Automated Analyzer for Particle Size and Shape Distribution Developed

An automated testing system that uses the novel concept of digital image analysis of free-falling particles to measure particle size, shape, and distribution has been developed at Clarkson University and the University of Tennessee, Knoxville. The automated PSDA system, shown in Figure 1, was specifically developed to measure particle size distribution over a wide range for materials that do not cohere and have equivalent diameters that fall in the range of 25 μm to 60 mm. This system has four major components: (1) particle-sizing hardware and software, (2) an optical lens system driven by a stepper motor, (3) a horizontal vibrating feeder, and (4) an appropriate lighting system.

A progressive-scan, charge-coupled device (CCD) camera with a computer-controlled optical system that has a large range of magnification is used to obtain high-contrast, two-dimensional digital images of free-falling particles. The vibrating feeder causes the material to flow and free-fall in front of the lens. The feeder is adjusted to obtain images of individual particles projected onto the image plane. Custom-developed application software continuously records the images of particles for analysis in real time. Software then counts the particles in each image, using a specified intensity threshold, and measures the size, shape, and various other features of each particle. A graphic interface is used to display the updated measurement results for real-time analysis and control. After obtaining information from a number of particles, convergence of the measured size distribution is evaluated. The analysis automatically stops once statistically admissible results are obtained on the sample being tested. Output data such as the particle size distribution curve and shape information are displayed in real time throughout the analysis, as shown in Figure 2.

In many industries, particle size distributions above 50 μm are obtained by sieve analysis, which produces a weight-based size distribution curve. Among the advantages of using PSDA for this application are that it is automated and has a relatively low cost, it eliminates the noise and vibration often associated with sieve analysis, and it provides particle shape information plus the grain size distribution representative of the sample in a short period of time. Since the PSDA technique uses area-based measurements from two-dimensional images, techniques have been developed to translate this information into volume/weight-based results. The size distribution of various types of materials compares well with traditional sieve-analysis data of the same materials.

For refractory and abrasive materials, information about particle shape and texture is important. PSDA technology can provide statistically admissible shape information (e.g., roundness, aspect ratio). For applications related to flow behavior and particle degradation with

Figure 1. Automated laboratory particle size and shape distribution analyzer.

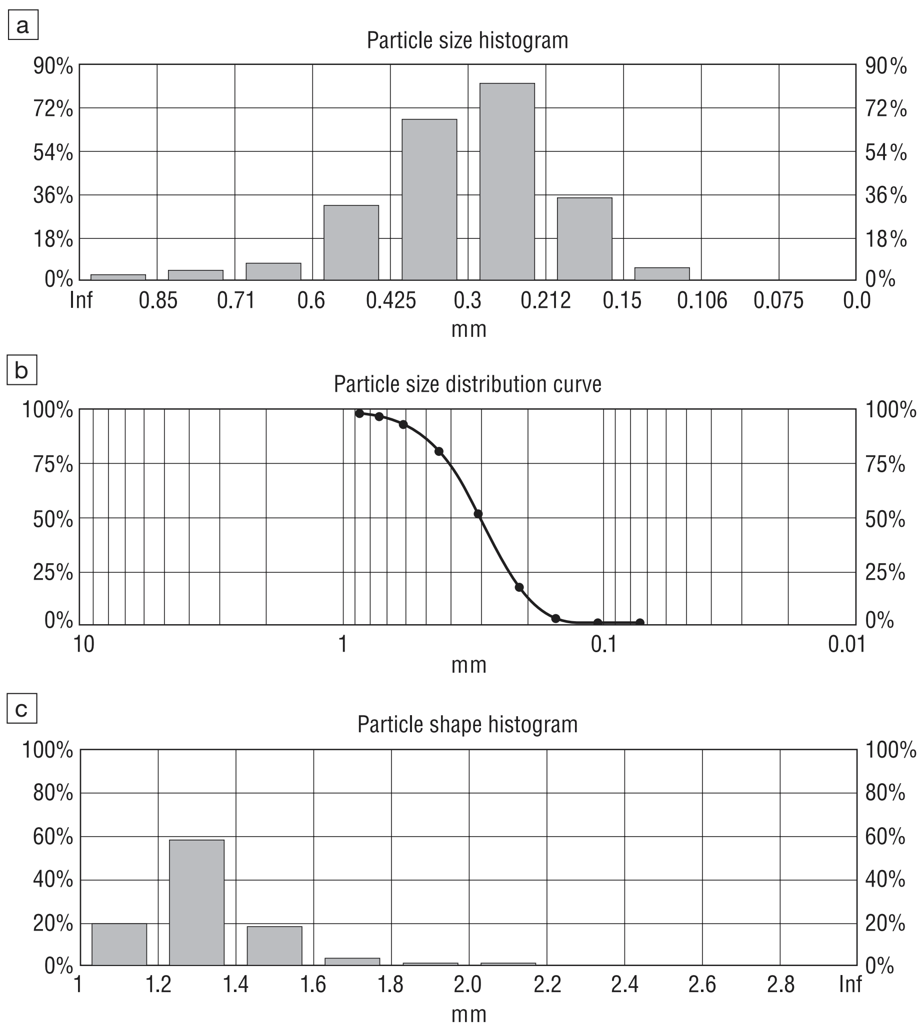

Figure 2. (a) A typical particle size histogram and (b) distribution curve; (c) a typical particle shape histogram.

Technology Advances provides up-to-date reports of materials developments that show potential to bridge the gap between research innovation and application of advanced materials technologies. If you encounter or are involved with materials research that shows potential for commercialization and would like to present these developments, contact Renée G. Ford, Renford Communications, Ltd., tel. 914-967-0955; fax 914-967-7927; or e-mail renford@compuserve.com.

time, several advanced algorithms have been developed involving Fourier techniques to evaluate novel shape information and fractal dimension for particle texture information.

The PSDA instrument is commercially manufactured by VisionWorks. Several models covering the 25 μm to 60 mm size range are available.

Opportunities

The company is interested in working with potential users to identify the optimum unit for their product line, applications, and current testing methods. Technical training prior to the installation and a week of on-site training with ongoing application engineering support is provided.

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Solid-State Energy Converter Shows Up to 35% of Thermodynamic Limit

Thermoelectric energy converters can convert heat to electricity without noise or moving parts, but have low efficiencies. No commercial thermoelectric energy converters have efficiencies higher than 25% of the ideal Carnot cycle. Vacuum thermionic converters can provide higher efficiencies, but can only operate at temperatures above 1000°C. Two physical effects that can improve the efficiency of a thermoelectric material have been identified: Addition of potential barriers on the emitter and collector sides allows injection of carriers into the gap and blocks the return current from the collector, thus improving device efficiency.

When a temperature gradient is placed across a thermoelectric material, an open-circuit voltage is induced that is proportional to the material's thermopower. A highly doped emitter layer added to the high-temperature side of a weakly doped thermoelectric material (creating a thermal diode) was found to increase the open-circuit voltage by as much as a factor of 2.8 due to thermionic injection effects. This effect was observed in indium antimonide devices and in mercury-cadmium telluride devices. An additional open-circuit voltage increase was observed following the introduction of a compensation layer near the cold-side contact. This effect is attributed to a blockage of the ohmic return current that

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balances the internal forward thermoelectric and thermionic currents under zero-current conditions. The effect was seen to increase the voltage by about 50%. These two mechanisms can be used to increase the efficiency of energy conversion by nearly four times compared to the gap material thermoelectric performance.

For example, an enhancement in the effective figure of merit for $Hg_{0.86}Cd_{0.14}Te$ in one experiment was about a factor of eight above the thermoelectric result due to thermionic injection. Vacuum thermionic converters can be very efficient, but require temperatures of the order of 1000°C at the hot-side contact in order to obtain significant thermionic currents. Researchers at ENECO have found that using a solid-state implementation of the basic scheme provides a way to maintain the good features of the vacuum thermionic scheme while lowering the operating temperature.

This solid-state energy converter is built on a semiconductor wafer (gap material) and has a thin, highly doped emitter layer and an intrinsic or compensated collector layer. The specific emitter design allows the injection of carriers into the gap, and the collector layer blocks the ohmic return current. It has been shown experimentally that each layer separately can nearly double the thermoelectric efficiency. Efficiencies greater than 35% of the ideal Carnot cycle have been demonstrated experimentally. In theory, this design should improve the performance of most of the known semiconductor thermoelectric materials. So far, only $Hg_{1-x}Cd_xTe$ (MCT) and InSb converters have been tested. Higher numbers were obtained with MCT as the gap material. The present numerical model of the device, based on a nonlinear Boltzmann equation, allows the converter design to be optimized for any material and application. According to the numerical model, the present efficiencies can be improved further. Improved efficiencies should enable the development of a number of applications that involve heat-to-electricity energy conversion and also refrigeration. Four patents covering converter and refrigerator designs are pending.

To improve converter stability, researchers at ENECO are investigating various approaches, including diffusion barriers and encapsulation. The availability of new materials and emitter- and collector-layer formation for new materials are also being investigated. Prototypes are anticipated within two years.

Opportunities

ENECO is interested in establishing relationships with both research and industrial partners to develop this solid-state energy converter for a variety of applications.

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Bulk Metallic Glasses Used for Manufacturing Net-Shape Metal Products

During the last decades, researchers have developed several families of metal alloys that readily form glasses, or “vitrify” to form bulk amorphous alloys, also called bulk metallic glasses (BMGs), when cast from the molten state. A growing number of these glassy alloys are becoming available for manufacturing applications. They possess unique properties including elastic strengths two to three times that of steel or titanium alloys, relatively high elastic moduli, and toughness and resistance to cracking (see Table I). The potential of BMG materials for manufacturing is being explored by Liquidmetal™ Technologies (LMT).

In 1993, the company licensed the commercial rights to a family of Zr-Ti-based alloys developed at the California Institute of Technology. These alloys have exceptional performance characteristics as indicated in the Table, which compare, for example, their strength, strength-to-weight ratio (specific strength), and elasticity (elastic strain limit) with other commonly used engineering metals.

Many of the challenging problems in casting and processing of ordinary metals are a consequence of the transformation from the liquid to the crystalline state during solidification. Unlike ordinary metals, liquid BMG alloys do not undergo a phase change on solidification. Rather the liquid becomes continuously more viscous with cooling, becoming kinetically frozen at the glass transition. In the casting of crystalline metals, the phase change on freezing causes “solidification shrinkage” as well as a release of latent heat (recalescence). These effects result in shape changes, development of porosity, and coarsened crystalline microstructures, which in turn result in relatively poor mechanical properties in cast products of crystalline metals. The continuous variation of properties with temperature in bulk glass-forming metals enables processing and manufacturing of precision net-shape glassy components, which faithfully fill and replicate the die cavity, have no crystalline microstructure, and have correspondingly excellent mechanical properties.

Table I: Typical Mechanical Properties of Metallic Glass Compared to Other Metallic Alloys.

	Liquidmetal® Alloy Zr63Ti11Ni10Cu12.5Be3.5	Mg AZ-91	Al 380 Series	Ti-6Al-4V
Mechanical Properties				
Yield Strength				
ksi	290	23	24	115
(MPa)	(1900)	(150)	(155)	(770)
Hardness				
Vickers	550	75	100	340
Impact Strength				
ft-lb	6.0	1.6	3.0	18.0
(J)	(8.3)	(2.2)	(4)	(24)
Elasticity				
(% of original shape)	2.00%	0.35%	0.23%	0.65%
Young’s Modulus				
Psi x 10^6	13.4	6.5	10	16.3
(GPa)	(93)	(45)	(70)	(114)
Specific Strength				
ksi	49	13	9	29
(MPa)	(311)	(83)	(55)	(175)

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In an ongoing project that began in 1996, LMT has developed methods for producing these alloys in commercial quantities and forming them into useful metallic glass products. Their first commercial product was the Liquidmetal golf club (Figure 1). The golf club application was motivated by the elastic properties (the large elastic strain limit) of bulk metallic glass compared with conventional metals. This property determines the ability of a material to store and release elastic energy and can be directly exploited to improve the performance of the golf club. To commercialize this product, LMT developed technology that utilized the "castability" of the BMG liquid to produce high-quality, net-shape golf components at competitive costs.

On the processing side, manufacturing processes have been developed that permit the casting of complex three-dimensional components with precise net shapes. The technology used to accomplish this is similar to manufacturing methods used to produce inexpensive, high-quality plastic hardware. Metallic glasses, however, are much stiffer, stronger, and harder (by more than an order of magnitude) than commonly used engineering plastics. It is anticipated that the superior mechanical properties of bulk metallic glass combined with the process and manufacturing advantages of plastic will affect the way metal products are manufactured and used.

Figure 1. Net-shape golf club heads cast from Liquidmetal™.

The combination of high strength, hardness, elasticity, and resilience, along with the excellent resistance of bulk metallic glasses to corrosion and wear, opens potential markets in a diverse spectrum of products. Applications include sporting goods, high performance springs, cases for electronic products, surgical instruments, implants for bone replacement, and other medical devices. For example, Liquidmetal has partnered with phone manufacturers to produce very strong but very thin cell phone cases with highly finished surfaces resistant to wear and scratching. The cases are stronger and three times tougher than competitive cases made from magnesium and are cost competitive. In a project sponsored by the Army, Liquidmetal is exploring the use of BMG-composite materials for use in armor/anti-armor applications. Here the unique features of BMG are combined with properties of other materials (heavy metals or ceramics) to produce composites to be used in penetrators and/or armor. Micro and nano-replication of functional surface features using methods currently employed to microform plastics is another area of current development. As focused research and development efforts proceed, Liquidmetal expects that bulk metallic glass technology will become more commercially pervasive in the future.

Opportunities

Liquidmetal Technologies welcomes the opportunity to discuss uses and development of bulk metallic glasses for commercial applications.

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