

Norton Diamond Film

Accelerated Commercialization of Diamond-Coated Round Tools and Wear Parts

The development of advanced composite and metallic materials progressed rapidly within the U.S. automotive and aerospace industries during the early- to mid- 1990s, as these industries increasingly applied advanced materials to their new and existing products. However, the tooling required to machine hard and sometimes abrasive materials did not keep pace with the industries' advances. Norton Diamond Film and Kennametal, Inc., applied their complementary expertise in synthetic diamond-film technology and ceramic and carbide metal materials to the development of diamond-coated round tools and wear parts. Faced with three significant technical barriers that presented a high degree of project risk, the companies sought funding from the Advanced Technology Program (ATP), and in 1995, the joint venture received cost-shared funds from ATP to explore their proposed innovative methods for chemical vapor deposition (CVD) diamond coating. By project completion in 1997, the companies had demonstrated the viability of diamond-coated wear products and had increased tool life by 10 to 32 times. Although Norton Diamond has dropped its efforts to commercialize the technology, Kennametal has commercialized a diamond-coated end-mill product for the machining industry.

COMPOSITE PERFORMANCE SCORE

(based on a four star rating)

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Research and data for Status Report 94-01-0357 were collected during October-December 2001.

Manufacturing Industries Strive to Keep Pace with High-Performance Demands

Advances in microelectronics, tooling, automotive, aerospace, and other industries have increased requirements for materials' performance, leading to harder and more abrasive materials. To create a component that has the desired geometry, dimension, and finish, a part must be machined. Machining is a manufacturing process in which a cutting tool is used to remove excess material from a work part. Tools must be able to work on hard and abrasive materials without wearing out quickly, so using the right tool coating is an important function in the machining of parts. Many industries have focused on developing new and innovative methods for coating parts used in tooling and machining, as manufacturers strive to find ways to

increase tool life, while minimizing chipping of the coatings themselves.

In the search to find a coating material that could provide the requisite toughness and wear resistance, the industry explored diamond as a coating substance. Industrial diamonds possessed the attractive properties of hardness, transparency, high thermal conductivity, and high resistance to chemical corrosion. The problem with diamond, however, was that manufacturers needed a method to use the diamond in a thin film to coat metal tools to ensure adherence of the film over time. Diamond and metal have very different coefficients of thermal expansion, and when the two are joined at high temperatures and then cooled, residual stresses develop at room temperature and cause the diamond film to pop off.

During the early to mid-1990s, the use of natural and synthetic diamonds as a commercial material faced a number of disadvantages: 1) diamonds were only available in powder or grit form, 2) they were unavailable in sufficient sizes or quantities, and 3) they were prohibitively expensive. Therefore, researchers sought to identify methods for using these valuable substances in a more usable form. The discovery of diamond fabrication by chemical vapor deposition (CVD) allowed companies to overcome these problems and take advantage of diamond's attributes. CVD diamond manufacturing processes coat pure diamond directly onto wear surfaces. However, the use of CVD posed challenges in developing coating methods for complex, convoluted-shaped objects (such as drill bits) and in successfully coating parts containing cobalt.

Partners Foresee Significant Technical Challenges

Norton Diamond, a division of Saint-Gobain, hoped to develop its CVD coating technology into a standard process for producing adherent, uniform diamond coatings on three-dimensional surfaces that could be economically manufactured in large quantities for commercial use. Kennametal's contribution was to prepare special tungsten carbide tools, which promoted the adhesion of diamond films. While the proposed technology had the potential to revolutionize the machining of aluminum and composite materials for automotive, aerospace, and other applications, there were significant technical risks in adhering diamond film to complex, convoluted shapes.

Kennametal's special carbide formula and Norton Diamond's diamond deposition technology gave this project a significant advantage over competing approaches; however, both companies needed to overcome three main challenges to successfully accomplish their mission:

- Improve adhesion of diamond film onto cobalt-containing alloys that comprise the bulk of tools and components
- Demonstrate reliable coating of complicated three-dimensional round shapes

- Coat a large enough number of parts in one deposition to make the process economically sound

Faced with the challenge of overcoming three major technical barriers, the two companies sought ATP funding. With ATP support, Norton Diamond Film and Kennametal, Inc., believed they could combine their technical strengths in synthetic diamond-film technology and ceramic and carbide metal materials, respectively, to explore innovative methods for CVD diamond coating.

Companies Combine Strengths to Develop Diamond-Coating Technology

The companies proposed to develop diamond-coated tools and wear parts that last 10 to 100 times longer than the components available at the time. CVD diamond coating had the potential to improve the productivity of the U.S. industry in the drilling, tapping, reaming, and end-milling of non-ferrous and non-metallic workpiece materials. Through collaboration, the two companies sought to create an enabling technology that would provide more durable tools, lower manufacturing costs, and increase productivity. Norton Diamond and Kennametal officers were enthusiastic about the possibility of accelerating technology development by several generations.

Diamond-Coating Technology Has Far-Reaching Economic Potential

At the time of this project, the successful development of the diamond-coating technology offered promise for a number of industries and applications. The U.S. market for wear components (e.g., seals, dies, and tooling) for high-performance materials, such as tungsten carbide, ceramics, and coatings, was in excess of \$1 billion.

The conservative estimate for diamond-film-coated mechanical seals was \$100 million annually. In addition to improving the market potential, the development of the technology could lead to lower domestic transportation costs, increased U.S. market share, increased warranty periods for automotive parts,

increased production in many industries, and the creation of more jobs for manufacturers and their suppliers.

Joint Venture Advances Technology Via Testbeds and Demonstrated Improvements

Major automotive and aerospace companies, including General Motors, Ford, Boeing, and Cummins, served as testbeds to ensure that the technology was robust enough for the manufacturing environment. The testbed results demonstrated an improvement in tool life of 10 to 32 times the lifespan of existing tools and, in addition, led to process improvements. Norton Diamond and Kennametal were able to minimize thermal-induced distortion of low-precision tools and produce a cobalt-free surface that provided excellent diamond adhesion and distortion-free, high-precision tools.

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The joint venture also demonstrated that convoluted round shapes, such as drills and end mills, could be coated with diamond films that still have good adhesion after more than 1,000 drill operations. This was an important technological advance since delamination from non-planar substrates was a major problem with this technology. Additionally, the companies accomplished the project's primary technical goal by establishing a manufacturing capability for tungsten carbide substrates that promotes the adhesion of diamond films.

Kennametal Pursues Separate Path to Commercialization

Though the collaboration of Norton Diamond and Kennametal was at first synergistic, toward the end of the two-year project, the companies found that they had differing approaches to taking their technology to market. These differences led each company down divergent paths in the development of their technologies. Norton Diamond attempted to market the

technology until the summer of 1998. After then, it abandoned its attempts. As of July 2000, Norton Diamond Film no longer existed as a business division within Saint-Gobain.

Kennametal changed its strategy and focused on hot filament CVD technology and invested its own internal funds to take its CVD pretreatment and coating technology to market after the project concluded. Kennametal commercialized a diamond-coated endmill product that it currently supplies to the graphite, nonmetallic materials, and metal machining industries. The market has been slow to adopt the new technology as manufacturers remain cautious of new processes and are reluctant to pay high premiums for them. Kennametal continues its efforts to make tools more robust and to provide them to existing and new industries, such as metal machining.

Conclusion

Norton Diamond and Kennametal combined their expertise in synthetic diamond-film technology and ceramic and carbide metal materials in an effort to develop an effective diamond-coating technique for the automotive and aerospace industries. Together, they were able to demonstrate significant improvements, however, individually, each company decided to pursue a different course in its effort to further develop diamond-coating technologies. Norton Diamond discontinued its efforts to commercialize the technology, but Kennametal went on to develop a diamond-coating technology that is now being used by the manufacturing industry.

PROJECT HIGHLIGHTS

Norton Diamond Film

Project Title: Accelerated Commercialization of Diamond-Coated Round Tools and Wear Parts

Project: To develop diamond-coated round tools and wear parts for automotive and aerospace manufacturing that last 10 to 100 times longer than existing counterparts.

Duration: 5/1/1995-10/31/1997

ATP Number: 94-01-0357

Funding (in thousands):

ATP Final Cost	\$1,883	42%
Participant Final Cost	<u>2,609</u>	58%
Total	\$4,492	

Accomplishments: The joint venture between Norton Diamond and Kennametal was a successful research and development partnership that accelerated the commercialization of rotary tool products and demonstrated the viability of diamond-coated wear parts. The companies developed testbeds that were installed in major automotive and aerospace companies, including General Motors, Ford, Boeing, and Cummins and demonstrated tool life 10 to 32 times longer than existing tools. They also demonstrated that convoluted round shapes such as drills and seals could be coated with diamond films that have good adhesion after more than 1,000 drill operations. The joint venture resulted in the following patent, which was awarded to Kennametal as a result of technology related to the ATP project:

- o "Method of making diamond coated member" (No. 5,701,578: filed November 20, 1996, granted December 23, 1997)

Through this ATP project, the joint venture also strengthened the U.S. position in the competitive global market for rotary tools and wear parts.

Commercialization Status: Prior to this ATP project, Norton Diamond and Kennametal each developed diamond-coating and pretreatment technology for simple, flat shapes, but had not developed the technology for convoluted shapes. Through the ATP-funded project, the companies were able to develop the technology for coating complex parts. After the conclusion of the project in 1997, Kennametal commercialized a diamond-coated endmill product that it currently supplies to the graphite, nonmetallic materials, and metal machining industries.

Outlook: While the use of the technology has not grown as quickly as the two companies anticipated at the beginning of this project, Kennametal continues to offer its diamond-coated product to various industries and continues research and development efforts to create more robust diamond-coating technology. It is anticipated that barriers to making this technology economical enough for widespread acceptance within the manufacturing environment will continue to exist.

Composite Performance Score: * *

Company:

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Norton Diamond was a division of Saint-Gobain since 1990. As of July 2000, Norton Diamond was dissolved and employees were transferred to other divisions of Saint-Gobain.

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