SENIOR DESIGN PROJECT

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THE RAPID SOLIDIFICATION PROCESS (RSP):

Its Theoretical Basis, and the Benefits it Offers the Manufacturing Industry

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Abstract:

An H13 tool steel die insert synthesized via the rapid solidification process (RSP) was used to create a forged part and an injection molded part. The integration of these example parts into an RSP presentation will tangibly demonstrate the aesthetic and practical nature of RSP to an audience that is subjected to an in-depth discussion of the purely theoretical aspects of the process.

A practical demonstration highlighting the functionality of RSP is essential to convincing both industry and the lay public of the inherent soundness of this revolutionary processes theoretical underpinnings. Hard data from properly chosen experiments (such as dynamic, in-die, FEA of "sprayed tooling") acts to prove the superior aspects of RSP. This is the only effective way to irrefutably convince prospective companies and to ultimately integrate this revolutionary process into established manufacturing practice.

An explicit description of the actual rapid solidification process, and everything that such an unorthodox technology may mean to industry, comprises this report.

Introduction:

To visually and tangibly demonstrate RSP's unique characteristics an actual die insert that was made via the process was obtained and used to create both forged and injection tools. Such an undertaking evoked the beauty and simplicity of the RSP approach; part creation with no machining. It became evident throughout this report, that an in-depth examination of how and why RSP works, and a comparison of its revolutionary methods with those techniques that are currently in use, provides RSP's best justification for implementation into industry.

The rapid solidification process is fundamentally different from conventional tool making, but as will be demonstrated, the results are virtually identical. In conventional tool making a mold core and cavity are machined from a block of tool steel, RSP equipment creates a shape by spraying molten metal onto a pattern and reproducing the pattern's shape, details, and texture. Die inserts and actual tools created with RSP prove to have identical mechanical characteristics when compared to their forged equivalents. Such tools can be rapidly mass produced using RSP, from a practical and an economic standpoint this is highly advantageous.

Acknowledgements:

The authors would like to thank Dr. John Frater who did his best at every turn to provide solid connections with the necessary people and equipment to help our group properly explore this new and exciting topic. Though fate has thwarted us, our creativity has not; we would like to acknowledge our own hopefulness, and perseverance. As a group, we have learned to deal with the adversity that is all too often faced by students who seek knowledge for its own sake, but can only bring their enthusiasm, and not gold, to the bargaining table.

Existing Design and Method:

Conventional tooling fabrication is time consuming. Lead time for an average plastic injection mold is three to six months. Tool checking and part qualification may require an additional three months. Large dies may have a lead time of twelve months. Currently, the production of molds, dies, and related tooling is very expensive and time consuming since each part must be custom made to capture its desired shape and texture. The materials used to make tooling are hard to machine and work with. Hardened tool steels are the norm due to the need for long production runs. Tool production is also time intensive due to the fact that all tooling must be machined accurately since many individual components must fit together correctly in the final product.

Tooling costs for molds used for plastic injection molding range from about ten thousand to over three hundred thousand. Large die-casting dies for automobile transmissions and sheet metal stamping dies for making automobile body parts (such as hoods) can exceed one million dollars.

Conventional methods for making specialized, custom tooling are capital equipment intensive. The process involves machining the negative of a desired part shape, its core and cavity, from a forged tool steel or rough metal casting, adding cooling channels, vents, and other mechanical features, and then grinding. Many molds and dies undergo a heat treatment operation to improve the properties of the steel, followed by final grinding and polishing for the desired finish. Specialized equipment is needed for the individual machining steps. These steps represent a large capital investment and require considerable shop floor space.

The starting material for machining molds and dies is typically forged tool steel plate, rod, or bar. Cast materials are usually unacceptable due to the rigors of processing demands. The manufacture of forged tool steel is carried out by specialized steel mills, and is very energy intensive.

New Manufacturing Method and Design:

The companies that comprise the manufacturing industry are constantly looking for ways to cut tooling costs and methods to get products to market sooner. A new technique, which is called the rapid solidification process, or RSP, has been shown to lower costs and shorten lead times of production tooling. Such a technology is highly desirable since currently plastic injection molds can cost upward of three hundred thousand dollars and require three to six months for tool checking and part qualification. Large casting dies and sheet metal stamping dies can cost even more (around one million) requiring lead times of forty weeks.

Much different from conventional tool making, RSP equipment creates a shape by spraying molten metal onto a pattern, faithfully reproducing the pattern's shape, detail, and texture. Tools can be completed in as little as three days, and are suitable for both prototyping and production runs. RSP can be used to manufacture tools for a range of processes, including injection molding, blow molding, die casting, stamping, and forging. RSP tooling begins with a mold design described by a CAD file which is then converted to a tooling master by a rapid prototyping technology such as stereolithography (SLA). Metal spray is deposited on a pattern, which can be made of various materials, depending on the tooling alloy that is being sprayed. Because the temperature of molten tool steel is too high for most plastics, a castable ceramic pattern is made from the rapid prototyping master. Molten metal (usually a common tool steel like P20, H13, or D2) is sprayed against the ceramic pattern, replicating the pattern's contours, surface texture and details. It's done one time for the core and once for the cavity. After spraying, the molten tool steel is cooled at room temperature and separated from the pattern. The irregular periphery of the freshly sprayed insert is squared off either by machining or, in the case of harder tool steels such as H13, by wire EDM. 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.

Starting with the master, a full cycle can be completed in as little as three days. The most time consuming portion of the process is preparing the pattern for spraying. The actual spraying of the molten tool alloy onto the pattern takes as little as four minutes due to the "rapid build up". It takes one day to produce an SLA model, one day to cast the ceramic pattern, five minutes to spray the molten metal on the pattern, and one to three days to mount the insert in a mold base. The process starts with nearly any form of the metal – cast ingot, forged metal, powder or scrap – that has the desired chemistry of the tool alloy. The metal is loaded into a crucible, where it is heated to one hundred degrees Celsius above its melting point. The molten metal is injected into a nozzle, where it is exposed to a flowing gas stream. From that point, the device operates much like a conventional paint sprayer. The high velocity gas jet breaks the molten metal into tiny droplets, on the order of fifty microns each, which are carried by the gas stream and deposited on the pattern surface. RSP equipment is a self-contained unit. The equipment is configured so that the nozzle remains stationary while a robotic arm manipulates the pattern. The metal is maintained in a liquid state while it is inside the nozzle. Upon exiting, the gas stream flowing through the nozzle entrains (attracts) gas equal to about eight times its own volume. Gas at room temperature is drawn into the jet, cooling the droplets and causing them to solidify rapidly. The spray of droplets results in a huge increase (ten orders of magnitude) in the surface area of the metal. The large increase in surface area causes heat to be extracted rapidly from the particles as they travel from the nozzle to the substrate. About seventy percent of the droplets are solid by the time they hit the pattern, the remaining liquid fraction is enough to effectively weld the metal together on the pattern surface. Because the metal solidifies very rapidly, it forms a continuous build up on the pattern (no layering).

It may be informative for concerned manufacturing companies to look at the material tailoring properties unique to RSP tooling. RSP tooling can undergo either conventional heat treatment or low temperature heat treatment known as artificial aging. Artificial aging allows the tailoring of steel properties, such as hardness, toughness, and thermal heat resistance, without the risk of tool distortion. Conventionally processed tool steel which has been melted and cast at the steel mill contains segregates, resulting in non-uniform material properties that make high temperature heat treatment necessary. Segregation occurs when molten metal solidifies slowly. With RSP, tool steel is melted and mixed up in the crucible, then solidifies rapidly during spraying, to prevent a chance for segregation to take place. RSP spray forming results in tool steel with a more uniform carbide distribution, allowing it to be artificially aged at a lower temperature. RSP also makes it possible to experiment with exotic alloys, thus spraying the material types that are difficult to machine.

An additional benefit of this new process is that RSP offers the possibility for more efficient cooling. It makes conformal cooling, in which cooling lines closely follow the contours of a mold cavity, a viable cooling system which can possibly be incorporated into molds. Conformal cooling normally is not possible with conventionally machined molds and dies. With RSP, an operator can spray metal onto a pattern, stop the spray, attach a cooling line, and then continue spraying to encapsulate the cooling line.

Conclusion:

Nearly all the manufactured goods that we use every day in the home or at work, require precise, customized tool steel molds and dies to produce them, whether by plastic injection molding, die casting, stamping, blow molding, or forging. In any case, tooling methods are extremely critical to the manufacturing sector.

Conventional tooling fabrication is time consuming. Lead-time for an average plastic injection mold is three to six months. Tool checking and part qualification may require an additional three months. Large dies may have a lead-time of twelve months. RSP tooling on the other hand produces finished molds and dies in days.

RSP tooling is a fast, low-cost alternative to conventional fabrication of precision tooling used to manufacture nearly all mass-produced products, from cell phones to automobiles. By eliminating costly and energy-intensive unit operations in the conventional approach, RSP tooling reduces cost and lead time for producing tooling by a factor of two to ten, substantially shortening the time it takes industry to get products to market.

Conventional tooling continues to be manufactured through the use of machining practices, and materials and heat treatment practices developed many years ago. The need for innovation is reflected in recent research and development projects. These projects seek to improve the turnaround time of tooling for making prototypes, and to develop a better understanding of the microstructure, chemistry, and heat treatment of hot forming die steels that lead to die life extension. All evidence suggests that if RSP becomes a staple technique used in the manufacturing industry, there will be a pronounced increase in productivity and a substantial reduction in energy use.

Facilities:

The initial brainstorming and the layout of the project timeline were done at the house of one of the group members. This venue provided an atmosphere conducive to creative thinking. The main functional facility used for the project was the engineering lab at CSU; CAD drawings of theoretical parts and the ALGOR analysis on the final part were performed there. The main presentation on RSP was given at a manufacturing facility in Solon, Ohio, called Belcan. Belcan housed the actual RSP machine (named "88") at the time. During the presentation, notes were taken and questions were asked to clear up all discrepancies and to become wholly familiar with the RSP process. Stereolithography and EDM were presented to our group at The Technology House, a design engineering company in Solon, Ohio. The Technology House visit was highly illuminating as it provided an understanding of the preliminary processes necessary before the Rapid Solidification Process can occur.

References:

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