U.S. Department of Energy
Energy Efficiency and Renewable Energy
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RSP Tooling in brief:

Benefits:
- Industrial energy savings: 0.14 TBtu/yr in 2010 and 5.56 TBtu/yr in 2020
- Time savings of 20-25% over conventional die
- 22-33% reduction in manufacturing costs

Awards:
- 1998: R&D 100 Award
- 2000: DOE Energy @ 23 Award
- 2001: Federal Laboratory Consortium (FLC) Award

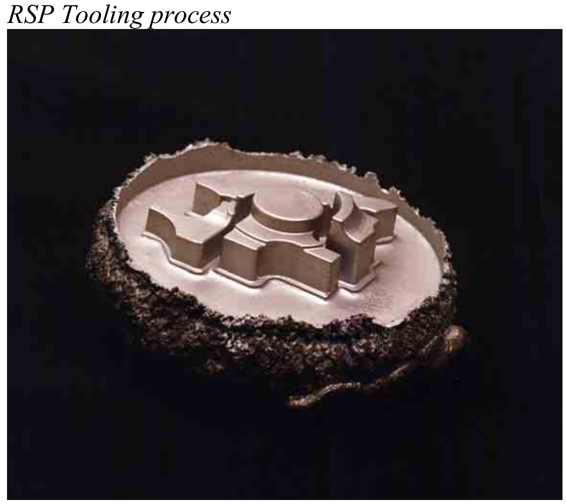
Applications:
- **Glass:** Improved hot glass contact materials; e.g., molds and rolls.
- **Metalcasting:** Development of die materials to eliminate solder and heat checks in permanent castings.
- **Steel:** Materials and manufacturing methods for die materials and sheetforming die development. Development of additional methods for materials and manufacturing, especially for short-run tooling.

Additional applications also exist in the supporting industries:
- **Forging Industry:** Advanced die materials.
- **Heat Treating:** Materials of construction in furnaces.

Development and Demonstration of Advanced Tooling Alloys for Molds and Dies:
A Technology Transfer and Commercialization Case Study

1. TOOL STEELS AND THE MARKET

Figure 1.1 A close look at the GMTI Die from the RSP Tooling process



Molds, tools, and dies are required for the formation and production of nearly all mass-produced items, spanning industries such as glass, metal casting, steel, forging, heat treating, aerospace, automotive, power generation for various applications, consumer products, and medical. The annual market for tool steels in the United States is in the range of 165,000 to 175,000 tons [1], and machine tool consumption in the United States continued to grow through the latter part of 2004 [2]. Manufacturers, from car makers to toy companies, are always looking for ways to make dies more quickly and cheaply. However, significant barriers to energy and economic benefits in the manufacture of tools and dies still exist, primarily related to conventional machining methods, which are time consuming and expensive due to the required accuracy and tolerances. Improved alloys that result in longer tool life can lead to energy and cost savings.

Figure 1.2 This party balloon covered with tin alloy demonstrates the abilities of rapid solidification

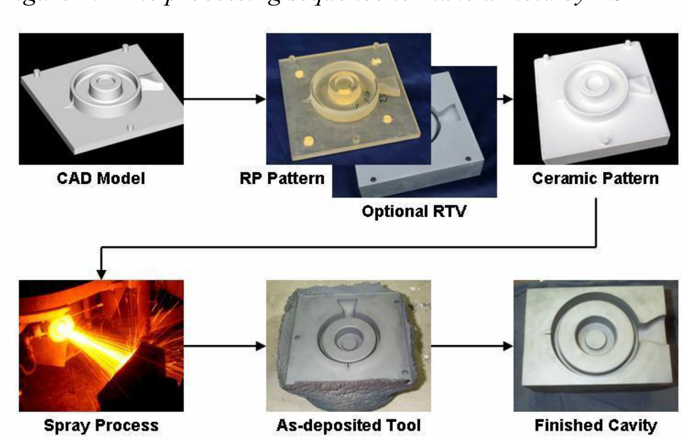
Efforts are underway to develop new processes to reduce machining time, eliminate distortion, and increase the life of tools and dies. Several new rapid tooling technologies that address these issues have energy conservation as an associated benefit and are either under development or have recently been commercialized. These tool making methods can fit into two categories: direct and indirect technologies. Direct methods utilize rapid prototyping systems to form the tool insert without an intermediate processing step. Indirect technologies, such as Rapid Solidification Processing (RSP) tooling, require a pattern that is usually created by a rapid prototyping process.

2. THE RSP TOOLING PROCESS

Compared to conventional fabrication methods, RSP Tooling reduces cost and turn-around time for production of precision tooling by a factor of 5 to 10. The process, invented, developed, and patented by Idaho National Laboratory (INL), is based on the discovery that a liquid can be broken down into small droplets by use of the shearing effect of a flowing gas, and involves spraying layers of molten metal onto a three-dimensional pattern, building up the layers into a full-size die. This results in a combination of liquid, solid and "slushy" droplets coating the tool pattern. The slushiness allows the droplets to stick together as they hit the pattern, and may contribute to the remarkable level of detail RSP can achieve. Because the surface area of the droplets is so great compared to their volume, the droplets cool very rapidly, somewhere between 100 and 100,000 degrees per second, resulting in beneficial characteristics of the alloy [3]. These properties are vividly illustrated in Figure 1.2 through both the precision of the metal coating and the swift cooling which preserved the integrity of the balloon.

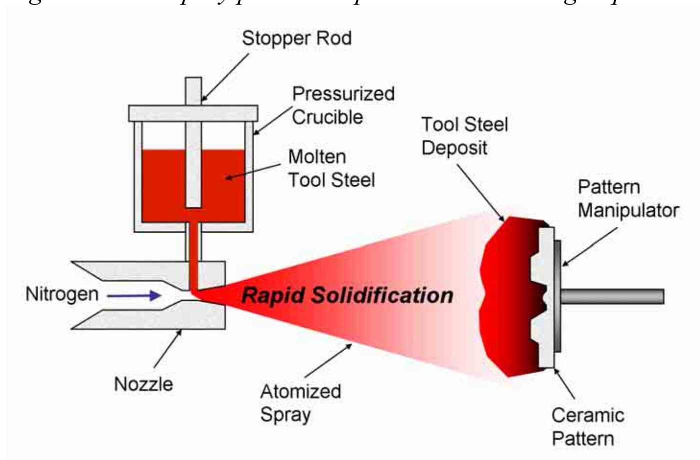
The Rapid Solidification Processing begins with the production of a mold (Figure 2.1). A CAD file is created that describes the mold design, from which a tooling master is created via rapid prototyping methods such as stereolithography or selective laser annealing. Ceramic casting methods are then used to make a ceramic pattern from the tooling master.

Figure 2.1 The processing sequence to make a mold by RSP



Once the mold is created, metal alloy with the desired chemistry (in cast, forged, powder or scrap form) is melted in a crucible and then injected into a nozzle with a flowing gas stream. The high velocity inert gas jet generates molten metal droplets, on the order of 50 microns in diameter, which are sprayed onto the ceramic pattern, replicating the pattern's contours, surface texture, and details (Figure 2.2).

Figure 2.2 The spray process step in the RSP Tooling sequence



After spraying, the metal is cooled to room temperature and separated from the pattern. The irregular periphery, or overspray, of the freshly sprayed tool is squared off either by machining or, in the case of harder tool steels such as H13, by wire EDM [4]. The squared-off insert is then fixed to a mold base. Injection molds or die-cast molds require two inserts, one for each mold half.

Rapid solidification produces a very uniform microstructure and allows the properties of many die steels to be tailored using 'artificial aging' instead of conventional heat treatment. Demonstrations have shown that artificial aging benefits many die steels. RSP dies last about 20% longer than conventional, machined dies. In prototype development, initial dies can be designed, created and tested within a few days. Changes to the die can be incorporated quickly and inexpensively. When the design is satisfactory, the prototype can be used directly for production without additional steps.

3. BENEFITS

The industrial energy savings associated with the implementation of the RSP Tooling technology are forecasted to be 0.14 TBtu/yr in 2010 and 5.56 TBtu/yr in 2020 [5]. Time savings over conventional die manufacturing is estimated to be in the 20-25% range and costs can be reduced approximately 22-33% (Table 1).

Compared to conventional machining processes, the implementation of the RSP technology can result in significant energy savings in the production of dies. These savings occur in various stages of the process, from preparation of the starting materials through the actual die formation to the service life of the die.

Table1. RSP Tooling time and cost improvements

Product Comparison	Time (Days)	Cost
Weber (die casting die)	21	$6578
RSP Tooling	16	$5100
Improvement	23%	22%
Metaldyne (forging die)	10	$1200
RSP Tooling	8	$800
Improvement	20%	33%

The major areas of energy savings in the die manufacturing process include:

- Elimination of steel mill unit operations for producing forged plate, rod, bar, etc. suitable for the demands of die casting.
- Elimination of several machining, grinding, and polishing unit operations necessary to convert forged steel into dies.
- Die life extension due to unique microstructure created during rapid solidification.
- Substituting a relatively low temperature artificial aging thermal treatment for the conventional austenization/quench/temper heat treatment.

The potential for energy savings and commercial application of RSP Tooling technology have been recognized by DOE and other organizations, and resulted in the RSP Tooling Technology receiving an *R&D 100 Award* in 1998, a DOE *Energy @ 23 Award* in 2000 (recognizing innovations that best demonstrate benefits to the American public and contribute to U.S. competitiveness in the global marketplace and the potential for significant future growth), and a *Federal Laboratory Consortium (FLC) Award* in 2001.

Table 2. Idaho National Engineering and Environmental Laboratory Rapid Solidification Processing Patents

U.S. Patent No.	Date Issued	Title
4,919,853	April 24, 1990	Apparatus and method for spraying liquid materials
5,445,324	August 29, 1995	Pressurized feed-injection spray-forming apparatus
5,718,863	February 17, 1998	Spray forming process for producing molds, dies and related tooling
6,074,194	June 13, 2000	Spray forming system for producing molds, dies and related tooling
6,746,225	June 8, 2004	Rapid solidification processing system for producing molds, dies, and related tooling

4. IMPLEMENTATION AND COMMERCIALIZATION

RSP Tooling, LLC in Solon, OH was established in January of 2002 with the goal to commercialize the RSP Tooling technology that was developed at INL. The strategy was to find partners familiar with the tooling industry who would be active stakeholders in the business, not just investors. Start-up funding for RSP Tooling, LLC, approximately $2.5 million, was raised from The Technology House and Belcan Corporation, plus several individual investors, and through loans from the state of Ohio and a financial institution. RSP Tooling, LLC negotiated a field of use license agreement with INL for the Rapid Solidification Processing technology for all tooling applications. INL RSP Tooling patents which have been licensed to RSP Tooling, LLC are listed in Table 2.

Figure 4.1 The beta RSP Tooling machine constructed by Belcan Corporation for RSP Tooling, LLC

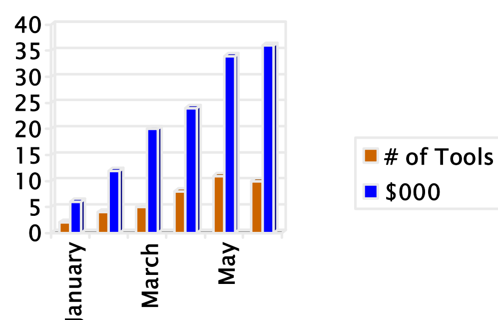
The beta RSP Tooling machine (Figure 4.1) is being used to develop and understand the spray deposition parameters of various alloys. A series of forging die development tests have been performed with M2 and H13 tool steel compositions, and the dimensional accuracy and microstructural quality has been improved. It was determined that metallurgical issues are encountered when 100% recycled alloy is used, and now forging dies have been produced and are ready for production trials. Extrusion dies were prepared by RSP Tooling, LLC and tested by Wright Patterson Air Force Base. The wear life of non-age hardened RSP tooling was equivalent to the incumbent tooling.

Additional testing and analysis will be performed: spray trials have been initiated with stainless steel and process data is being analyzed to determine a correlation between the deposition rate and tool quality. In an effort to further expand the potential of this technology, RSP Tooling, LLC has submitted Small Business Innovation Research (SBIR) proposals for funding to support research on spray forming alloys that are normally processed by other techniques.

Continued effort is put forth incorporating improvements into the beta machine that increase its repeatability and increase component life resulting in higher part quality and reduced costs. Engineering design concepts are being developed for a production machine that can produce more than 500 tools per month. Arrangements have been discussed with leasing companies so businesses interested in purchasing RSP Tooling machines can lease them at a monthly rate.

Small quantities of product are produced and shipped each month. Plastic injection molding tools were shipped in August, 2004, and die casting and forging dies were completed in September, 2004. A forging die was successfully used by a customer in September, 2004 to produce parts. Figure 4.2 shows the growth in sales and numbers of parts sold earlier in 2004. Given the progress to date and the potential impact of the RSP technology, a sales person was hired to focus on the forging industry.

Figure 4.2 Early 2004 sales data for RSP Tooling, LLC



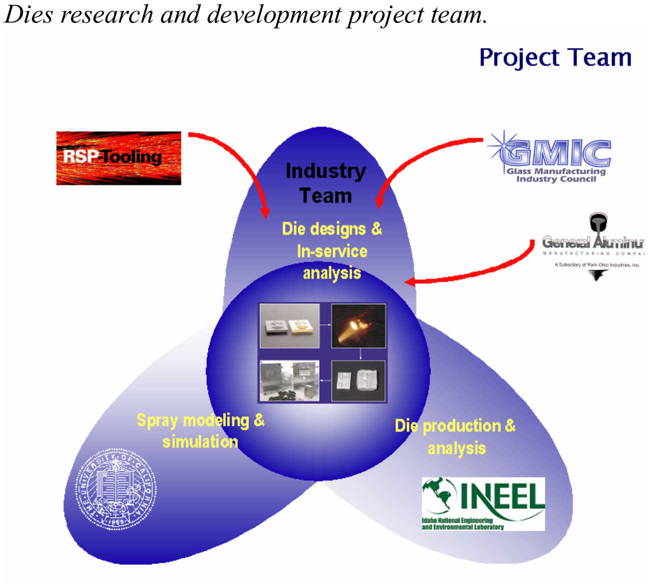
5. SUMMARY

The Rapid Solidification Process was developed at Idaho National Laboratory (INL), through funding from the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) Industrial Technologies Program (ITP). The mission of ITP is to decrease the energy intensity of the industrial sector through a coordinated program of research and development, validation, and dissemination of energy-efficiency technologies and operating practices.

The RSP Tooling terminology was introduced in 1997 [6], and RSP Tooling, LLC was formed in 2002 to design, build, use, and sell machines that manufacture tooling using this process [7]. RSP Tooling is currently using the beta machine to run tests on new materials, improve product quality, in addition to manufacturing production tooling for customers.

INL is continuing work on equipment modifications to improve the spray performance of the RSP technology and working to optimize alloy properties through a close study of microstructural evolution during spray deposition.

Figure 5.1 The Advanced Tooling Alloys for Molds and Dies research and development project team.



Other recent EERE-ITP funded RSP investigations at INL include:

- *Integrating RSP Tooling and Rapid Prototyping in Die Casting* (http://www.eere.energy.gov/industry/metalcasting/pdfs/csu_rsp_tooling.pdf)
- *Development and Demonstration of Advanced Tooling Alloys for Molds and Dies* (http://www.eere.energy.gov/industry/imf/pdfs/ineel_tooling_alloys.pdf) (team structure and interaction illustrated in Figure 5.1)

Analysis of the RSP Tooling technology development and commercialization has revealed the following observations and factors that can be associated with successful technology transfer from a federal laboratory to industry:

- A good materials processing technology, as evidenced by the awards won, can take in the neighborhood of 15 years from idea concept to commercial prototype
- Technical support from the laboratory greatly improves the efficiency of the technology transfer to industry
- The identification of strategic industrial partners and their buy-in to the commercialization strategy is critical to the successful implementation of the technology.
- The effort that was put into marketing and publicizing the technology, though seemingly enormous, resulted in exposure and interest throughout the industry.

Key References:

1. Carpenter Technology Corporation, (Nov 15, 2004). Personal communication with marketing representative.
2. The American Machine Tool Distributors' Association (AMTDA) website: http://www.amtda.org/index.htm
3. Beckman, Mary. (January 2001). *A Mass Production Marvel, Spraying molten metal promises a faster way to make dies for mass production*. INL Research Communications, http://www.inel.gov/featurestories/01-01rsptooling.shtml
4. DeGaspari, John. (June 2000). Tools to Die for, Mechanical Engineering Magazine, p. 54-57 http://www.memagazine.org/backissues/june00/features/tools/tools.html
5. U.S. Department of Energy, Energy Efficiency and Renewable Energy, Industrial Technologies Program, Industrial Materials for the Future, Government Performance and Result Act (GPRA) 2004 data.
6. RSP Tooling, LLC website: http://www.rsptooling.com
7. Die Casting Engineer. (May 2002). http://www.diecasting.org/dce

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