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Study and Applications of Net Shape Components through Automated Selective Inhibition Sintering Process (SISP) for Small Armament

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ABSTRACT

Selective Inhibition Sintering (SIS) has been proven effective in producing polymeric and metallic parts. Due to the low cost and high quality of SIS printing, the impact of SIS printing in the 3D printing industry could be disruptive. The potential of SIS is further extended to ceramics, an important but hard to print material, by the same mechanism of creating an easy-to-break sacrificial mold. Due to the high sintering temperature of ceramics, fluid based inhibitors delivered by inkjet printing tend to not be effective in SIS for ceramics. Accordingly, the new concept of inhibition by dry powder delivery is implemented. Preliminary experiments have shown the feasibility and ease of printing of simple ceramic parts. Additional experiments are underway to increase the possible part complexity and accuracy, and to optimize the sintering process. Selective Inhibition of Sintering (SIS) is a Rapid Prototyping process that makes parts in a layer based method by using polymer powders. Current SIS machines accomplish this layer-based method by heating a fixed area of polymer powder. The current process is an area of concern because the entire fixed area of each layer is cured, resulting in large amounts of polymer powder being wasted. This paper explains the design of an automated, mechanical system that will mask off areas of polymer powder with heat-resistant fingers, allowing for the adjustment of the heated area in order to cure minimal amounts of polymer powder at each layer. Test results of a prototype model showed significant reduction in polymer powder usage.

Keywords: Additive Manufacturing (AM), Selective Inhibition Sintering (SIS), Sintering Inhibitor, Ceramics 3D Printing , Selective Inhibition of Sintering, SIS, Waste saving, Heater Design

I.INTRODUCTION

NetShape Technologies is a global manufacturer and metal components supplier headquartered in Floyds Knobs, Indiana, with manufacturing and sales sites located in North America, Asia and Europe. NetShape designs and produces engineered components through state of the art Powder Metallurgy (PM) and Metal Injection Molding (MIM) technologies. We are the largest industrial powder metallurgy company in North America.

Our senior leadership brings decades of experience with Powder Metal technologies. We have dedicated product development and engineering teams to partner with you to take your ideas from concept to cost effective, reliable

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powder metal solutions. We are always working forward with innovative materials and processes developed through our central metallurgical lab and shop floor.Our applications expertise focuses on collaborative product design and high performance materials. Our participation in thousands of customer designs has given us an unmatched reputation in applications such as:

- Hydraulic and fluid power systems
- Fuel cell and medium voltage electrical components Intricate, miniature metal components
- Engineered products for mechanical applications and more..

Fig (1)

II. Experimental Powder Metal (PM) Parts Manufacturing

Powder metallurgy, or PM, manufacturing is a state-of-the art metal forming technology used to provide component solutions for a variety of applications. The science of the technology brings distinct advantages over other metal forming technologies in material utilization, shape complexity, and near-net-shape dimensional control, all supported by a broad range of alloy systems that can be tailored to your application. All contribute to sustainability, making PM a recognized green technology, and the Preferred Metal Forming Solution.

The powder metal forming solution offers many advantages

Eliminates or minimizes machining by producing parts to near net shape

- Minimizes scrap losses by typically using more than 97% of the starting raw material
- Permits a wide variety of alloy systems that can be tailored for the application
- Provides an excellent surface finish as formed
- Provides materials that may be heat treated for added strength and wear resistance
- Provides controlled porosity for self lubrication or filtration
- Complex shapes and geometries not practical or impossible with other metal forming processes
- Supports moderate to high-volume component production volumes
- Part to part consistency at exacting tolerances
- Offers long-term performance reliability for the most stringent applications
- Sustainable manufacturing - Green technology

At NetShape Technologies, we take the science of Powder Metallurgy to the next level as we work with advanced metal alloys in becoming the design-of-choice solution.

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Fig -2

- Sizing/re striking to improve tolerance and or feature.
- While PM most often eliminates the need for secondary processes, nearly all types can be applied as necessary (e.g. heat treatment).

Powder metallurgy (PM) permits an unmatched wide variety of alloy systems and typically uses more than 97% of the starting raw material, making the technique inherently "green."

NetShape's state-of-the-art CNC compaction capabilities combined with advanced material science offers unparalleled compaction flexibility and control across the widest range of geometries and materials available today. NetShape's CNC compaction technology produces complex geometries not attainable with conventional processing techniques. CNC Compaction's Benefits Include:

- Full feature forming through CNC compaction
- Unrivaled process control and flexibility
- CNC press sizes from 350 to 1000 metric tons
- Forming capability up to 9-levels
- Part to part consistency

Finishing Operations

fig-3

The NetShape PM advantage typically eliminates the need for additional secondary machining operations, but in cases where it is required, virtually any secondary process utilized for wrought or cast parts can be applied. NetShape has unmatched secondary machining and grinding capabilities in-house for the most stringent specifications and control. Processes such as hard turning, fine grinding, ID, and OD grinding are utilized to finish components with a precision of microns. For fluid power applications, we optimize performance and efficiency through match grinding of pump components. The enhanced surface characteristics of PM components combined with fine grinding make the powder metal parts manufacturing process a superior method compared to competing technologies.

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NetShape can provide a variety of other finishing processes, including CNC turning, milling, drilling, threading, deburring, steam treatment, heat treatment, powder metal porosity sealing, and plating. We collaborate with our customer in choosing the right material and process for a cost effective solution.

III. Materials used in Powder Metal Manufacturing

- Iron & Carbon Steels
- Steel Alloys - copper - nickel - manganese
- Chromium - Molybdenum and Chromium -Molybdenum - Manganese Steels
- Austenitic and Ferritic Stainless Steel Grades
- Chromium and Ferritic Stainless Steel Grades for Solid Oxide Fuel Cells
- Copper, Copper-Chromium, copper tungsten
- Soft Magnetic Grades of Materials
- Soft Magnetic Composites for Higher Frequency Applications
- Tungsten and Other High Temperature Alloys
- Brass and Bronze

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Fig-4.NetShape Technologies offers a wide variety of materials and alloy systems. We have the capability to develop custom alloys to optimize your product performance. We can design materials for specific applications to match tribology, sealing, surface characteristics, or other material properties. For high performance steel parts, fully dense Copper parts, and much more, customers world-wide trust NetShape Technologies with their PM manufacturing capabilities.

NetShape PM manufacturing can produce parts with the following materials:

- Iron & Carbon Steels
- Steel Alloys - copper - nickel - manganese
- Chromium - Molybdenum and Chromium - Molybdenum - Manganese Steels
- Austenitic and Ferritic Stainless Steel Grades
- Chromium and Ferritic Stainless Steel Grades for Solid Oxide Fuel Cells
- Copper, Copper-Chromium, copper tungsten
- Soft Magnetic Grades of Materials
- Soft Magnetic Composites for Higher Frequency Applications
- Tungsten and Other High Temperature Alloys
- Brass and Bronze

NetShape's metallurgy laboratory can provide full material characterization and testing according to MPIF and ASTM standards. Material development, analysis and troubleshooting, are handled by an expert team working with customers, manufacturing teams, and NetShape application engineers. NetShape also works with value chain partners to expand powder metallurgy's material flexibility and performance beyond established applications. Soft magnetic composites are a good example of a material technology driving higher performance and value for applications such as electric motors where they are used in place of older laminate technology.

3.1Powder Metallurgy Product Applications

Realize significant cost savings and improved performance

NetShape's experienced development team works with customers on hundreds of innovative designs resulting in significant cost savings and improved performance of components. Our powder metallurgy technologies routinely displace other metal forming processes and allow the production of components not possible with other process technologies, such as investment casting, forging, and machining. We are the technology of choice for a focused range of markets and applications, such as:

Fluid Power / Hydraulics

1. Hydrostatic steering components
2. Gerotor motors – fluid metering and valving components
3. Gerotor pump design and housing components
4. Axial piston pump, motor components
5. Low speed, high torque motor components
6. Gear and vane pump components

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Electrical Power Distribution

1. ABS sensors
2. Medium voltage conductive products
3. Soft magnetic and sensing components
4. Mechanism components

Power Transmission / Gears

1. Gear rack, helical, bevel and spur gears
2. Complex structural components

3.2. Electric / Power Distribution Components & Applications

Fig-5.NetShape has an extensive array of manufacturing solutions for the power distribution market. We offer world class production capabilities and tailored designs for a wide range of high performance applications. NetShape works with a number of electric motor manufacturers, including motor speed control, rotor and/or stator manufacturers.

Conductive Applications – Copper, Copper Alloys, Bronze, and Chromium

NetShape has invested heavily in materials research leading to the development of powdered metal copper and copper alloys with both conductive and strength properties comparable to wrought material. Conductivity up to 100% is possible, and shape complexity not practical with casting or machining is accomplished.

Material systems unique to powder metallurgy, such as copper chromium materials, offer tailored material designs to compensate for thermal, mechanical, or electrical properties. Example applications include coils, terminals, contacts, heat sinks or exchangers. Areas of use include:

1. Medium voltage distribution systems
2. Vacuum interrupters
3. Switch gear components including those brazed to contacts

Soft Magnetic Applications and Insulated Particle Materials

Powder metal soft magnetic materials offer shape complexity and tolerances superior to other production methods. Proven material systems are designed to meet customer targets for permeability, coercive force, induction and resistivity. Example applications include:

1. DC motors: stators, rotors, armatures
2. DC flux path components
3. Solenoid plungers

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4. Valve controls
5. Magnetic sensor and ABS sensors
6. Current transformers
7. Fuel injection systems
8. Motor speed control

Insulated particle materials are pure iron powder particles coated with a very thin electrically insulated layer. Combining this material technology with our CNC net-shape forming capability provides a significant advancement over traditional lamination stack production. Shapes not possible with laminations are created to produce Isotropic 3-D electro-magnetic flux patterns if desired, and near net shape processing eliminates waste, thus saving customers cost. Advantages include:

1. Low core loss material suitable for a variety of soft magnetic applications
2. Minimization of hysteresis and eddy current losses over a wide range of frequencies
3. Molding into complex net-shape or near net-shape components
4. Ability to create isotropic 3-D electro-magnetic flux patterns
5. Lower labor cost and higher quality due to powder metallurgy processing

3.3. Power Transmission Components & Gears

At NetShape Technologies, our expertise enables us to produce transmission, mechanism, braking and coupling components with characteristics that are difficult to achieve by conventional methods. We specialize in the manufacture of components through the powder metal process, including:

Fig(6)

- Powder metal clutches
- Helical gears
- Gear racks
- Miniature spur gears
- Other complex gears
- Many other parts

NetShape has won awards for gear design, and our secondary finishing capabilities allow us to finish gears to tolerances few can match. Inherent to our processes are industry-leading, part-to-part uniformity and tooth quality that yield high-performance, quiet, running gears. Whether your

applications are planetary gear sets and mating components, bevel gears, spur gears, or helical gears, NetShape offers unparalleled design and production expertise.

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3.4.Fluid Power Products

Fig-7 NetShape has over 40

years of history in developing and producing innovative parts for fluid power and hydraulics applications. We specialize in critical components in the heart of systems by converting parts from forgings, castings and machined parts to powdered metal. Our specialized knowledge not only covers the production of components but also includes system optimization and collaborative design. Our material, tooling and processing capabilities combined with design expertise make for a winning combination.

We have extensive design and production experience with many fluid power products, including:

1. Gerotor motors – Fluid metering and valving components
2. Gerotor pumps and housing components
3. Vane pump and motor components
4. Axial piston pumps
5. Hydrostatic steering systems

NetShape EXAMPLES:

- Collaborating with a customer, NetShape recently completed the design, prototyping and production of a new fuel transfer pump used in the heavy truck market. Using NetShape's proprietary gerotor design software, the team customized gerotor geometry to maximize pump efficiency and optimize production. The system utilizes gerotor pump elements, housing, and pump endcovers that NetShape helped design.
- Using our hydraulic component design experience and CNC powder metal forming capability, we recently designed and produced a valve component for a new application. The geometry of this component could not be formed with other PM production options, and was not feasible or competitive from other production technologies. The design included advanced material formed at a high density and proved able to deliver superior performance in the application.

More Capabilities

Components including cylinder blocks, valve plates, shoe retainers, piston shoes, and spherical washers are NetShape specialties. Our powder metal cylinder blocks are proven to outperform expensive ductile iron while providing improved machinability and cost. NetShape produces cylinder blocks for low and high pressures, including those for heavy duty off highway applications.

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3.5Heavy Truck and Off-Highway Components

fig-8.NetShape has over 40 years

of knowledgeable and collaborative engagement in heavy truck and off-highway markets, including construction, mining and agriculture equipment. Our specialized knowledge of fluid conveyance along with a clear understanding of our customers' product requirements has enabled us to develop and produce solutions for the following applications:

- Transmission clutch rings, large finished mechanical components
- Large precision finished spur gears and gerotors for engine, transmission and final drive lubrication
- High pressure sealed components for fluid, vacuum and air
- Finished Oil and fuel transfer pump components
- Steering vane pump and braking components
- ABS components

3.6. Your One Stop Source for Innovative PM Solutions

NetShape has over 40 years of history in developing and producing innovative PM solutions for a wide variety of markets including aerospace, heavy truck, hand and power tools, power distribution and many others.

Have a part tailored specfically for a competing metal forming method? Our design team specializes in converting components from other metal forming methods utilizing NetShape's Conversioneering® process.

3.7. Metal Injection Molding (MIM) Process

NetShape Technologies has mastered the metal injection molding process to supply accurate and repeatable components that meet or *exceed quality standards at a competitive cost*. MIM employs injection molding equipment that is used in plastic injection molding, but the rest of the process after molding is quite different.

Whether cost reducing production operations for a small machined part or overcoming complex design challenges, the

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metal injection molding manufacturing process requires special expertise. NetShape is highly experienced in the metal injection molding process:

Mixing: Mix <20 µm typical powder with polymer (binder) system to produce the MIM feedstock. Fig-7

3.7.1 Molding: Mold complex components from the feedstock using standard plastic injection molding equipment & techniques. All metal injection molding presses are equipped with robotic part removal systems.

3.7.2 Debinding: Debind without disturbing the shape of the parts, using water to extract roughly 70% of the binder in each part.

3.7.3 Sintering: Remove the remaining plastic binder by sintering parts in a high temperature H2/N2 pusher furnace. The part goes from roughly 60% dense at the start to >95% dense. fig-8, fig-9

Secondary Operations

After MIM manufacturing, parts can be machined, coined, heat treated, plated and black-oxided.

3.9Materials used in Metal Injection Molding

fig-11

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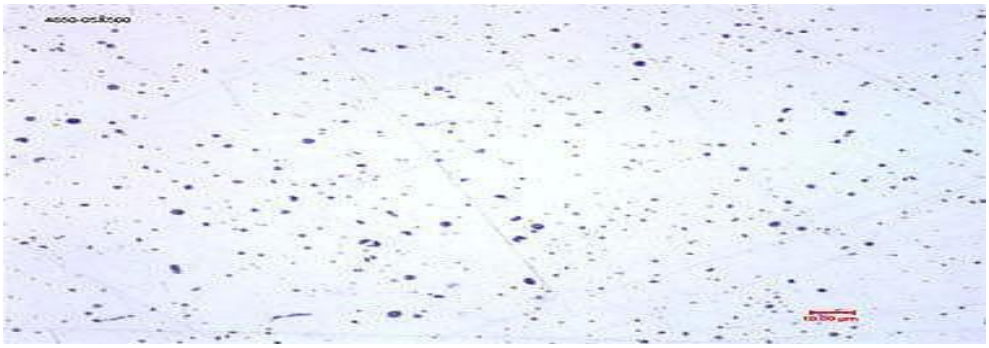

fig-12

A wide array of alloys and metals can be used in the metal injection molding process. From stainless steel to tungsten alloy to low alloy steel and more, Net Shape is an expert in working with any material that can be used in the metal injection molding process. MIM is an excellent alternative to other forming processes, including Inconel casting for aerospace manufacturing.The most commonly used elements in MIM processing are iron, nickel, chromium and molybdenum. Iron and nickel are two of the easiest elements to process due to their compatible melt temperature corrosion and heat-resisting characteristics
and ease of sintering. Iron-nickel alloys make up over 50% of the total tonnage used in the MIM industry. While binder material is added in the MIM process, all residual binder is eliminated in the sintering process.

3.8.A Partial Listing of NetShape MIM's Materials

Good wear, abrasion and corrosion resistance at high temperature Excellent corrosion resistance, high temperature strength Good oxidation resistance, high temperature strength Excellent.

Low Allow Stee

2200 Similiar to PM FN-0200; good magentic & toughness properties

4605 High treatable high-strength steel, up to HRC 52

4140 Heat treatable high-strength steel, up to HRC 60

Controlled Expansion Alloys

Fe- The alloy composition (i.e. Invar, Alloy 42, etc.) can be tailored for the application's thermal expansion Nirequirement.

F15 a.k.a. Kovar®, the alloy is engineered for hermetic glass-metal seals

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High Density Alloys

W- based — High temperature sintering capability allows various tungsten-nickel-iron alloy capability. Sintered densities range up to 18 g/cc.

Soft Magnetic Alloys

Fe-Si — Silicon content up to 9% allows for high resistivity with good soft magnetic response

Fe-Co — Excellent magnet saturation properties

3.10. Product Applications for Metal Injection Moulding

Metal injection molding (MIM) parts are advantageous in a variety of applications and in a variety of markets. For more than 40 years, MIM has been a standard process for manufacturing small, complex components that meet the diverse and demanding requirements of industries around the world. MIM delivers accurate net shapes in high volumes. Whether you seek to economically manufacture a high-quality computer component, small medical instrument or a firearm component, metal injection molding is a process that delivers multiple benefits.

At NetShape, we are accustomed to turning complex designs with exacting specifications into reliable, cost effective components. Our experienced development and metallurgical team can turn the most difficult concept into a reality not possible with other technologies.

Criteria for Typical MIM Parts:

- Complex shapes (can't be stamped, screw machined, made in powder metal, etc.).
- Relatively small components (<100 grams best) due to price of MIM powders & cost of thermal processing.
- Cross-sectional thicknesses of 7 mm or less. MIM tooling can often be designed to reduce cross-sectional thicknesses without sacrificing component performance.
- Part volume high enough to amortize tooling.
- Geometry suitable to be made through standard plastic injection molding tooling.

Applications

- Medical Manufacturing
- Firearm Components
- Aerospace/Defense
- Orthodontics
- Electrical
- Industrial/Consumer
- Jewelry

3.12Medical Injection Molding

At NetShape Technologies, we serve as medical manufacturers, producing a variety of products through the medical injection molding process. From endoscopic instruments to tiny pacemaker components and more, we specialize in working with medical components. We aid the entire manufacturing process, from design to production. Typical applications with which we work include:

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- Medical Manufacturing
- Firearm Components
- Aerospace/Defense
- Orthodontics
- Electrical
- Industrial/Consumer
- Jewelry

fig-13

- Wheel Chairs
- Hospital Beds
- Analyzing Equipment
- Prosthetics
- X-ray Machines
- Hospital Automation
- Pacemakers
- Surgical Instruments & Equipment

3.11.Metal Injection Molding of Firearm Components

The metal injection molding (MIM) gun manufacturing process is gaining in popularity because of the low-cost, high-quality firearm components the technique produces. NetShape Technologies provides extensive experience in producing turnkey firearm parts.

Benefits of working with NetShape to manufacture firearm components through the metal injection

Molding process include:

Fig-15

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- Precise, net shape parts
- Significant reduction or elimination of secondary processes
- Cost savings
- Customization
- Quick turn-around
- High quality

3.13MIM Parts for Aerospace & Defense

fig-14.Increasingly, the aerospace and defense

industries are converting to the metal injection molding (MIM) process to produce parts. MIM, rather than metal casting, is an excellent way to manufacture aerospace components that are high-quality, accurate and long-lasting. Common materials used include:

- Stainless steels
- Superalloys (Inconel, Hastelloy X)
- High Density Alloys (Tungsten - Iron - Nickel)
- Controlled Expansion Alloys (Alloy 42, Kovar)

3.15.Metal Injection Molding (MIM) for Orthodontics

fig-16

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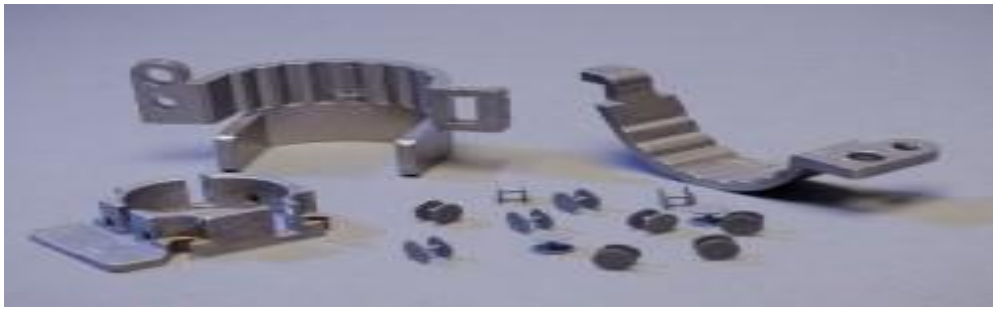
 One of the most common uses of metal injection molding is for the creation of orthodontic devices, including brackets and hooks. While orthodontic devices were traditionally created using investment casting, manufacturers have realized the cost savings and high quality products that MIM provides. MIM is able to produce strong, smooth, and precise components in a variety of metals, including, most commonly, stainless steel.

3.14.Metal Injection Molding (MIM) of Electrical Components

NetShape Technologies has aggressively invested in technology to keep pace with the fast moving telecom and electronics market. Our metal injection molding process is comparable to or better than expensive machining processes. The metal injection molding process can provide high-quality parts at reduced costs.NetShape Technologies specializes in the design and manufacture of parts such as the following:

fig-18



- Filter Components
- Fiber Optic Connectors
- Heat Sinks
- Microwave Equipment
- Mobile Phones
- Solenoids
- Micro-Switches
- Standoffs
- Connectors
- Distribution Frames
- Switching Components

NetShape Technologies specializes in metal injection molding of soft magnetic alloys, stainless steel, and an array of other metals. The MIM technique is ideal for producing small, complex electrical components with excellent mechanical properties.

3.15.Metal Injection Molding (MIM) Parts for Industrial & Consumer Applications

Fig-17.Metal injection

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molding is a technology useful for creating small, complex parts to be used in a variety of applications. Because MIM allows for high production volumes, the reduction or elimination of secondary machining, and a cost-effective price point, the technology is rapidly increasing in popularity.NetShape Technologies designs and manufactures components for the following applications: fig-19

- Drives
- Controls
- Material Handling
- Robotics
- Scales
- Conveyers
- Speed Reduction
- Clutch Drives
- Gear Drives
- Accessories
- Ratchets
- Drill Chucks
- Motors
- Lock Mechanisms
- Padlocks
- Panic Bar Components
- Plumbing Components
- Door Closure Systems
- Attachments & Accessories
- Garage Doors
- Spraying& Paint Systems
- Precision Orifices
- Cargo Latches

MIM Jewelry Components

The technology of metal injection molding (MIM) is relativly new to the jewelry industry but has already proved itself to be a highly competitive alternative to casting, capable of producing finished stainless steel and tungsten pieces as well as findings, watch band components and other jewelry pieces. A few key benefits of MIM jewelry components

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include part-to-part consistency, quick turn around, cost savings and a significant reduction in secondary processes.

3.16.a. Your Source for Knowledgeable and Collaborative Design

Metal Injection Molding provides design freedom that enables people to create metal parts once too expensive to make based on complexity or production scale. MIM is not limited to markets and is capable of making such items as stainless steel jewelry, commemorative metal parts, and completely new parts created by inventors and design engineers. Have a part tailored specifically for a competing metal forming method like casting? Our design team specializes in converting components from other metal forming methods utilizing Net Shape's Conversion Engineering® process.

3.17The Net Shape Advantage

Net Shape Technologies is a global leader in the design and production of engineered components using advanced Powder Metallurgy and Metal Injection molding technologies. Whether offering quality improvements over investment casting or eliminating CNC turning operations from a manufacturing process, we provide several strategic advantages that are unmatched in the industry . . .Net Shape provides key advantages by taking the science of Powder Metal technologies to new levels.

- **Speed to Market**
  A proven new product introduction process, coupled with advanced engineering and mechanical modeling techniques, delivers optimal product launch success.
- **Materials**
  We can tailor alloy systems to optimize performance and cost effectiveness.
- **CNC Compaction**
  With the ability to form parts with up to 9 levels, we are able to produce complex geometries that would be impractical or impossible with other metal working processes.
- **Thermal Processing**
  Specialized thermal processing capabilities to support unique materials for critical applications.
- **Flexible Product Volumes**
  Netscape Technologies supports customer production runs from thousands of parts per year to the millions.
- **Tolerance Control**
  NetShape Technologies has the ability to meet exacting specifications, creating value by eliminating or minimizing costly secondary machining operations, inherent with other metal forming processes.
- **Part-to-Part Uniformity**
  NetShape's robust powder metal or MIM processes coupled with our six sigma manufacturing philosophy produces extremely consistent parts with a high material yield ratio.
- **Finishing Capabilities**
  World class in house secondary machining capabilities to support the most stringent designs and requirements.

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IV. ANALYSIS 4.1 MANUFACTURING SOLUTIONS ENGINEERING

fig-20

Conversioneering is NetShape Technologies' proprietary manufacturing solutions engineering process that defines, analyzes and improves your precision components, reduces time-to-market and saves you money. The Conversioneering process works equally as well on new product development or cost reducing existing components.A collaborative process, our multidisciplinary team evaluates your application with the goal of improving your total cost and providing significant application advantages utilizing technical expertise and advanced technologies.The NetShape team, consisting of experienced Metallurgists, Tool Designers, Process Engineers and Quality experts, has developed this proven process for engineering precision components using powder metallurgy (PM) or Metal Injection Molding (MIM).Conversioneering® is an agile, lean process founded upon VA/VE principals. It's not as simple as just taking your engineering designs and making a mold, although that's how some PM companies do it. As an extension of your Engineering department and involving us early, maximum value and robust solutions are guaranteed.NetShape tailors the PM or MIM manufacturing process to provide optimum performance and lowest production cost for every precision component. We manage and execute every phase of your application – from initial concept to a completed design that is assembled and tested.

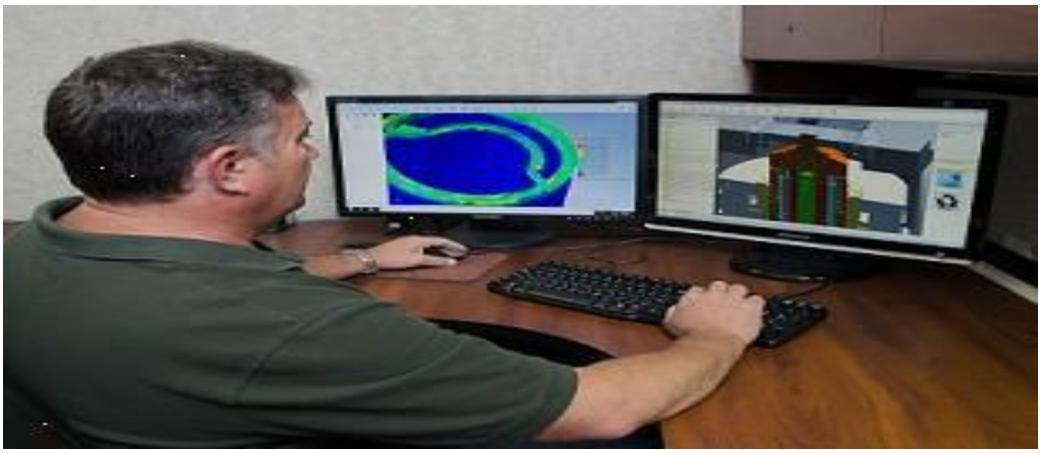

Fig-21NetShape serves a global market offering design and/or material options to improve performance and lower your production costs. Our service is backed by our world-class production capabilities and advanced equipment.For more than a quarter century we have been developing practical solutions and deep insights into the systems and industries utilizing our products. Our experience will help you produce higher system efficiencies with reliable performance at significantly lower production costs. Our tests show that the printed parts are strong and have high impact strength. The extreme ease of separation guarantees the feasibility of the process for complex part geometry.Much thinner inhibitor

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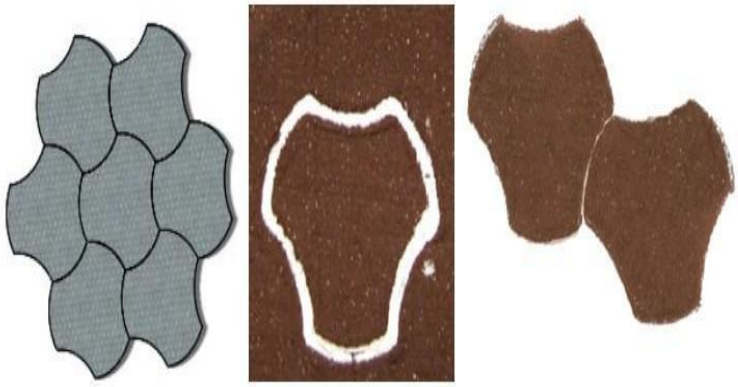
walls may be built to increase part resolution. As long as the inhibitor has a distinctly higher sintering temperature than the base material for making the part, the inhibitor would be a qualified candidate for use.

V. APPLICATIONS

The SIS-Ceramics process may be used to manufacture complex ceramic parts with high quality. The temporary sacrificial mold protects the part from deformation and the built parts can have high strength with no internal impurities. Ceramic parts generally have higher service temperature and are oxidation resistant. SIS printed ceramic parts could resist very high temperature as the process allows the sintering of ceramics with very high melting point. For outer space fabrication of objects such as landing pad tiles the materials need to sustain high temperature exhaust plume of the Landers. The sintered lunar regolith could well satisfy this purpose. The SIS process described here can utilize in-situ resources to create a variety of ceramic objects in outer space. In Figure 6, interlocking tiles built with lunar regolith stimulant are shown.

fig-22



Printed interlocking brick (left) Interlocking pattern for lunar landing pad; (middle)Sintered brick; (right) Printed Bricks

VI. CONCLUSION

SIS-Ceramic has been proven effective and efficient in producing ceramic parts. The fabricated parts are free from contaminants and can be used in a broader fields of application. Our current focus on the improvement of resolution using novel mechanisms for inhibitor powder delivery.

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[7] 16 International th Solid Freeform Fabrication (SFF) Symposium, August 1-3 2005, Austin, TX. In addition, it is planned a journal paper (in Journal of Rapid Prototyping) to be submitted by the end of summer 2005.

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