximum thickness of this region was determined. By using methods such as etching to remove this region, the open porosity of the electrode can be greatly increased.

In addition to the electrodes, more efficient electrolytes can increase the efficiency and thus lower the operating temperature of the solid oxide fuel cell. Electrolytes were chosen for analysis which would theoretically be more efficient and lower the operating temperature. The behavior of these electrolytes was analyzed, and though complications have thus far prevented actual testing, the behavior exhibited is promising. *For more information, contact Ivi Smid at 814-863-8208 or smid@psu.edu.*

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