ALLIEDSIGNAL, INC.

A Process for Making Ceramic Parts

Many types of industrial and commercial equipment contain parts that revolve at very high speeds, under great stress, and in extreme heat. Jet engines, power generation turbines, and automobile engines are a few examples. In the past, metal has been accepted as the only material for making such parts.

COMPOSITE PERFORMANCE SCORE
(Based on a four star rating.)
★ ★

Safe, Low-Cost Fabrication of High-Performance Ceramic Parts

With the recent development of high-performance structural ceramic materials, this ATP project with AlliedSignal asked whether it was possible to develop a process for fabricating ceramic parts inexpensively enough to allow them to be substituted for metal parts, thereby significantly improving equipment performance and reliability.

. . . a novel near net-shape . . . process for making high-performance ceramic parts for automobile and aircraft engines.

Ceramic substitutes for metal have performed well in certain critical situations. Space flight is one. Ceramic tile coverings on spacecraft form heat shields that protect astronauts re-entering earth atmosphere. Atmospheric friction heats the tiles to a fiery glow. But the tiles stay in place and dissipate enough heat for safe re-entry. Metal surfaces would melt under these circumstances, with disastrous results.

Cost and Safety Issues Hinder Use

Despite such performance advantages, the application of advanced ceramics has been held back by the high cost of fabrication. Whereas metal can be melt-processed or plastically deformed using molding, extruding, stamping, or other standard metalworking techniques, many ceramics cannot be processed by these methods. Ceramic parts must be made by forming ceramic powder into a desired shape at room temperature and then "reacting" the powder compact at various temperatures to densify it. This process is much more limited in the shapes it can achieve than melt-processing or plastic deformation approaches.

A 16-blade silicon nitride turbine wheel for use in small turbogenerators.

This ATP project offered a novel approach to ceramics production via a relatively new process called gelcasting, a technology developed at Oak Ridge National Laboratory. In gelcasting, powdered ceramic precursors are mixed with a polymer precursor (monomer) and solvent (usually water) to make a slurry that is poured into a mold. The gel is then polymerized, locking the ceramic powder in a polymer matrix. The solvent is removed, and the part is heated

An automated gelcasting machine capable of forming 10,000 ceramic turbine wheels per year.

to burn out the polymer. At this point, if necessary, the "green" part can be machined to some degree. Finally, the part is fired to produce the ceramic. The process is capable of making very complex parts such as turbine wheels. Some shapes made with this technique cannot be made any other way.

. . . potential applications in energy, chemicals, aerospace, electronics, advanced materials and telecommunications.

A major drawback to the original gelcasting technology was its reliance on acrylamide as the gelling additive. Acrylamide is highly sensitive to oxygen, which inhibits polymerization. So the process must be done in an inert environment, which raises the cost. Acrylamide gel is also very difficult to remove if an inert environment is used, raising costs even more. Most important, however, acrylamide is a cumulative neurotoxin, and safety concerns had prevented the technology's widespread use.

AlliedSignal's innovation in this ATP project was to develop a low-cost, nontoxic alternative that retains acrylamide's excellent process characteristics. During the project, AlliedSignal researchers developed and demonstrated a novel near net-shape (requiring almost no machining) process for making high-performance ceramic parts for automobile and aircraft engines. In addition, the new gelcasting process has potential applications in energy, chemicals, aerospace, electronics, advanced materials, and telecommunications.

Early Commercialization Expected

Development of the technology is continuing. In 1995, under the "Partnership to Productionize and Commercialize a Manufacturing Process for Silicon Nitride Turbomachinery Components," AlliedSignal began receiving funds from the Defense Advanced Research Projects Agency for work that grew directly out of the ATP-funded gelcasting project. The company received additional funding for this effort from the Department of Energy in 1997, and it has made substantial progress toward a commercially viable manufacturing process. Marketable products have yet to be sold. But commercial production is expected to begin in the very near future, with annual sales projected to be several million dollars.

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AlliedSignal has constructed a new plant for manufacturing ceramic parts, including those made with the gelcasting technology. Since the close of the ATP project in June 1995, the company has invested $3 million to further develop the technology for particular commercial applications. In addition, based explicitly on the successful completion of the ATP project, it received funding from the Department of Energy and the Defense Advanced Research Projects Agency to advance gelcasting technology into commercialization.

Near net-shape turbine wheels for use in commercial or military jet engine starters.

Cost Reductions and Improved Performance

Users of vehicles and other equipment using gelcast ceramic parts instead of metal ones will benefit from cost reduction and improved performance — in the case of some applications, to a considerable degree. Since Oak Ridge National Laboratory holds the underlying intellectual property for gelcasting, additional spillover benefits

PROJECT HIGHLIGHTS

PROJECT:
To develop a low-cost, near-net-shape gelcasting process for making structural ceramics in a safer, less-costly way than conventional gelcasting based on acrylamide, a cumulative neurotoxin. Successful development of this process would open the door to commercial gelcasting production of these high-performance ceramics.

Duration: 7/1/1992 — 6/30/1995

ATP Number: 91-01-0187

FUNDING (in thousands):

ATP	$1,136	56%
Company	884	44%
Total	$2,020	

ACCOMPLISHMENTS:
AlliedSignal achieved its R&D goal. The company also:

- presented the new technology at several professional conferences;
- invested after the ATP project another $3 million of its own money on additional gelcasting R&D aimed at the development and installation in 1998 of an automated gelcasting system that can fabricate ceramic automotive turbogenerator wheels at a rate of 10,000 per year; and
- received funding from the Department of Energy and the Defense Advanced Research Projects Agency to further advance gelcasting technology, with the specific goal of establishing viable manufacturing processes.

COMMERCIALIZATION STATUS:
Commercialization is in progress, and the first gelcast parts made with the new technology are expected to reach the market very soon. Opportunities exist for commercialization in a variety of fields.

OUTLOOK:
The company is making excellent progress toward its commercialization goals and is expected to start producing gelcast parts in large volume in the near future. Users of vehicles or equipment made with gelcast ceramic parts will benefit from lower cost and better performance, with potentially huge benefits accruing in areas like auto engines, commercial aircraft and industrial applications such as stationary power generation.

Composite Performance Score: ★ ★

COMPANY:
AlliedSignal, Inc., Ceramic Components
(formerly Garrett Ceramic Components
Division, AlliedSignal Aerospace)
2525 W. 190th St.
Torrance, CA 90504

Contact: John Pollinger

Phone: (310) 512-5654

Informal Collaborator: Oak Ridge National Laboratory

are likely to accrue. As a national laboratory, Oak Ridge offers its technologies to the public, and other companies are likely to realize considerable spillover benefits from the AlliedSignal/ATP-funded gelcasting technology. Oak Ridge has already licensed gelcasting technology to two other U.S. companies — a magnetic ferrite manufacturer and a small manufacturer of ceramics for automotive and fuel cell applications — and is working with a number of other companies evaluating the technology.

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Future benefits are also expected to come from applications of the new gelcasting process in a number of sectors, including large aircraft engine parts. In addition, there may be applications in small parts for jet engines, small turbine generators for hybrid electric/fossil fuel cars and auxiliary power systems for aircraft.

Progress Accelerated by Five Years

Because of its success in developing the new gelcasting technology, AlliedSignal has also succeeded in developing the manufacturing technology and component fabrication projects that allow commercialization to progress. The company says that without the ATP funds, it would have needed another five years to reach this stage of development. And it would have been that much further behind its major competitor, Kyocera of Japan. Instead, AlliedSignal

. . . made possible by the ATP grant was the establishment of a technology-development relationship between AlliedSignal and Oak Ridge National Laboratory.

believes that with the help of the ATP funds, it has now pulled even with Kyocera in most applications and is able to make superior-quality products in several areas.

Another clear benefit made possible by the ATP grant was the establishment of a technology-development relationship between AlliedSignal and Oak Ridge National Laboratory. Relations have continued through a scientific exchange agreement for an Oak Ridge scientist who co-invented the original gelcasting technology to work at AlliedSignal for two years.