MIKRO

MAKING IT POSSIBLE

November 03, 2016

Mikro Systems Today

Mikro Systems

- An innovation-focused manufacturing technology company founded in 2001
- Inventor of Tomo-Lithographic Molding (“TOMO”)
- Commercial operations in multiple end markets

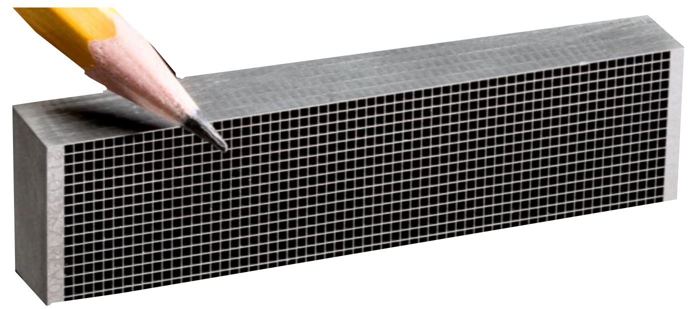
TOMO

- Patented advanced manufacturing process with broad application potential
- Revolutionary advance for the manufacturing industry
- Faster and more cost effective development
- Higher performance products with exceedingly complex geometries

Key Stats

- Based in Charlottesville, Virginia with ~80 full time employees
- Over $40 million invested in R&D to date by government and commercial partners
- Over 120 patents filed to date
- Facilities include 30,000 sq. ft. of R&D and manufacturing labs
- Founder owned and operated

Healthcare Market Success Drivers



- **Development through government small business R&D grants**
- **Partnered with industry players**
- **Focus on high technology component (2D Anti-Scatter Grid)**
  - Need for cost effective complexity that directly impacts system performance
  - Other additive technologies evaluated and dismissed for TOMO

- **TOMO Commercialized**
  - Automated TOMO manufacturing at Mikro (25k units per year and growing)
  - Mikro ASG's currently in high end of CT scanner market; mid-range and lower-end systems are in our development pipeline
  - Annual production requirements will grow to over 120K units within the next three year for one OEM
  - Estimated global revenue opportunity of ~ $50mm for Mikro ASG's in the $5bn CT scanner market

Energy Market Success Drivers

- **Development through government small business R&D grants**
- **Partnered with industry player**
- **Focus on high technology component (large turbine airfoils)**
  - Need for higher turbine efficiency through enhanced internal cooling and improved heat transfer with efficient production
  - TOMO is the preferred technology to deliver complex 3D surfaces and fine feature resolution for ceramic cores over competing advanced manufacturing processes (additive)
- **TOMO Commercialized**
  - Exclusive license agreement with Siemens Energy
  - Manufacturing by Siemens at a new TOMO facility built in Charlottesville, VA
  - Significant TCV achieved through development support and technology licensing

Commercial Success and the DoE

Key technology developed under DoE programs

Leveraging DoE R&D programs…

- ***Large Area Detectors for MeV Radiography: LANL***
- ***Innovative Turbine Cooling Technology: SBIR Ph I, II***
- ***Rapid Commercialization of Advanced Turbine Blades: SBIR Ph III***
- ***Advanced Cores and Castings: NETL and RUA***
- ***Rapid Manufacturing for Turbine Components: SBIR Ph I, II***
- ***Advanced Filtration for SX Castings: SBIR Ph I, II***

…to deliver commercial technology and products

- ***Tungsten materials and process technology: ASG production***
- ***Key ceramic materials and process technology: IGT cores and castings***
- ***Production scale up: IGT cores and castings***
- ***Advanced turbine cooling: IGT and Aero cores and castings***
- ***Rapid Prototyping: IGT and Aero turbine components***
- ***High Temperature Structural Ceramic Capability: nozzles, filters, etc.***

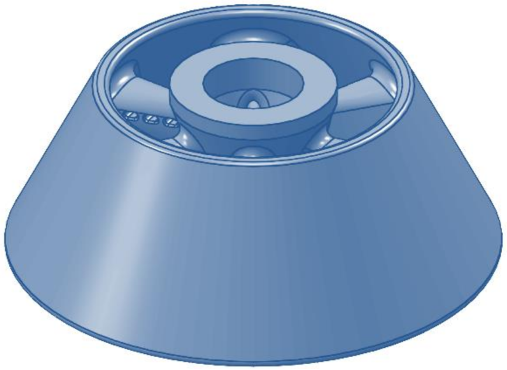
DoE Programs

Key Technology

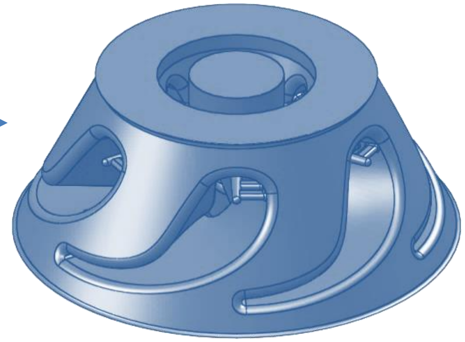
Mikro Approach to Additive Manufacturing

- Additive process is used to make prototype wax fugitive mold tooling, not the actual part.
- Powdered materials are cast into the fugitive tooling following the more developed TOMO core manufacturing process and the proprietary green state binder.
- The process is then convertible to injected wax tooling for some or all of the fugitive tooling components to create a low cost high volume manufacturing platform.
- Wax injection tooling can be derived from any combination of machined tooling, lithographic etched stacks, SLA, or any other process to create a hard surface shape.
- Uses standard MIM powder; no special particle sizing required.
- Green state part is easily machinable or workable with hand tools.
- Uses standard MIM sintering process and equipment.
- Target market is complex multi-walled components similar to DMLS.
- Useable with a wide range of powdered materials.

Process Description

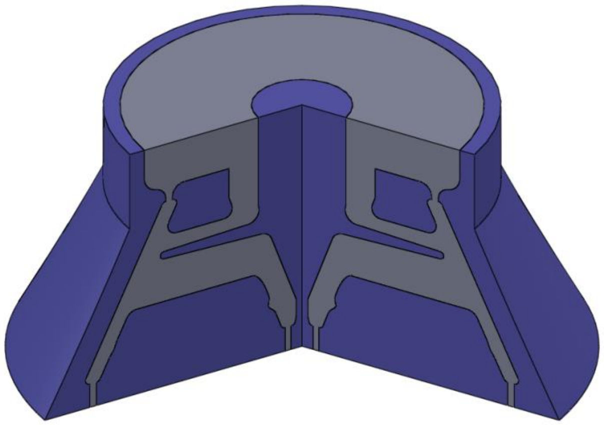


1) Produce 3D CAD model (part positive)

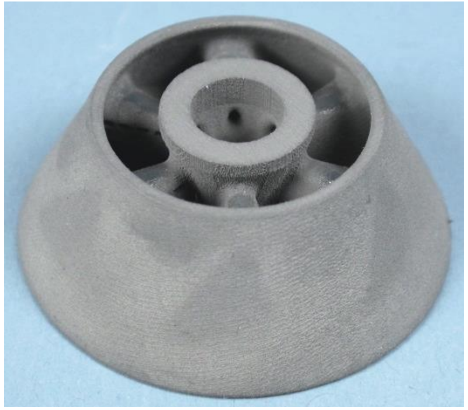


2) Produce 3D CAD model (part negative)

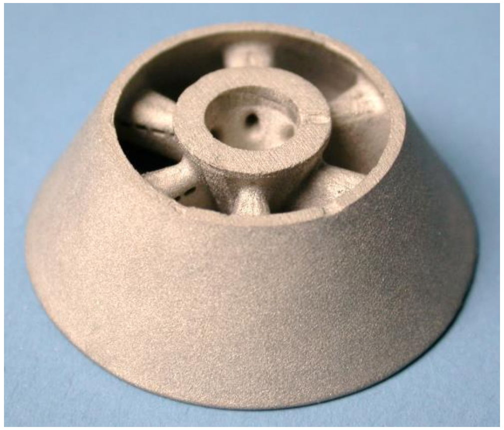
3) Print 3D mold (part negative)



4) Cast powdered metal in mold



5) Remove tool from green state part



6) Sinter part to produce finished component

Material Capabilities

- Mikro has so far made parts from IN 625 and 316L Stainless
- Process is being optimized for Haynes 230 and Hastelloy X
- Process will also work for a variety of other sinter-able metals and non-metallic materials such as zirconia mullite and silica

IN 625 nozzle
(nickel superalloy)

Zirconia Mullite nozzle
(high temp structural ceramic)

DOE Funded Rapid Manufacturing Projects

Phase 1 technical objectives: (6/2013- 3/2014)

- Integrate and adapt our existing material systems and casting process for use with a 3D printed mold.
- Produce a series of sintered metal test articles and coupons using the Phase I prototyping method.
- Analyze the test coupons and determine the baseline materials properties (shrink, porosity, break strength etc.)
- Produce a small lot of combustor nozzles (minimum of 3 design iterations) and demonstrate prototyping capability.

Phase 2 technical objectives: (8/2014 – 8/2016)

- Further develop the materials and binder systems for powdered metal sintering.
- Improve the rapid production processes including wax support material removal, debind and sintering cycles.
- Produce high temperature components for testing and commercial readiness, demonstrating TRL 6 and MRL 5.
- Create a path to commercialization.

Phase 2A technical objectives: (9/2016 – 10/2018)

- Continue from Phase 2.

Rapid Manufacturing Accomplishments

Phase 1 accomplishments: (6/2013- 3/2014)

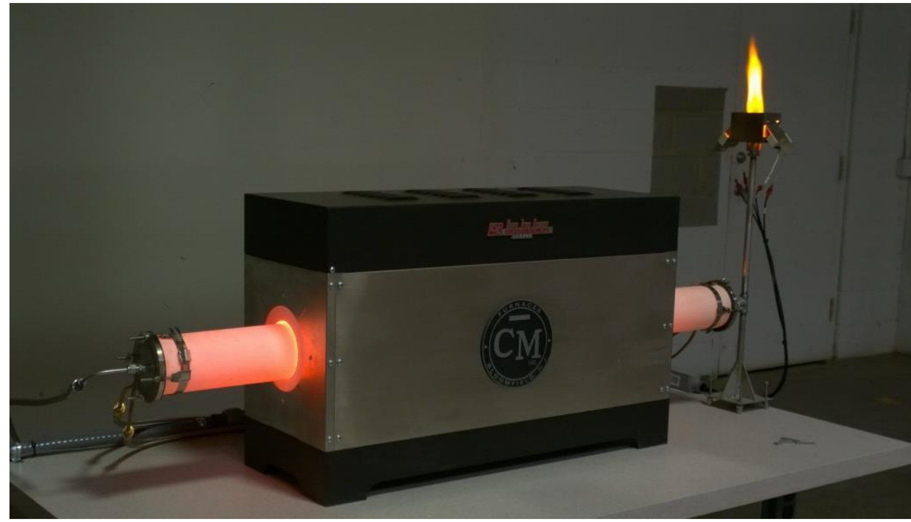
- Demonstrate basic feasibility.
  - Made 3 different complex parts.
  - Achieved material properties equal to about 80% UTS of cast metal
  - All sintering and testing done outside.

Phase 2 accomplishments: (8/2014 – 8/2016)

- Brought critical equipment in house.
- Improved material properties to near commercial readiness.
- Began development on 2 other metals.
- Included post processing such as HIP.
- Produced 2 different parts for an additional OEM who funded the work.
- Converted one part to injected wax tooling.

Rapid Manufacturing in-house capability

- Developed in-house metal sintering capability.
- Small Hydrogen tube furnace allows rapid sintering development.



- Developed in-house density testing
- This allowed for rapid first order evaluation of test variations without waiting for outside lab results.

Rapid Manufacturing Mold Tool Inspection

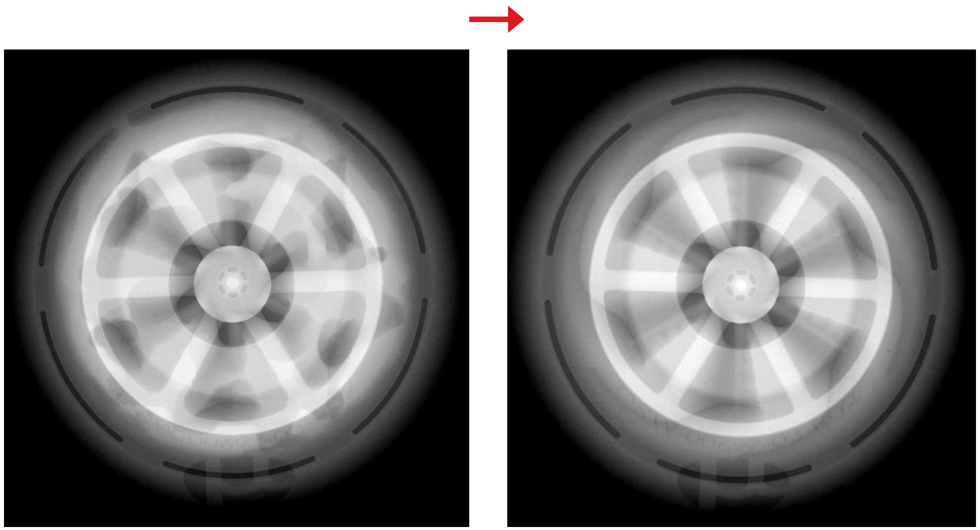
Challenge: Determining if support wax is completely removed from the printed wax part.

Some areas are visually occluded.

Support wax can be seen with flat x-ray or CT.

Able to use in-house flat digital x-ray to verify readiness of fugitive molds.

Nozzle mold



Mold x-rays before and after support removal

Rapid Manufacturing in-house capability

Nikon Industrial CT Scanner

XT H 225 for all-purpose X-ray and CT inspection

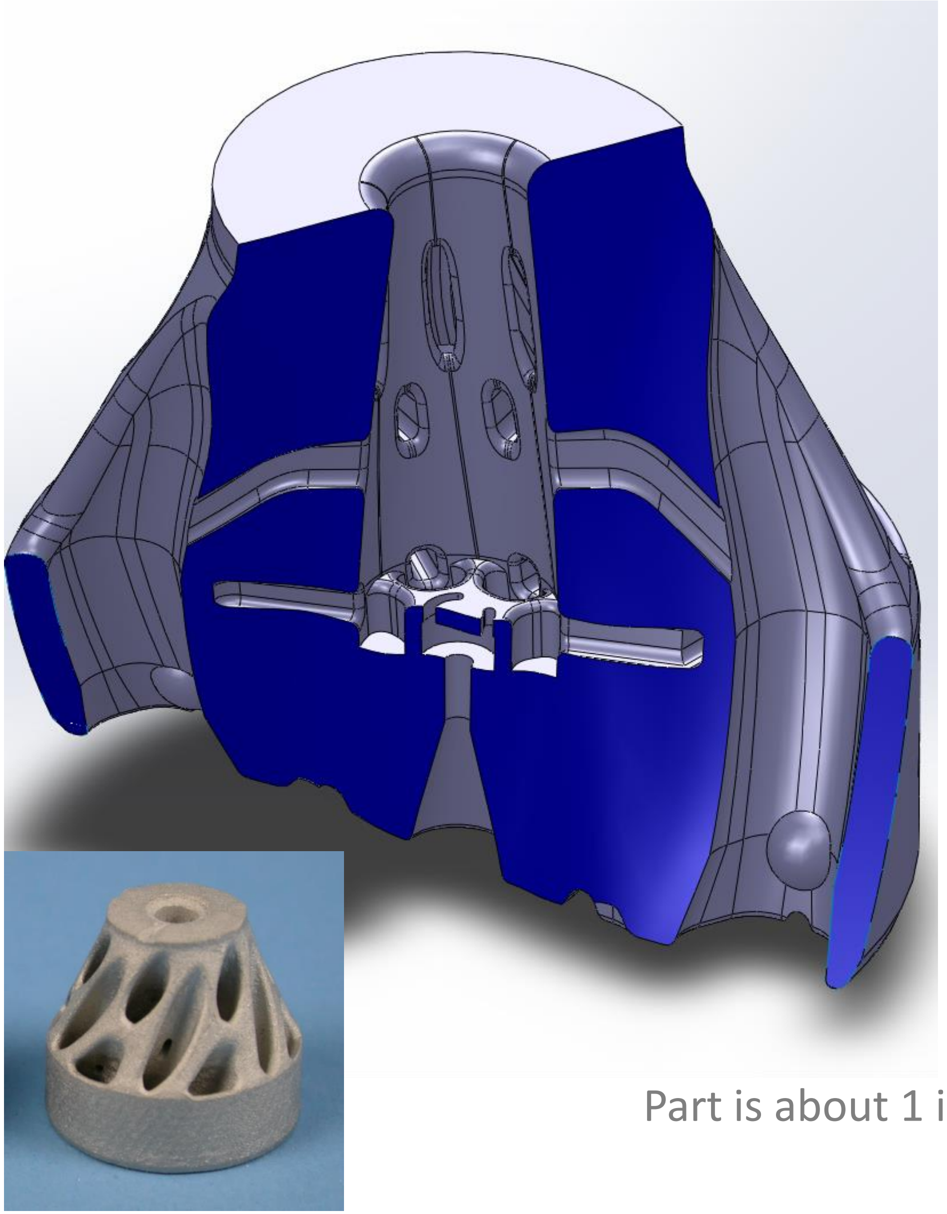
The entry-level XT H 160 and the versatile XT H 225 systems offer a microfocus X-ray source, a large inspection volume, high image resolution and is ready for ultrafast CT reconstruction. They cover a wide range of applications, including the inspection of plastic parts, small castings and complex mechanisms as well as researching materials and natural specimens.

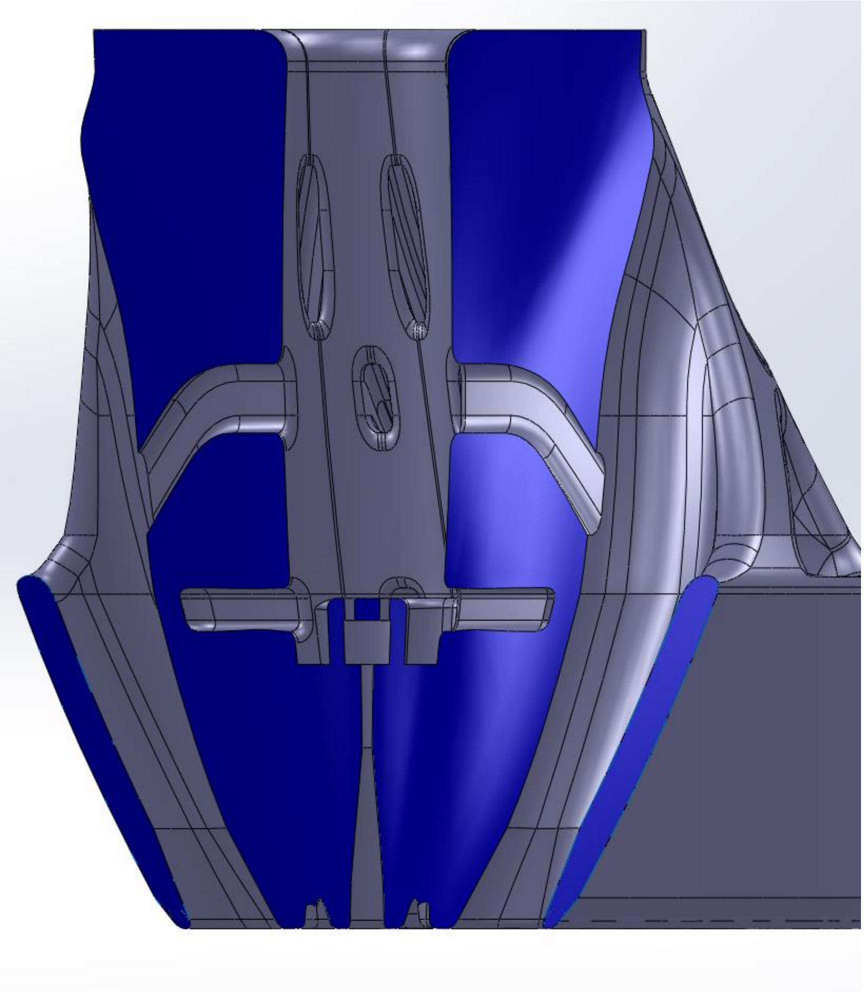
Key benefits

- Proprietary 225kV microfocus X-ray source with 3µm focal spot size
- Easy system operation and low cost-of-ownership
- Stunning images providing great insight
- High performance image acquisition and volume processing
- Straightforward inspection automation
- Safety first

Learn more

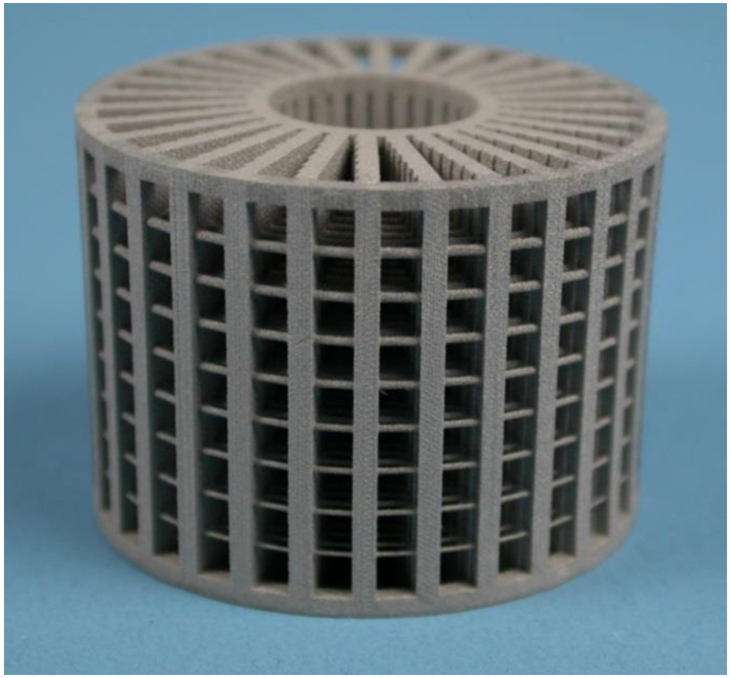
Internal passages

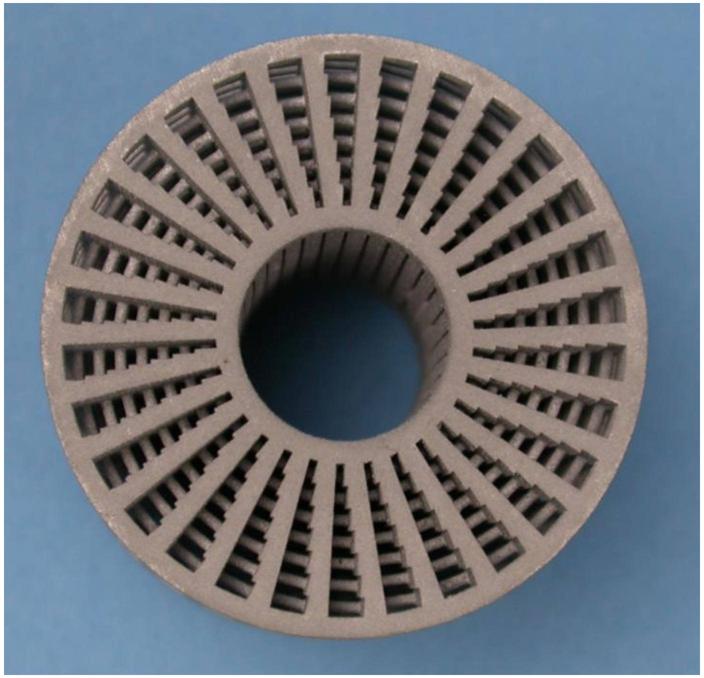




Part is about 1 inch wide

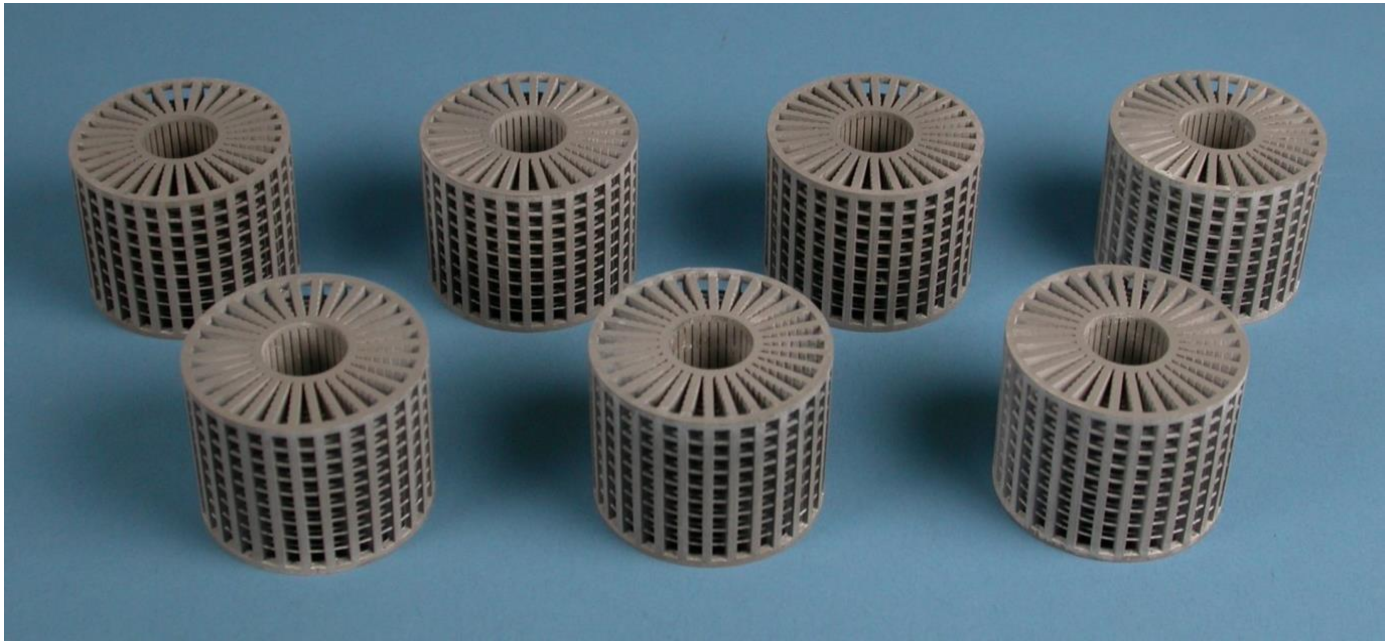
Rod Aspect Ratio Test





Part is about 1 ½ inches wide
Top rod is 0.024” in diameter
Bottom rod is 0.010” in diameter

Rod Aspect Ratio Test



Material Testing

Part #	Material	Process	UTS (PSI)	% Ductility
022516-2-3	IN625	A	108,511	11.1
022516-2-4	IN625	A	82,506	6.75
020416-2-6	IN625	A/HIP	96,586	14.25
020416-2-2	IN625	B	118,546	16.1
020416-2-4	IN625	B	109,491	14.45
021116-1-1	IN625	B	107,412	8
021116-2-6	IN625	B/HIP	94,229	7.1
021116-2-2	IN625	C	109,281	11.45
021116-2-3	IN625	C	109,041	8.9
021116-2-4	IN625	C	115,880	15.9
021816-1-6	IN625	C/HIP	48,950	1.15
021816-1-1	IN625	D	83,736	8.5
022516-2-2	IN625	D	73,345	6.8
021816-1-5	IN625	D/HIP	57,860	1.7
031016-1-4	IN625	E	75,331	8.5
031016-1-2	IN625	E/HIP	153,793	30.45
031016-1-6	IN625	E/HIP	154,622	33.075
060916-1-6	IN625	F	103,321	11.3
060916-2-3	IN625	F	89,712	7.25
032816-1-1	Haynes 230	A	76,718	12.65
032816-1-4	Haynes 230	A	69,078	4.9
032816-2-2	Haynes 230	A	72,844	7.05
032816-2-3	Haynes 230	A	85,070	9
041316-2-5	Hastelloy X	A	48,285	2.3
060116-1-4	Hastelloy X	A	45,325	3.35
041316-2-6	Hastelloy X	G	67,020	11.6
060116-1-6	Hastelloy X	G	67,933	12.4

Material Testing

Part #	Process	Carbon Content	% Density	Hardness (HRB)
022516-2-3	A	0.35%	93.5%	77.63
022516-2-4	A	0.35%	92.6%	86.73
020416-2-6	A/HIP	0.40%	92.4%	71.60
020416-2-2	B	0.60%	90.2%	93.42
020416-2-4	B	0.55%	90.2%	77.46
021116-1-1	B	0.35%	89.9%	94.23
021116-2-6	B/HIP	0.40%	91.2%	77.10
021116-2-2	C	0.45%	92.7%	87.24
021116-2-3	C	0.45%	90.9%	94.77
021116-2-4	C	0.35%	89.5%	89.90
021816-1-6	C/HIP	0.35%	95.3%	76.30
021816-1-1	D	0.30%	89.3%	74.00
022516-2-2	D	0.35%	91.8%	87.35
021816-1-5	D/HIP	0.30%	91.2%	87.70
031016-1-4	E	0.30%	95.4%	85.70
031016-1-2	E/HIP	0.30%	97.4%	89.40
031016-1-6	E/HIP	0.25%	98.5%	91.90
060916-1-6	F	0.30%	92.4%	86.70
060916-2-3	F	0.50%	93.1%	76.40
032816-1-1	A	0.35%	90.9%	69.30
032816-1-4	A	0.40%	90.4%	72.30
032816-2-2	A	0.35%	90.6%	73.80
032816-2-3	A	0.35%	94.2%	73.80
041316-2-5	A	0.40%	83.3%	46.90
060116-1-4	A	0.60%	81.4%	33.40
041316-2-6	G	0.55%	87.3%	51.30
060116-1-6	G	0.35%	86.6%	63.70

Material Testing

From Specialty Metals web site

Table 5 – Nominal Room-Temperature Mechanical Properties[a]

Form And Condition	Tensile Strength		Yield Strength (0.2% Offset)		Elongation	Reduction Of Area	Hardness, Brinell
	ksi	MPa	ksi	MPa	%	%	
ROD, BAR, PLATE							
As-Rolled	120-160	827-1103	60-110	414-758	60-30	60-40	175-240
Annealed	120-150	827-1034	60-95	414-655	60-30	60-40	145-220
Solution-Treated	105-130	724-896	42-60	290-414	65-40	90-60	116-194
SHEET and STRIP							
Annealed	120-150	827-1034	60-90	414-621	55-30	-	145-240
TUBE and PIPE, COLD-DRAWN							
Annealed	120-140	827-965	60-75	414-517	55-30	-	-
Solution-Treated	100-120	689-827	40-60	276-414	60-40	-	-

[a]Values shown are composites for various product sizes up to 4 in. They are not suitable for specification purposes. For properties of larger-sized products, consult Special Metals Corporation.

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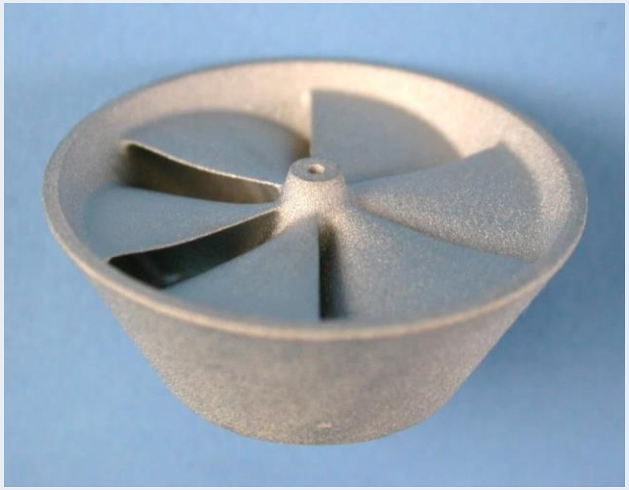
Mikro Rapid Manufacturing Process vs. DMLS

Mikro	DMLS
	
	

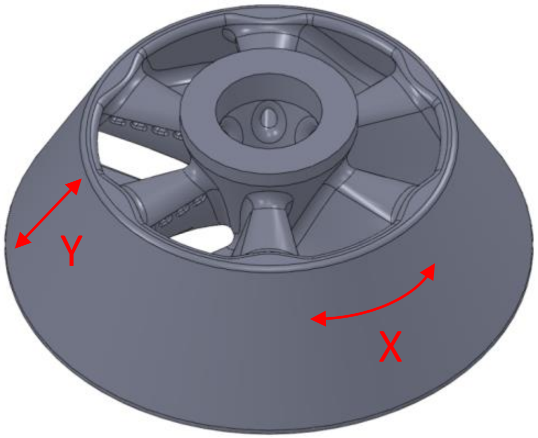
Mikro Rapid Manufacturing Process vs. DMLS

Mikro	DMLS
	

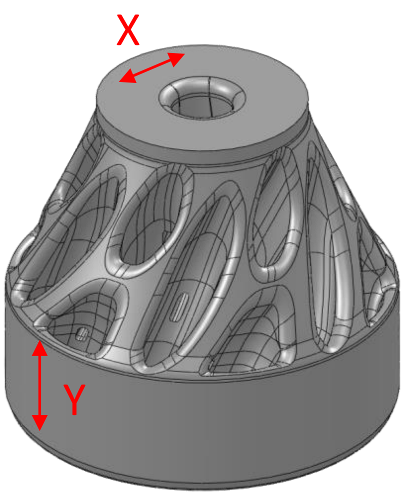
Rapid Mfg Parts – Surface Roughness Measurement

Average Ra values (in microinches)

Mikro Rapid Mfg: X = 152, Y = 192
DMLS: X = 257, Y = 423



Mikro Rapid Mfg: X = 90, Y = 165



QUESTIONS?