Dynamic Systems Inc.
Tel: (518) 283-5350 Fax: (518) 283-3160

The Gleeble® NEWSLETTER

Summer 1995

ISPS Call for Papers

The 6th International Symposium on Physical Simulation will focus on the following areas of research:

- Physical simulation of welding processes for low and high strength steels, aluminum alloys, stainless steels, titanium alloys, and other advanced materials.
- Physical simulation of hot deformation processes, including hot rolling and forging.
- Physical simulation of heat treatment processes.
- Physical simulation of casting, melting, and solidification processes.
- Thermal and/or mechanical fatigue and other thermal/mechanical process simulations.
- Physical simulation of semi-solid processing of materials.

Investigators who are researching these areas of physical simulation are invited to submit abstracts to:

ISPS Technical Director
c/o Dynamic Systems Inc.
P.O. Box 1234
Poestenkill, NY 12140 U.S.A.
Tel: (518) 283-5350
Fax: (518) 283-3160
Telex: 646544

Paper Submission Schedule

- Abstracts due — October 1, 1995
- Presentation requirements mailed to authors — November 1995
- Papers due at conference — June 3, 1996
- Proceedings printed and mailed — Fall 1996

Conference proceedings will be published by DSI. Conference will be held June 3–5, 1996 in Columbus, Ohio, USA.

Gleeble Application Profiles:

The Gleeble at Lockheed Martin Space Systems in Colorado

Future spacecraft missions are creating a need for lightweight, highly reliable mechanisms for precision articulation, low shock separation, and deployment of solar arrays and antennas. Smart mechanisms employing shape memory actuation provide improved reliability and performance via their ability to actively control key spacecraft functions under the influence of variable environmental and operational stimuli. The advantages of smart mechanisms are increased pointing accuracy, low shock separation and deployment, and reduced noise and vibration compared to traditional mechanisms employing stepping motors, solenoids, or wax actuators.

In 1964, Buchler and Criley of the U.S. Naval Ordnance Laboratory developed a series of engineering alloys that possess a unique mechanical property: shape memory. The generic name of the series of alloys is 55-Nitinol, where Nitinol stands for Nickel Titanium Naval Ordnance Laboratory. These alloys are based on the intermetallic compound NiTi with a chemical composition in the range of 53 to 57 weight percent nickel, and the balance is titanium. Since the introduction of binary shape memory alloys, other systems involving Cu, Hf, or Pd additions have been developed to improve shape memory properties.

Shape memory alloys (SMAs) exhibit two unique characteristics: 1) shape recovery effect which manifests itself in a

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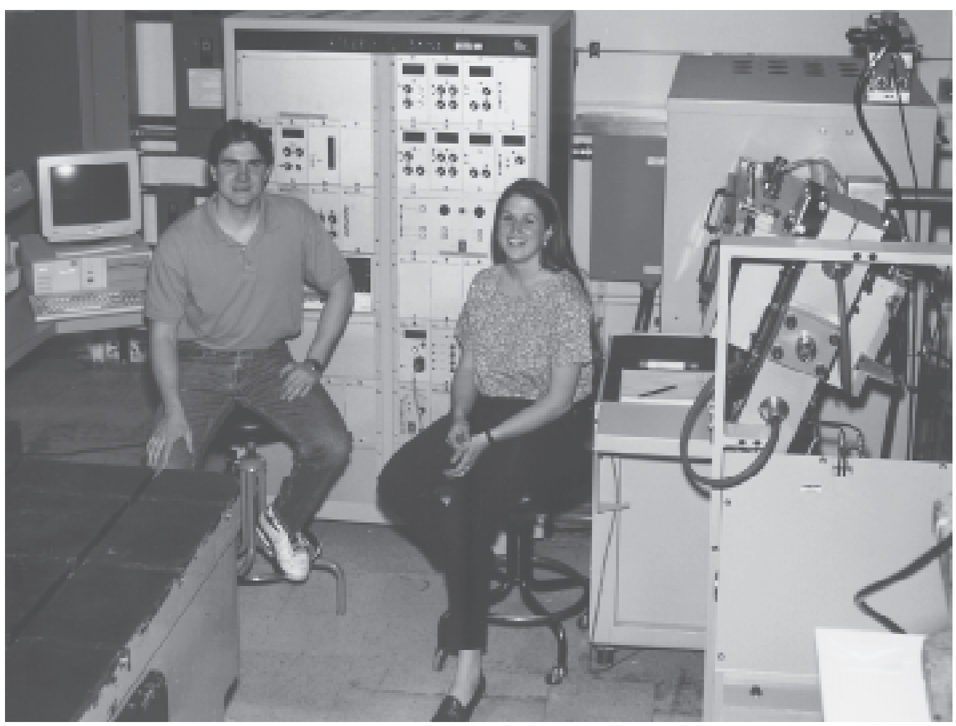

Processing Engineers Jerry Draper and Kristi Farley, in the Gleeble lab at Lockheed Martin, are part of the Advanced Structures and Materials Group.

Recent Gleeble Papers

262

A Study of the HAZ Crack Susceptible Region in Alloy 625

by W. Lin, T.W. Nelson, and J.C. Lippold

In this study, the crack susceptible region in the heat-affected zone (HAZ) of nickel-base, Alloy 625 was evaluated and its magnitude quantified. Previous work involving hot-ductility, spot- and longitudinal-Varestraint testing of stainless steels developed a new methodology for quantifying HAZ liquation cracking susceptibility and described a thermal crack susceptible region (CSR) in the HAZ in which liquation cracking may occur. This thermal CSR is material-specific and represents a true qualification of weldability. Results from this study showed that both the spot-Varestraint and hot-ductility tests correlate very well in determining the HAZ thermal CSR for Alloy 625. Using this methodology, the HAZ cracking susceptibility of Alloy 625 was compared to stainless steels tested previously and found to be considerably less susceptible than A-286 and slightly more susceptible than Type 310. Metallurgical evaluation indicates that the CSR in Alloy 625 corresponds to the partially melted zone along the fusion boundary. In this paper, the detailed procedure for determining the HAZ thermal CSR for Alloy 625 is described and the metallurgical and fractographic features of HAZ liquation cracking in this alloy are discussed.

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Model Predictions of HAZ Boundary Chromium Depletion Development for Austenitic Stainless Steel

by D.G. Atteridge, M. Li, J.W. Simmons, C.D. Lundin, and S.M. Bruemmer

An analytical model has been developed for predicting thermomechanical effects on chromium depletion of austenitic stainless steel. Model development and validation is based on sensitization development analysis of over 30 type 316 and 304 stainless steel heats. The database included analysis of deformation effects on resultant sensitization development for both isothermal and continuous cooling heat treatments. The effects of gas tungsten arc girth pipe weldments on heat-affected zone sensitization development was measured, simulated and predicted. The inclusion of accelerated sensitization due to weld induced heat-affected zone deformation was found to be required to obtain observed sensitization development. The model was used to assess effects of stainless steel type and composition on resultant heat-affected zone sensitization development.

268

Behaviour of 2205 Duplex Stainless Under Hot Working Conditions

by A. Paul, J.L. Martos, and R. Sanchez

Hot working behavior of as cast 22Cr5Ni3MoN (2205) duplex stainless steel was investigated and compared with that of type-304 austenitic stainless from plane strain compression tests, that were conducted on a thermal/mechanical simulation system Gleeble in the range 1000–1250°C and 0.1 to 10 per second. Stress/strain curves revealed that strain rate and temperature have the same qualitative effect on the strength of *a*/*y* duplex austenitic structures. Creep analysis of curve peek data resulted, for duplex and austenitic steels respectively, in stress exponent of 3.85 and 5.8 at 1250°C, and apparent activation energy of 380 kJ/mol and 450 kJ/mol. Duplex steel reached the hot working stage at early strain of 0.07 for the lowest *z* value, whereas type-304 needs 0.26 in the same condition. Observation on TEM samples from duplex specimens deformed at several intermediate strains at 1200°C and 1/s showed that ferrite develops a well defined substructure as deformation increases, featuring a constant 8 µm mean subgrain size. Austenite develops a heterogeneous deformation structure consisting of 6 mm subgrains and 1 mm cells.

264

Influence of Alloying and Processing on the HAZ and Base Plate Properties of Experimental HSLA-80 Steels

by M.R. Krishnadev, W.L. Zhang, J.T. Bowker, and MTL Canmet

A study has been made of the microstructure and mechanical properties of the base plate and the heat-affected zone of experimental extra low carbon copper strengthened HSLA-80 steels in which manganese level has been systematically varied. The Gleeble thermal/mechanical simulator has been used to simulate the coarse grained heat-affected zone (CGHAZ) and to determine the transformation kinetics. Instrumented impact testing has been used to characterize the toughness. Optical and transmission electron microscopy has been used to characterize the microstructures. The variation in HAZ toughness with the heat input has been related to the nature of HAZ microstructure resulting from the influence of alloying elements on the transformation kinetics.

272

Hot Ductility of Titanium Alloys—A Comparison with Carbon Steels

by H.G. Suzuki and D. Eylon

Characteristics of hot ductility of various kinds of titanium alloys were examined and compared with that of carbon steels. Although carbon steels have three typical embrittling zones above 900 K, titanium alloys do not show any embrittlement in the temperature range between *b* transus and 1500 K, which is considered to be the best region for hot rolling. The embrittlement occurs just below *b* transus in the coarse grain titanium alloys. The ductility is poor in the coarse grain materials, but independent of the strain rate. The mechanism of the embrittlement is considered to be due to the accumulation of strain in the *b* phase attached to the grain boundary *a* in *a* + *b* alloys.

267

Effect of Alloy Elements on the Microstructure and Toughness of Simulated HAZ in Ti-Killed Steels
by Y-T. Pan and J-L. Lee

A series of experiments have been carried out to investigate the effect of silicon, aluminum and oxygen on the microstructure and toughness of simulated heat-affected zone (HAZ) in Ti-killed steels. The HAZ toughness deteriorated remarkably with a small silicon or aluminum addition due to the decrease of volume fraction of intragranular ferrite in microstructure. The microstructural change was attributed to the decrease of number density of Ti-oxide dominant inclusion due to the deoxidization of molten steel caused by silicon or aluminum addition. Aluminum addition caused more serious detriment to HAZ toughness than silicon addition because aluminum has higher affinity for oxygen. By contrast, providing more Ti-oxide dominant inclusions and refining the intragranular ferrite, increasing soluble oxygen in molten steel improved the HAZ toughness of Ti-killed steels.

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The Influence of Composition and Microstructure on the HAZ Toughness of Duplex Stainless Steels at –20°C
by J.C. Lippold, I. Varol, and W.A. Baeslack III

HAZ toughness decreases as a function of both ferrite content and grain size. The toughness of two commercial duplex stainless steels, Ferralium Alloy 255 and Alloy 2205, was evaluated over a range of cooling rates representative of conditions in the weld heat-affected zone (HAZ). Both alloys exhibited a loss of toughness at the cooling rate extremes, 90° and 2°C/s, resulting from high ferrite content and large prior ferrite grain size, respectively. Alloy 255 also showed a drop in toughness at an intermediate cooling rate of 50°C/s. This intermediate loss of toughness, not observed in Alloy 2205, results from the interrelationship between austenite and Cr-rich precipitate formation along ferrite grain boundaries. The precipitation mechanisms and their subsequent effect on toughness are described. The practical implications of HAZ microstucture control are also discussed.

The Gleeble at Lockheed Martin

Continued from Page 1

remarkable restoring force and/or recovery of a tremendous amount of plastic strain (Figure 1) by means of a reversible crystalline phase transformation. SMAs generate recovery stresses in excess of 690 MPa (~100 ksi) or recover their original heat treated strain (up to 8%) when heated above a critical transformation temperature, and 2) elastic modulus changes from 27 GPa (3.9 Msi) to 110 GPa (15.9 Msi) when the material transforms from the martensite phase to the austenite phase (NiTiCu SMAs). These characteristics of SMAs can be exploited to design smart mechanisms capable of shockless separation, shape control, precision pointing, and controlled structural deployment.

Despite their attractive attributes, the use of SMAs in the past has been limited due to an incomplete understanding of their very interdependent Force-Length-Temperature (FLT) response and associated nonlinear and hysteretic behavior, as well as the effects of creep, fatigue, and material property drift which results from transformational cycling. This is indicated by the force-strain response of a NiTiCu alloy isothermally cycled at 70°C, as shown in Figure 2. Creep and hysteresis are observed to decrease in a semilog function with cycle. Annealing temperature is also known to influence force-strain behavior according to data presented in Figure 3.

To aid in the research and development of shape memory alloys, a Gleeble 2000 was fitted with a special vacuum chamber and control system to train the actuators within a force, displacement, and temperature domain. The Gleeble has also been used to characterize NiTiCu material properties, including:

- Effect of shape memory alloy composition on transformation behavior,
- Determination of transformation force and displacement as a function of annealing temperature,
- Characterization of superelastic response as a function of stress-strain cycle,
- Evaluation of martensite and austenite modulus.

The material properties described by these data are incorporated into mechanical design equations to generate actuator specifications for spacecraft mechanisms. Actuators fabricated from NiTiCu are subjected to additional thermomechanical treatment in the Gleeble to verify response bandwidth and stability. These actuators are then suitable for incorporation into spacecraft mechanisms.

— *Dr. Bernie Carpenter*
Smart Materials and Structure Manager
Lockheed Martin Corporation

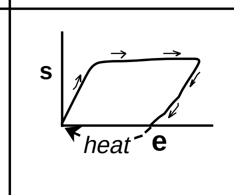
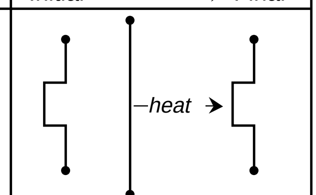
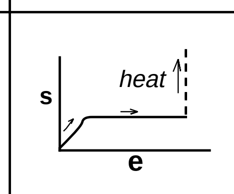
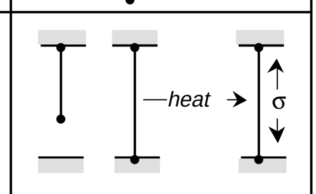
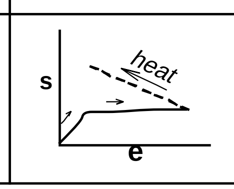
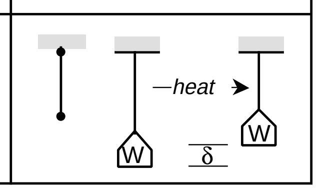
SMA Operation Mode	SMA Output	SMA Stress-Strain Response	SMA Physical Response Initial ⟶ Final
Free Recovery	No work (up to 8% Strain Recovery)		
Restrained Recovery	Up to 690 MPa (100 ksi)		
Controlled Recovery	Controlled Work		

Figure 1. *SMA recovery modes showing unique ability of generating stresses in excess of 690 MPa over 8% strain.*

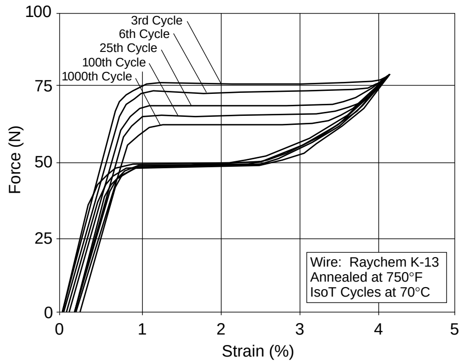


Figure 2. *70°C isothermal cycling response of the 750°F anneal to 4% cycles.*

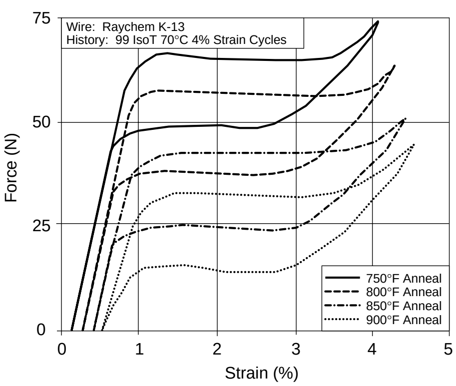
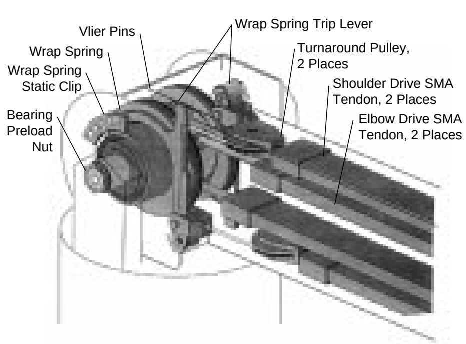
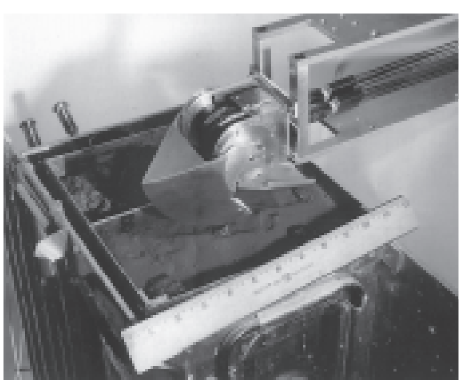


Figure 3. *Comparison of the 100th isothermal strain cycle for each of the four anneals.*





Detail of the shape memory mechanism—robotic arm. The wire bundles in the arm are conditioned in the Gleeble.

Refining the Gleeble 2000 for Specialized Research at Lockheed Martin

When Dr. Carpenter of Lockheed Martin Space Systems needed a high speed heating system for further research and development of Shape Metal Alloys (SMAs), our engineers worked with him to refine and develop a Gleeble 2000R system that could meet his special needs.

The unique design of the Gleeble 2000R system allows the Gleeble to be reconfigured for many different tasks. The Gleeble 2000R can be equipped with different Mobile Conversion Units (MCUs). An MCU consists of a specific jaw or grip system along with an atmosphere or vacuum tank mounted in a cabinet on wheels so that the entire unit can be disconnected and another MCU of a different configuration can be attached in its place.

DSI makes MCUs for standard Gleeble testing (conventional grips and load cell arrangement), hot deformation (the 2008-8 Hydrawedge unit) and hot torsion (the 2005-100 Torsion unit). To convert the Gleeble 2000R from one type of testing to another involves removing one MCU from the load unit and rolling another MCU in its place. The new MCU is then locked in position and is ready for testing.

In this fashion, one Gleeble 2000R system can be used for applications such as welding, hot deformation, and even hot torsion tests. This reduces the overall investment that a laboratory must make in equipment to perform a wide variety of tests. This design also allows DSI to provide special MCUs, as was done for Lockheed Martin, to allow a very specific type of test to be performed. Yet when a standard MCU is installed, the Gleeble 2000R can be used for the same range of conventional work as any Gleeble 2000.

The following MCUs are available:

- **Standard MCU** with wedge grips in a vacuum tank for all types of HAZ simulations, hot tensile tests, SICO tests, and other types of Gleeble testing involving round, square, or flat specimens. The high speed heating system is ideal for reproducing HAZ thermal cycles. This configuration supports the use of options including the laser dilatometer, quench systems, CCT dilatometer, pyrometers, and L-strain systems.
- **Hydrawedge MCU** is equipped with Hydrawedge hydraulics and controls, stop/yoke assembly, vacuum tank, and accommodates various platen packages for high speed hot deformation studies. The patented Hydrawedge System allows independent control of strain and strain rate for precise control of high speed hot deformations. Strain, strain rate and temperatures can be programmed and changed for each deformation. Up to 10 deformations may be made in a single program. Flow stress (Slug type) specimens or plane strain specimens can be run in the unit. Optional quench systems and pyrometers are available.
- **Hot Torsion MCU** is equipped with a hydraulic torsion motor and controls, high speed furnace, atmosphere tank, and collet grips for hot torsion studies. The Hot Torsion system can perform partial or continuous rotations at high speeds with the ability for multiple starts and stops within a single program. The hydraulic system in the load unit can apply and control axial tension and compression forces prior to, during or after torsion. Temperature control is provided by a fine wire thermocouple and a two-color pyrometer. The unique furnace design allows air or water quenching to be done in-situ during the torsion test.

If you would like to discuss the unique opportunities the Gleeble 2000R system offers, please contact us.

Joining Advanced Materials

Modern variations of an old process hold great promise for joining difficult combinations of ceramics, intermetallics, composites, and metals.

Self-propagating high-temperature synthesis (SHS) holds particular promise for joining ceramics and intermetallics in either monolithic or reinforced forms, to themselves, to one another, or to metals. The process can be used for primary joining, simultaneously with material and shape synthesis (as in sinter-bonding of ceramics), or for the more familiar secondary joining of preexisting parts.

The ability to bond ceramics and intermetallics to themselves is significant because these materials are normally difficult to join. Both materials typically have high melting temperatures, making fusion difficult. Worse, many ceramics sublime or decompose rather than melt. Neither material type exhibits much ductility or toughness, so joining by solid-state welding processes that rely on plastic deformation is impossible. In addition, the chemical inertness that makes ceramics and intermetallics attractive for corrosion-resisting applications, also makes the wetting needed for brazing difficult or impossible.

The ability to join either class of material to metals would be extremely beneficial for hybrid structures. These typically require one section to have the function-specific properties of ceramics or intermetallics, such as wear-, temperature-, or corrosion-resistance, while another section may require the strength and toughness of metals, often for structural support. Production of such hybrid structures is becoming increasingly important as service environments become more demanding and costs continue to rise.

Other potential uses of SHS for joining include: application of thin surface coatings for wear, corrosion, or oxidation protection; production of thick surface overlays, primarily for wear protection; bonding of thick clad layers or laminated materials; and joining of composite materials with a composite filler.

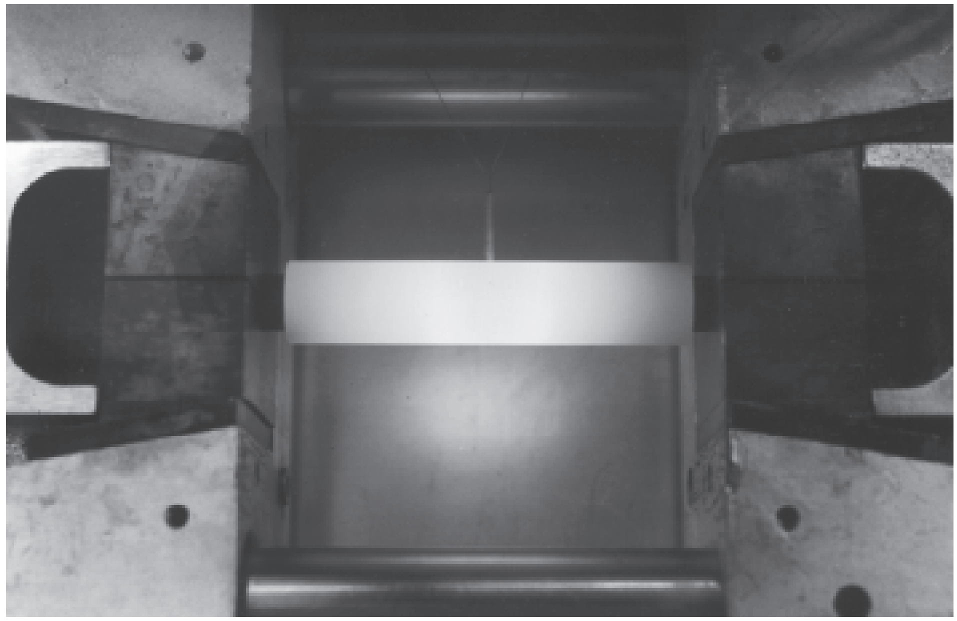


Figure 1. *A Gleeble thermal-mechanical simulator showing a glowing, resistance-heated containment tube and load-application plungers. A similar arrangement was used to join materials by SHS.*

How the Process Works

In SHS, a reaction is initiated between reactants to form a compound that generates a significant exothermic heat of formation. Reactants may be powdered solid elements, a powdered solid element and a gaseous element, or a powdered compound and element or other compound. The reaction begins at a triggering or ignition temperature (T_i), and is sustained by the self-heating of further reactant associated with the release of exothermic heat of formation. If the reaction is triggered by heating only a small portion of the reactant above T_i, the reaction propagates along moving front in a so-called “propagating mode.” If the reaction is triggered throughout the volume of reactant by heating the entire mass above T_i, the reaction occurs in a so-called “simultaneous combustion mode.” Either way, the heat released is often sufficient to raise the temperature enough to cause melting of one or more of the reaction products or non-reactive additives to the reactants, or even a substrate in contact with the reactants. Bonding can then take place through “reactive joining,” a process analogous to reactive sintering. Pressure usually must be applied during processing to produce dense joints, so the SHS process is also referred to as “pressurized combustion synthesis.”

An SHS joining process taking place in a Gleeble thermal-mechanical simulator is represented by the material shown in Figure 1, and the arrangement is shown schematically in Figure 2. For example, a mixture of elemental aluminum powders in an atomic proportion of 3:1 may be reacted while sandwiched between Alloy 600 end elements. The resulting joint consists of gamma nickel-aluminide joining Alloy 600. The bond interface between the reaction product and substrate has high integrity, and the product fill has high density.

Tackling the Tough Jobs

The SHS process is well-suited for joining ceramics and intermetallics to

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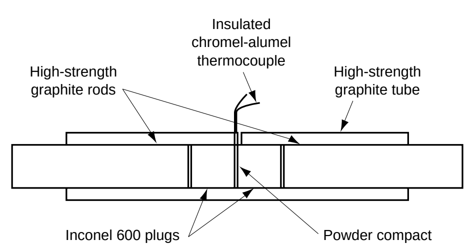

Figure 2. *A schematic drawing showing the arrangement for joining by SHS. The layer of reactant is sandwiched between end elements of Inconel Alloy 600. The system is contained in a graphite tube and the load is applied with solid graphite rods.*

Come See Us at These Shows!

DSI will exhibit at the Trends in Welding Research Conference, June 5–9, 1995, Park Vista Hotel, Gatlinburg, Tennessee.

In addition, you can see us at the ASM/TMS Materials Week, October 30–November 2, 1995, The Cleveland Convention Center, Cleveland, Ohio.

For information about either of these shows, contact ASM International, Materials Park, Ohio 44073-0002, phone (518) 338-5151, or fax (518) 338-4634.

Gleeble Newsletter

The Gleeble Newsletter is intended to be a forum for Gleeble users worldwide to exchange ideas and information. We welcome your comments and suggestions. Letters, comments, and articles for the newsletter may be addressed to David Ferguson at Dynamic Systems Inc., or faxed to us at 518-283-3160.

Joining Advanced Materials

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themselves and other materials because the high temperatures needed for bond formation are achieved efficiently through internal chemical heat generation. Also, the speed and highly localized nature of the reaction, which occurs in-situ between joint elements or substrates, limits thermal degradation or shock to sensitive substrates.

Through proper formulation of the reactants, chemical compatibility with ceramic, intermetallic, or metal substrates is relatively easy to achieve. Functionally Gradient Material (FGM) joints can be produced in which the composition of the reactants is varied across the joint, to bridge incompatibilities in chemical composition, physical characteristics (such as coefficient of thermal expansion), or mechanical properties. Finally, reinforcing particles, chopped fibers, or whiskers can be readily incorporated into the reactant and resulting product, to enhance joint properties when bonding composites.

Looking Ahead

Despite the tremendous potential of SHS for joining, much needs to be done to understand and optimize the process for this purpose. Areas being studied by researchers around the world include the fundamental mechanism by which bonding is achieved within or between various materials, and the role of key process parameters. Such parameters include reaction mode, heating rate to reaction temperatures, substrate temperature, reaction peak temperature, hold-time following reaction, reaction atmosphere, and the effects of the post reaction cooling rate on bond integrity, joint stresses, and joint chemical homogeneity.

Research is also being focused on developing means of achieving dense joints, free of the porosity that normally accompanies most synthesis reactions. This porosity is caused by retention of the residual interparticle voids, differences in specific volume between products and reactants, or evolution of dissolved or adsorbed gases. Other research areas include measurement and optimization of joint properties and practical embodiments of the process for joining in various production applications and environments.

The amount of work to be done is great, but the payoff will be greater. Future applications of SHS are likely to include joining of ceramics to ceramics, or to metals, for advanced automobile or aircraft engines; joining of intermetallics to themselves or to metals, for advanced airframes; cladding of metals with wear- or corrosion-resistant ceramics for new power generation, energy conversion, or chemical processing components; and joining of wear-resistant ceramics to metals for abrasion-resistant mining equipment.

— Robert W. Messler, Jr.
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