Worldwide Technological Advances in Micro Molding

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Abstract

This paper provides an overview of a worldwide assessment of the advances in micro molding processes. A decision analysis matrix for the best possible technology fitting various applications will be explored. Processes include micro molding, liquid silicone molding, metal injection molding, and a variety of micro machining techniques.

Introduction

Medical Device, Electronics, and Biopharmaceutical manufactures need new products that create tinier, less invasive, fluid-induced, and/or space saving micro devices. These products require integrated, micro and automated solutions to ensure their success out of the gate. The tiniest parts in an assembly are the ones most likely to be a challenge and are also usually the enabling component of the entire devices form, fit, and function. Many new advances in micro molding have been developed worldwide for the creation of microscopic features and components. Micro molding is a necessary form of manufacturing for many polymeric, metallic, and nano-composite materials and processes alike.

Theory & Definitions

Webster's dictionary defines "micro" as:

- Very small; *especially***:** MICROSCOPIC
- Involving minute quantities or variations
- Extremely small in scale or scope or capability

Although there is no standard definition of micro molded components, a general industry-accepted definition is one or more of the following attributes:

- Fractions of a plastic pellet or weighing fractions of a gram
- Having wall thickness of less than .005"(0.127mm)
- Having tolerances of .0001" to .0002"(0.0025 to .0050mm)
- Having geometry seen only by use of a microscope

Many new products exist today because of the introduction of micro molding which has been around since the 1950's due to the Swiss watch industry. At the beginning stages of micro molding, few machining and molding machines were available on the market that were considered small enough and precise enough to produce components that are the size of specks of dust. Today, dozens of small shot size, ultra precision micro molding machines exist. The technology is ripe for creating new and innovative microscopic components but the technology is limited to a select entrepreneurial few who may have had the foresight in the 2000-2002 manufacturing economic downturn to invest in micro technology. For this reason, scarce knowledge is known and more importantly shared throughout the micromolding industry, creating a need for micro manufacturing expertise, advanced, and integrated micro solutions.

Designing and manufacturing successful solutions for the micro manufacturing market is a subtle marriage between the making of extremely precise micro components and the packaging of micro assemblies. The industry demand for even smaller microscopic components and features leads component manufacturers to implement automated assembly and integrated solutions in order to maintain or improve the quality of their micro devices.

Faster times-to-market for new micro products are achieved by combining micro manufacturing experience and engineering input in the design and manufacturing of a fully integrated micro molding and assembly system. Cross-disciplinary teams of micro manufacturing and design engineers working together on a micromolding system provide expedited development cycle for new micro products.

Micro Tooling/Micro Molds

There is no question that the barrier to entry in micro molding is finding a source for the micro mold. Any micro molder will tell you that the enabling component to creating micro molded parts is the micro mold. Since there is very little shrinkage relative to the size of the components during and after molding, what you have in steel is what you will have in plastic.

For this reason, it is an absolute requirement to have an extremely accurate micro mold with very little core to cavity error across the parting lines of the mold halves. In many cases of thin walled components and/or tiny feature components, the cavity to core error can be no more than five microns (.0001"). Without this degree of accuracy, the parts will not fill uniformly and premature polymer freeze off will prevent parts from filling the entire cavity.

The economically viable and reliable production of micro-molds requires the complete command of the processes involved. The scaling of the process, however, creates new problems in the integrated process chain. Basic research of micro technology and the use of these technologies for creating micro molds is the enabling factor for making micromolded parts and features possible. Many technologies exist such as:

- Laser Machining
  Chemical Milling
- Electrochemical
  Electrochemical Machining
- EDM-WEDM
  Photochemical Milling
- Ultrasonic Machining
- Ion Machining
- CNC Machining

Although these technologies exist and are available, the challenge still exists to pull pieces of steel together that were made from different sources using different technologies to create a micro mold. Continuous research must be done in order to keep up-to-date with the latest micro machining methods that are useful, economical, and can be employed and utilized with for a particular micro mold project.

Micro Machining Capabilities

	High Speed Milling	Sinker EDM	Wire EDM	Xray Lith-ography
Minimum Structure Size-um	50	5 to 10	15 - 20	
Surface Finish Ra-um	1	0.2	0.05	
µm	50	< 10	~15	
Aspect Ratio	100 - 150	~ 20	100 - 150	100
Drawback	Heat Stress	Slow removal rates	Through Shapes Only	Learning Curve-Mold-makers

Table 1.1

Common micro machining methods are compared in the chart above. All methods are useful for creating components of micro molds. X-ray lithography and Ion Beam Machining are not commonly used in mold making today but will gain notoriety as micro machining grows worldwide. A drawback to milling is that under high speed, high heat is generated and may promote micro cracks in the components causing steel failure. Rutgers University's Professor Tugrul Ozel's answer to this problem can be seen in the Figure 1.2. The simulation shows high heat applied to 40,000 rev/minute spindles. Professor Ozel has been researching a laser beam-assisted milling machine (Figure 1.3) that applies preheating of the materials prior to and during the milling process which produces much less heat fracture from the high speed spindle action.

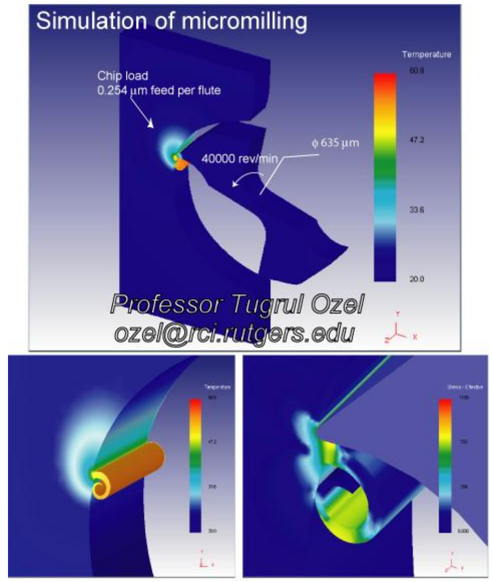

Figure 1.2 Simulation of End Mill Temperature Gradient, photo provided by Rutgers Engineering

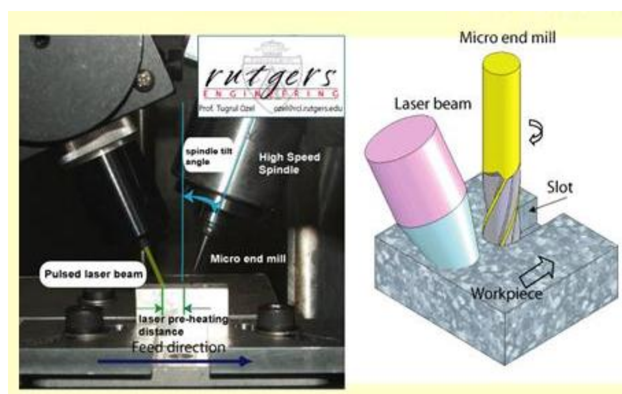

Figure 1.3 Photo and close-up depiction of Laser-Assisted Micro Milling, photo provided by Rutgers Engineering

Future Trends in Micro Tooling/Micro Molds

Another tooling technology creating some of the smallest micro structures is Ion Beam Machining. This is a process by which sub-micron features and 100 nanometer radii can be created by bombarding a solid tool blank with energetic focused beam of ions. This technique can also be coupled with chemicals to make the removal process faster.

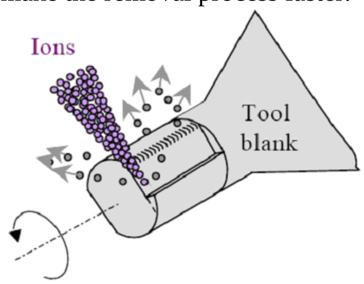

Figure 1.4-Schematic of ion beam sputtering technique-Photo courtesy of Sandia National Laboratories, Livermore, CA

EDM, a widely used process is a stress-free machining choice, but is very slow and requires two steps-one to make an electrode and one to burn the electrode in the tool. Wire EDM is a very fast process and can create radii down to .0005" with its smallest wire but is limited to through shapes and 2D machining for the most part.

Many times, the best choice is a combination of these micro machining methods. The challenge facing many micro molders and mold makers is how to pull all of these machining techniques together and create a robust steel mold that will withstand the 30,000+ psi injection pressures and the wear over time with abrasive materials. Micro molds can have core pins as small as 0.003" (less than the diameter of a human hair) but they still need to depreciate over 5-7 years as do conventional molds. Consequently the maintenance costs for micro molds must be considered in the programs capital appropriation schedule.

Another unconventional approach with conventional equipment is one way to create tiny geometric shapes in steel. One out-of-the-box approach to creating 3D shapes is being developed at Folch Laboratory at Washington State called "micro-tunable molds". As seen in Figure 1.5, these micro structures, many of which are impossible to produce with other processes have been produced in this manner. The basic concept is creating features (cavities topped with elastomeric membranes) that can be individually deformed (or "tuned") by selective pressure application. Many replica cavities have been created from one mold with this process.

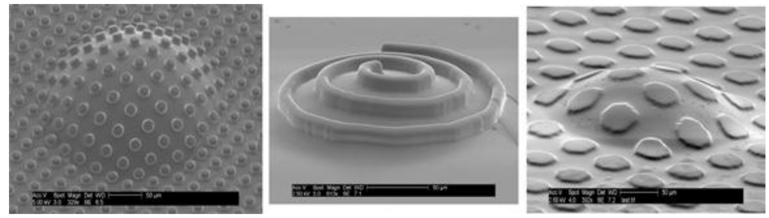

Figure 1.5-"Micro-tunable molds-photo courtesy of Folch Laboratory

Advanced Applications in Micro Molding

- Bio-resorbable polymer implantable applications
- Advanced Proprietary Materials requiring OEM in-house development
- "Work around" processes that either failed conventionally or require extremely controlled validation criteria not possible conventionally

Benefits of Integrated Turnkey Micro Molding Systems

- Development with micro expertise
- Minimizes risk of assembling micro components separately
- Highly technical personnel
- Increased speed to market
- Concurrent engineering on both plastic and metal parts
- Improved metal/plastic, plastic/glass design
- Interface and fit
- Supply management

Barriers to Entry for Micromolding

Many challenges exist in micromolding and micromolding systems are a way to minimize these challenges and corresponding risk of failure to component manufacturers. These challenges include:

Modeling of Micro Components – There remains a limited understanding of the fundamental physics at the micro scale, which are necessary to develop reliable models. Although there has been work performed in this area, much more research is required to perfect the modeling software, materials specifications, reliability models and simulation models for mold flow for micro molded components.

Environment – As one single degree of temperature change can affect precision when machining at the submicron level, many micromolders and micro machining experts enclose the entire machine and/or inspection area in order to create a controlled working environment.

Metrology/Inspection Techniques – Inspection techniques in measuring very small micromolded parts requires customized vises, tweezers, and fixturing. Inspecting steel measurements usually provides a flat, robust surface that can be measured with non-contact means or in some cases contact measurement. These same surfaces that make the molded components can be used to "certify" the dimensions much closer in repeatability and reproducibility than attempting the same corresponding measurement in the micromolded components. It's not uncommon for the first article inspection to consume as much time if not more time than the entire micro moldmaking and micromolding project combined. Gage R&R from client to vendor requires duplicate fixturing and exact methods of inspection technique to repeat the results to near micron tolerances.

Figure 1.6 BX-41 microscope and data processing PC, photo supplied by UK MIG

One setup example for measuring micro molded components can be seen in Figure 1.6 set up at the UK MIG (United Kingdom Micro Molding Interest Group). This inspection station includes an Olympus BX-41 optical microscope with a Prior H-101 motorized XYZ stage. High resolution images are captured using a Lumenera LU125 CMOS monochromatic camera.
A low vibration and low noise environment is needed to capture micro molded feature images accurately.
Validation- Gage R&R from client to vendor requires duplicate fixturing and exact methods of inspection technique to repeat the results to near micron tolerances. Only a select few sources of inspection equipment exist that are capable of measuring to sub-micron tolerances and extremely clean and hepa-filtered, air controlled rooms are necessary to the environment needed for repeatable measurements. It is also common in macro components and specifically with medical devices to insist on 1.33 Cpk or better with respect to performance to drawing dimensions or tolerance. 1.33 Cpk on .0001" tolerances requires a mathematical impossibility in some cases when the gage R&R and operator R&R are taken into account. Component manufacturers and micromolders require similar inspection machines with identical fixtures to validate tolerances in micro components.

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Properly sized machines – It's very common to see micromolded components that have sprue and runner systems amount to 75% or more of the total shot. For many molders trying to enter this market, a common practice for creating micro components is referred to as the "work-around". Micro molding parts in larger shot size machines and/or with multiple cavities is commonly attempted with varying levels of success. Dust speck sized parts cannot be molded in this manner due to the long residence times and corresponding degradation that occurs with oversized screw and barrel combinations. The use of conventional auxiliary equipment (i.e. dryers, moisture analyzers, hot runner manifolds, temperature controllers) are also not recommended for micro components. Customized auxiliary equipment is necessary until equipment manufacturers develop micro sized equipment for drying, handling, weighing, analyzing, quantifying, and controlling micro processes.

Standardization – In the macro world or conventional molding arena, much research and development was done to provide tensile testing, Izod impact bars, and spiral flow molds-all great tools of prediction and theory on mold flow and physical properties of macro components. These standards are not applicable to micromolding because an extra element of shear and extreme injection pressures and velocities are inflicted in micromolding that change the viscosity of the material and all of the "rules" of general purpose molding and the predictability values that we once knew in theory and practice. Also, the polymer "skin" properties of many materials dominate since there is virtually no wall thickness to these parts. Companies are working with ASTM and NIST to investigate some alternatives to these challenges that will provide tools of prediction, verification, and validation for micro components.

Part Handling/Static – Part handling can be challenging given the sizes of micromolded components. Many micromolders use edge-gated runners to carry their parts from one location to another and many are used as part of the automation process. If parts cannot be edge-gated, customized end of arm tooling, vacuum systems, reel-to-reel take-up equipment and blister packs are utilized accordingly.
Static electricity is a common micro molders nightmare. Parts as small as dust can easily become airborne if proper grounding of part collection systems, robotics, packaging, and inspection systems are not installed. Static guns, wands, air curtains, and grounding mats are commonplace in micromolding facilities.

Micro Manufacturing Processes – Micro machining and micro tooling/molds hold the key for the development of micro molding processes and also for other critical tolerance-based processes. These processes include LIM (Liquid Silicone Molding), MIM (Metal Injection Molding) and CIM (Ceramic Injection Molding). LIM requires extreme precision tooling with proper venting resulting in no flash. CIM requires extreme precision tooling for green state components to eject from the mold properly. Micro MIM tooling requires extreme precision tooling for tiny features to be filled during processing. While each of these processes is vastly different in their processing, the tooling is the enabling component to developing the process. Because the sizes of the components are so small, bi-directional shrinkage within the cavities is minimal resulting in plastic, silicone, or metal matching very closely with that of the original tooling size.

Future Micro Manufacturing Trends

A glimpse into the future of micro molded components reveals a new level of manufacturing techniques. Current micro molded components are made using what is called "top down" methods which signifies taking steel away to make the tooling that creates the parts. New methods of the future will build micro molded components from "bottom up" methods, meaning building them layer upon molecular layer. This will create all new factories with clean room gowning individuals, with robotic handling of the components, and pellets to pack out lights out manufacturing techniques.

One example of this approach is called a "micro factory". Examples of these micro factories were explored by a worldwide study of Micro Manufacturing completed in October 2005 by the WTEC in association with NIST, NSF, Department of

Energy, and the Naval Research Academy among others. This study encompassed traveling to many micro manufacturing facilities in the U.S. and in many countries in Asia, and Europe.

Results of this study feature the future trend of micro factories, two such concepts are at the Fraunhofer Institute in Stuttgart, Germany. As seen the Figure 1.5 and 1.6, two approaches to micro factories are in development. One is a modular approach with multiple sections for assemblies and the other is a more table top approach for miniature to micro components. Both are the wave of the future with possible implications of consumer robotic innovations used in every home.

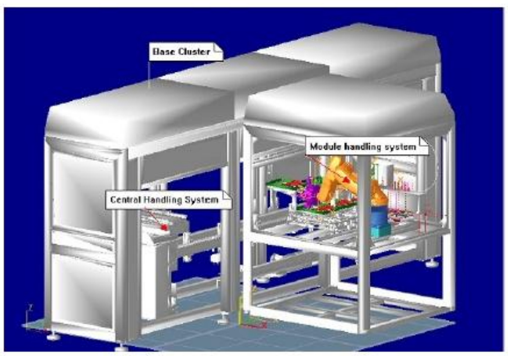

Figure 1.5 Assembly cluster, photo and concept courtesy of the Fraunhofer Institute, Stuttgart, Germany

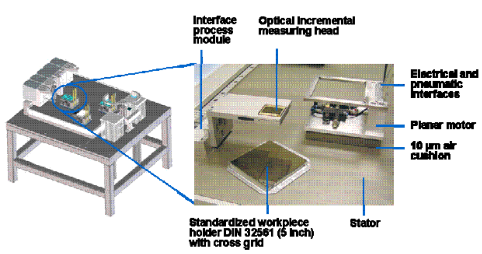

Figure 1.6 The Mini-Pod System, photo and concept courtesy of the Fraunhofer Institute, Stuttgart, Germany.

Conclusion

Medical Device, Electronics, and Biopharmaceutical manufactures need new products that create tinier, less invasive, fluid-induced, and/or space saving micro devices. These products require integrated, micro and automated solutions to ensure their success out of the gate. The tiniest parts in an assembly are the ones most likely to be a challenge and are also usually the enabling component of the entire devices form, fit, and function. Many new advances in micro technology have been developed worldwide for the creation of microscopic features and components. More advances of micro molding technology will push the envelope of tiny components and features enabling even smaller micro devices of the future.

References

Thank you to the following for their assistance in compiling technical information regarding this article:

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3. Sandia National Labs- Livermore, CA
4. UK Micromoulding Interest Group- United Kingdom
5. Folch Lab-University of Washington
6. WTEC Study on MicroManufacturing
7. Scottish Enterprise
8. Biomedical Engineering Alliance & Consortium Study on the Medical Device Industry