



LaserForm[®] AlSi7Mg0.6 (A)

AlSi7Mg0.6 fine-tuned for use with ProX[®] DMP 320 and DMP 350 metal printers to produce industrial parts with a combination of good mechanical properties and improved thermal conductivity.

LaserForm AlSi7Mg0.6 (A) is formulated and fine-tuned specifically for 3D Systems DMP 320 and DMP 350 series metal 3D printers to deliver high part quality and consistent part properties. The print parameter database that 3D Systems provides together with the material has been extensively developed, tested and optimized in 3D Systems' part production facilities that hold the unique expertise of printing 500,000 challenging metal production parts in various materials year over year. And for 24/7 production 3D Systems' thorough Supplier Quality Management System guarantees consistent, monitored material quality for reliable results.

Material Description

AlSi7Mg0.6 combines silicon and magnesium as alloying elements, which results in good mechanical properties. Due to the very rapid melting and solidification during Direct Metal Printing, LaserForm AlSi7Mg0.6 (A) in as-printed condition shows a fine microstructure and obtains a good combination of strength and ductility. Lower silicon content improves electrical and thermal conductivity properties compared to AlSi10Mg while the increased magnesium content maintains mechanical properties similar to AlSi10Mg. Heat treatment allows electrical and thermal conductivity to be fine-tuned to the needs of the application. Additionally, the lower silicon content improves the anodization quality as well as the corrosion resistance.

LaserForm AlSi7Mg0.6 (A)'s low material density is well suited for the aerospace and automotive industry. Innovative applications such as mold design and specific heat exchanger applications make use of the high thermal conductivity of this alloy.

Mechanical Properties^{1,2,3}

MEASUREMENT	CONDITION	METRIC			U.S.		
		AS-BUILT	AFTER STRESS RELIEF	DIRECT AGEING	AS-BUILT	AFTER STRESS RELIEF	DIRECT AGEING
Young's modulus (GPa ksi)	ASTM E1876	NA	NA	NA	NA	NA	NA
Horizontal direction - XY Vertical direction - Z		70-72	75-76	73-74	10100-10500	10800-11000	10600-10900
Ultimate strength (MPa ksi)	ASTM E8M	410 ± 20	280 ± 20	430 ± 20	59 ± 3	41 ± 3	62 ± 3
Horizontal direction - XY Vertical direction - Z		390 ± 40	290 ± 50	430 ± 30	56 ± 6	42 ± 7	62 ± 5
Yield strength Rp0.2% (MPa ksi)	ASTM E8M	240 ± 30	160 ± 40	310 ± 20	35 ± 5	23 ± 6	45 ± 3
Horizontal direction - XY Vertical direction - Z		210 ± 30	180 ± 40	280 ± 20	30 ± 5	26 ± 6	40 ± 3
Plastic elongation (%)	ASTM E8M	14 ± 4	18 ± 3	10 ± 3	14 ± 4	18 ± 3	10 ± 3
Horizontal direction - XY Vertical direction - Z		11 ± 5	11 ± 6	5 ± 3	11 ± 5	11 ± 6	5 ± 3
Hardness, Rockwell B (HRB)	ASTM E18	60 ± 3	39 ± 10	69 ± 2	60 ± 3	39 ± 10	69 ± 2

Thermal Properties

MEASUREMENT	CONDITION	METRIC			U.S.		
		AS BUILT	AFTER STRESS RELIEF	AFTER DIRECT AGEING	AS BUILT	AFTER STRESS RELIEF	AFTER DIRECT AGEING
Thermal conductivity ^{4,5} (W/(m.K) Btu/(h.ft.°F))	at 20°C / 68°F	120-140	180-190	150-170	70-80	105-110	85-100
CTE - Coefficient of thermal expansion ⁶ (µm/(m.°C) µ inch/(inch.°F))	in the range of 20 to 100 °C	typical 21.4			typical 11.9		
Melting range ⁶ (°C °F)		typical 557 - 613			typical 1035-1135		

Electrical Properties^{5,7}

MEASUREMENT	CONDITION	METRIC			U.S.		
		AS BUILT	AFTER STRESS RELIEF	AFTER DIRECT AGEING	AS BUILT	AFTER STRESS RELIEF	AFTER DIRECT AGEING
Electrical conductivity (10 ⁶ S/m)	ASTM B193 at 20°C / 68°F	17-19	25-27	22-24	17-19	25-27	22-24

¹ Parts manufactured with standard parameters on a ProX DMP 320, Config B

² Values based on average and double standard deviation

³ Surface condition of test samples: Horizontal samples (XY) tested in machined surface condition only, vertical (Z) tested in as-printed and machined surface condition

⁴ Thermal conductivity values are calculated via the Wiedemann-Franz law using the measured electrical resistivity values

⁵ Results are based on limited sample size, not statistically representative

⁶ Values based on literature

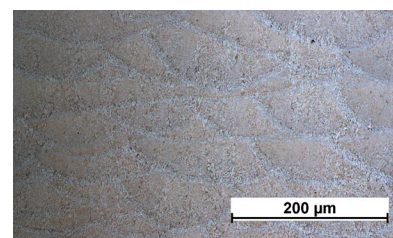
⁷ Electrical resistivity measurements are based on the four point contact method according to ASTM B193



LaserForm[®] AlSi7Mg0.6 (A)

Physical Properties

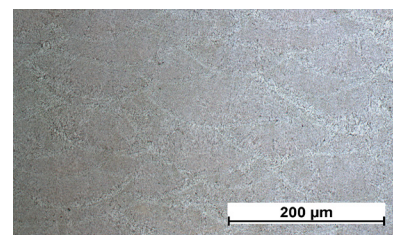
MEASUREMENT	CONDITION	METRIC	U.S.
Density			
Relative, based on pixel count ^{1,2,4} (%)	Optical method	> 99.2 typical 99.8	> 99.2 typical 99.8
Absolute theoretical ³ (g/cm ³ lb/in ³)		2.67	0.096



Microstructure as built

Surface Quality^{4,5}

MEASUREMENT	CONDITION	SAND BLASTED METRIC	SAND BLASTED U.S.
Surface Roughness R _a	ISO 25178		
Layer Thickness 30µm (µm µin)			
Vertical side surface ⁶		typical 5-7	typical 200-280
Layer Thickness 60µm (µm µin)			
Vertical side surface ⁶		typical 10-20	typical 400-800

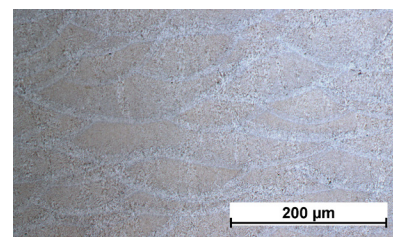


Microstructure after stress relief

Chemical Composition

The chemical composition of LaserForm AlSi7Mg0.6 (A) conforms to the requirements EN AC-42200, and is indicated in the table below in wt%.

ELEMENT	% OF WEIGHT
Al	Balance
Si	6.50-7.50
Mg	0.45-0.70
Fe	≤0.15
Cu	≤0.03
Mn	≤0.10
Ni	≤0.05
Zn	≤0.07
Pb	≤0.05
Sn	≤0.05
Ti	≤0.18
Other (each)	≤ 0.03
Other (total)	≤ 0.10



Microstructure after direct ageing



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¹ Minimum value based on 95% confidence interval. Tested on typical density test coupons

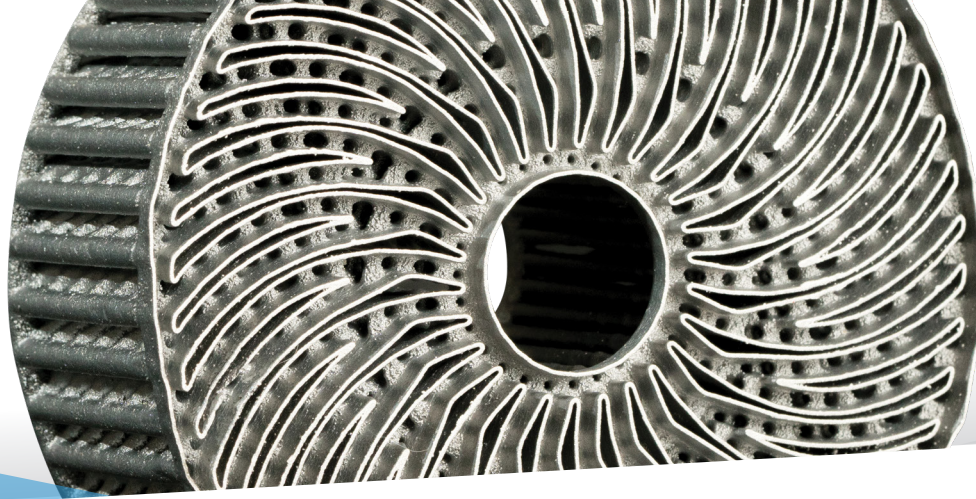
² May deviate depending on specific part geometry

³ Values based on literature

⁴ Parts manufactured with standard parameters on a ProX DMP 320, Config B

⁵ Sand blasting performed with zirconia blasting medium at 2 bar

⁶ Vertical side surface measurement along the building direction



LaserForm AlSi10Mg (A)

AlSi10Mg fine-tuned for use with ProX® DMP 320, DMP Flex 350, DMP Factory 350 and DMP Factory 500 printers producing industrial parts with a combination of good mechanical properties and good thermal conductivity.

LaserForm AlSi10Mg (A) is formulated and fine-tuned specifically for 3D Systems ProX® DMP 320, DMP Flex 350, DMP Factory 350 and DMP Factory 500 metal 3D printers to deliver high part quality and consistent part properties. The print parameter database that 3D Systems provides together with the material has been extensively developed, tested and optimized in 3D Systems' part production facilities that hold the unique expertise of printing more than 1,000,000 challenging metal production parts in various materials year over year. Based on a multitude of test samples, the properties listed below provide high confidence to the user in terms of job-to-job and machine-to-machine repeatability. Using the LaserForm material enables the user to experience consistent and reliable part quality.

Material Description

AlSi10Mg combines silicon and magnesium as alloying elements, which results in a significant increase in strength and hardness compared to other aluminum alloys. Due to the very rapid melting and solidification during Direct Metal Printing, LaserForm AlSi10Mg (A) in as-printed condition shows fine microstructure and high strengths.

In the aerospace and automotive industry, LaserForm AlSi10Mg (A) is used for its light weight. Both innovative approaches to mold design and specific heat exchanger applications make use of the high thermal conductivity of this alloy.

CLASSIFICATION:

Parts built with LaserForm AlSi10Mg (A) have a chemical composition that complies with EN AC-43000 and ASTM F3318.

Mechanical Properties

PROX DMP 320, DMP FLEX 350, DMP FACTORY 350 - LT 30 ^{1,4,5}	TEST METHOD	METRIC			U.S.		
		NHT	SR1	SR2	NHT	SR1	SR2
Ultimate tensile strength (MPa ksi) Horizontal direction - XY Vertical direction - Z	ASTM E8	470 ± 10	300 ± 20	400 ± 15	68 ± 1	44 ± 3	58 ± 2
		460 ± 25	300 ± 20	430 ± 15	67 ± 4	44 ± 3	62 ± 2
Yield strength Rp0.2% (MPa ksi) Horizontal direction - XY Vertical direction - Z		280 ± 10	190 ± 20	270 ± 10	41 ± 1	28 ± 3	39 ± 1
		240 ± 10	180 ± 20	250 ± 10	35 ± 1	26 ± 3	36 ± 1
Plastic elongation (%) Horizontal direction - XY Vertical direction - Z		13.2 ± 4.8	15.6 ± 3.6	9.2 ± 3.8	13.2 ± 4.8	15.6 ± 3.6	9.2 ± 3.8
		8.3 ± 4.0	15.8 ± 2.7	5.2 ± 3.7/-2.6	8.3 ± 4.0	15.8 ± 2.7	5.2 ± 3.7/-2.6

PROX DMP 320, DMP FLEX 350, DMP FACTORY 350 - LT 60 ^{2,4,5}	TEST METHOD	METRIC			U.S.		
		NHT	SR1	SR2	NHT	SR1	SR2
Ultimate tensile strength (MPa ksi) Horizontal direction - XY Vertical direction - Z	ASTM E8	440 ± 30	290 ± 20	390 ± 20	64 ± 4	42 ± 3	57 ± 3
		425 ± 50	290 ± 20	400 ± 40	62 ± 7	42 ± 3	58 ± 6
Yield strength Rp0.2% (MPa ksi) Horizontal direction - XY Vertical direction - Z		260 ± 15	170 ± 20	255 ± 10	38 ± 2	25 ± 3	37 ± 1
		225 ± 10	170 ± 20	230 ± 10	33 ± 1	25 ± 3	33 ± 1
Plastic elongation (%) Horizontal direction - XY Vertical direction - Z		8.9 ± 5.0	14.0 ± 5.3	8.6 ± 2.0	8.9 ± 5.0	14.0 ± 5.3	8.6 ± 2.0
		7.6 ± 4.9	13.2 ± 6.0	5.1 ± 2.8	7.6 ± 4.9	13.2 ± 6.0	5.1 ± 2.8

DMP FACTORY 500 - LT 60 ^{3,4,5}	TEST METHOD	METRIC			U.S.		
		NHT	SR1	SR2	NHT	SR1	SR2
Ultimate tensile strength (MPa ksi) Horizontal direction - XY Vertical direction - Z	ASTM E8	NA	290 ± 20	405 ± 20	NA	42 ± 3	59 ± 3
			300 ± 20	420 ± 20/-60		44 ± 3	61 ± 3/-9
Yield strength Rp0.2% (MPa ksi) Horizontal direction - XY Vertical direction - Z		NA	170 ± 20	270 ± 15/-30	NA	25 ± 3	39 ± 2/-4
			180 ± 20	250 ± 20		26 ± 3	36 ± 3
Plastic elongation (%) Horizontal direction - XY Vertical direction - Z		NA	17.5 ± 4.9	9.4 ± 5.5	NA	17.5 ± 4.9	9.4 ± 5.5
			13.3 ± 5.7	5.8 ± 3.4		13.3 ± 5.7	5.8 ± 3.4

¹ Parts manufactured with standard parameters and protocols on a ProX DMP 320, DMP Flex and Factory 350, Config B, using layer thickness 30 µm (LT30)

² Parts manufactured with standard parameters and protocols on a ProX DMP 320, DMP Flex and Factory 350, Config B, using layer thickness 60 µm (LT60)

³ Parts manufactured with standard parameters and protocols on a DMP Factory 500, using layer thickness 60 µm (LT60)

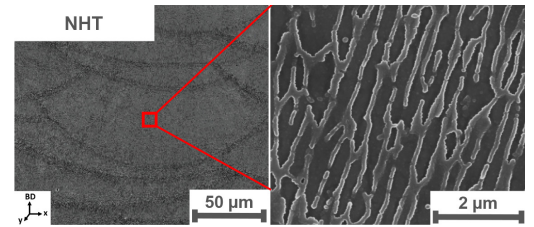
⁴ NHT is non-heat-treated sample condition; SR1 is a heat treatment at 285 °C for 2 h; SR2 is a heat treatment at 190 °C for 6h. Values based on average and 95% tolerance interval with 95% confidence

⁵ Tested according to ASTM E8 using round tensile test specimen type 4

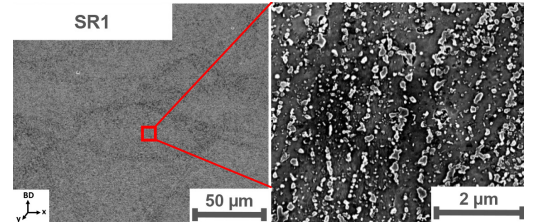
Printed Part Properties⁶

DENSITY	TEST METHOD	METRIC	U.S.
Theoretical density ⁷ (g/cm ³ lb/in ³)	Value from literature	2.68	0.097
Relative density (%), layer thickness 30 μm ^{1,8}	Optical method (pixel count)	≥ 99.7 Typical 99.9	≥ 99.7 Typical 99.9
Relative density (%), layer thickness 60 μm ^{2,3,8}	Optical method (pixel count)	≥ 99.5 Typical 99.8	≥ 99.5 Typical 99.8

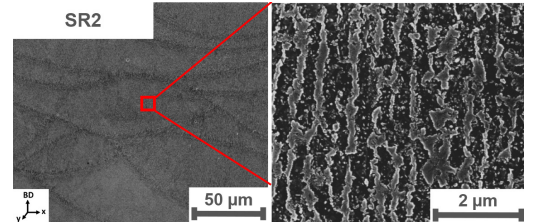
SURFACE ROUGHNESS R _a ^{9,10}	TEST METHOD	METRIC	U.S.
Vertical side surface (μm μin) Layer thickness 30 μm	ISO 25178	Typically, around 8	Typically, around 315
Vertical side surface (μm μin) Layer thickness 60 μm	ISO 25178	Typically, around 15	Typically, around 591



Microstructure without heat treatment (NHT)



Microstructure after SR1



Microstructure after SR2

Thermal Properties

MEASUREMENT	CONDITION	METRIC			U.S.		
		NHT	SR1	SR2	NHT	SR1	SR2
Thermal conductivity ^{11,12} (W/(m.K) BTU-in/h-ft ² ·°F)	at 20 °C / 68 °F	120-130	160-170	140-160	833-902	1110-1180	971-1110
CTE - Coefficient of thermal expansion ⁷ (μm/(m.°C) μ inch/(inch . °F))	in the range of 20 to 100 °C	—typical 20.9—			—typical 11.6—		
Melting range ⁷ (°C °F)		—typical 557 - 596—			—typical 1035 - 1105—		

Electrical Properties^{12,13}

MEASUREMENT	CONDITION	METRIC			U.S.		
		NHT	SR1	SR2	NHT	SR1	SR2
Electrical conductivity (10 ⁶ S/m)	ASTM B193 at 20°C / 68°F	17-18	22-24	20-22	17-18	22-24	20-22

Chemical Composition

ELEMENT	% OF WEIGHT
Al	Balance
Si	9.00-11.00
Mg	0.20-0.45
Fe	≤0.55
Cu	≤ 0.03
Mn	≤0.35
Ni	≤0.05
Zn	≤0.10
Pb	≤0.05
Sn	≤0.05
Ti	≤0.15
Other (each)	≤ 0.05
Other (total)	≤ 0.15



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⁶ May deviate depending on specific part geometry

⁷ Values based on literature

⁸ Minimum values based on 95% tolerance interval with 95% confidence.

Tested on specific 3DS density test coupons

⁹ Surface treatment performed with zirconia blasting medium at 2 bar

¹⁰ Vertical side surface measurement along the building direction

¹¹ Thermal conductivity values are calculated by the Wiedemann-Franz law using the respective electrical resistivity values

¹² Results are based on limited sample size, not statistically representative.

Samples printed on a ProX DMP 320, Config B

¹³ Electrical resistivity measurements are based on four point contact method according to ASTM B193

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Certified Scalmalloy® (A)

Thoroughly developed print parameters and certification process support for APWORKS Scalmalloy material on 3D Systems DMP Flex 350 printers. Scalmalloy is the highest strength aluminum alloy processable by laser powder bed fusion.

3D Systems offers an optimized print parameter database license for Certified Scalmalloy (A) on the DMP Flex 350 metal 3D printer that can be applied using the integrated additive manufacturing workflow software, 3DXpert. 3D Systems' metal print parameters have been extensively developed, tested, and optimized in 3D Systems' part production facilities, which have the unique distinction of printing more than 1,000,000 challenging metal production parts in various materials, year over year. Based on a multitude of test samples, the properties listed below provide high confidence to the user in terms of job-to-job and machine-to-machine repeatability.

For companies looking to use the Scalmalloy brand name internally and externally on their DMP Flex 350 printers, 3D Systems offers a cost-effective standard service for smooth APWORKS certification through its Application Innovation Group (AIG).

Material Description

Scalmalloy is an aluminum alloy, with a chemical composition optimized for laser based powder bed fusion processes such as direct metal printing (DMP). Scalmalloy bridges the gap between traditional aluminum cast alloys (e.g., AlSi10Mg) and Ti Gr23, and provides a combination of high specific strength (strength-to-weight ratio), excellent corrosion resistance, and good thermal and electrical conductivity.

Within the aerospace, motorsports, semiconductor machinery, and transportation industries, Scalmalloy is used for its high strength-to-weight ratio, enabling customers to further reduce mass. The material is ideally suited for highly loaded, safety critical parts. Parts printed in Scalmalloy are corrosion resistant and can be chemically cleaned to meet the strict purity requirements of fluid flow applications.

CLASSIFICATION:

Scalmalloy is an approved material under the FIA regulations.

Mechanical Properties

DMP FLEX 350 - LT 30 ^{1,3,4,5}	TEST METHOD	METRIC	U.S.
		SR	SR
Ultimate tensile strength (MPa ksi) Horizontal direction - XY Vertical direction - Z	ASTM E8	520 ± 10	75 ± 2
		520 ± 15	75 ± 2
Yield strength Rp0.2% (MPa ksi) Horizontal direction - XY Vertical direction - Z		490 ± 10	71 ± 2
		490 ± 15	71 ± 2
Plastic elongation (%) Horizontal direction - XY Vertical direction - Z		15.8 ± 2.7	15.8 ± 2.7
		15.8 ± 2.6	15.8 ± 2.6

DMP FLEX 350 - LT 60 ^{2,3,4,5}	TEST METHOD	METRIC	U.S.
		SR	SR
Ultimate tensile strength (MPa ksi) Horizontal direction - XY Vertical direction - Z	ASTM E8	530 ± 10	77 ± 2
		520 ± 10	75 ± 2
Yield strength Rp0.2% (MPa ksi) Horizontal direction - XY Vertical direction - Z		500 ± 10	72 ± 2
		490 ± 10	71 ± 2
Plastic elongation (%) Horizontal direction - XY Vertical direction - Z		14.0 ± 3.4	14.0 ± 3.4
		13.1 ± 3.0	13.1 ± 3.0

¹ Parts manufactured with standard parameters and protocols on a DMP Flex 350, Config B, using layer thickness 30 µm (LT30)

² Parts manufactured with standard parameters and protocols on a DMP Flex 350, Config B, using layer thickness 60 µm (LT60)

³ SR is a heat treatment at 325 °C for 4 h, followed by air cooling (heat treatment advised by APWORKS)

⁴ Tested according to ASTM E8 using round tensile test specimen type 4

⁵ values based on average and 95% tolerance interval with 95% confidence

Thermal Properties

MEASUREMENT	CONDITION	METRIC	U.S.
		SR	SR
Thermal conductivity ^{6,7} (W/(m.K) BTU·in/h·ft ² ·°F)	at 20 °C / 68 °F	95-100	660-695
CTE - Coefficient of thermal expansion ⁸ (µm/(m.°C) µ inch/(inch . °F))	in the range of 20 to 100 °C	Typical 23.5	Typical 13.1
Melting range ⁸ (°C °F)		Typical 600 – 800	Typical 1110 – 1470



Microstructure without heat treatment (NHT)

Electrical Properties⁶

MEASUREMENT	CONDITION	METRIC	U.S.
		SR	SR
Electrical conductivity (10 ⁶ S/m)	ASTM B193 at 20°C / 68°F	13-14	13-14



Microstructure after SR

Printed Part Properties⁶

DENSITY	TEST METHOD	METRIC	U.S.
Theoretical density ⁸ (g/cm ³ lb/in ³)	Value from literature	2.67	0.096
Relative density (%), layer thickness 30 µm ^{9,10}	Optical method (pixel count)	≥ 99.6 Typical 99.8	≥ 99.6 Typical 99.8
Relative density (%), layer thickness 60 µm ^{9,10}	Optical method (pixel count)	≥ 99.5 Typical 99.7	≥ 99.5 Typical 99.7

SURFACE ROUGHNESS R _a ^{11,12}	TEST METHOD	METRIC	U.S.
Vertical side surface (µm µin) Layer thickness 30 µm	ISO 25178	Typically, around 11	Typically, around 435
Vertical side surface (µm µin) Layer thickness 60 µm	ISO 25178	Typically, around 13	Typically, around 510

To confirm the suitability of this material for your specific application, please contact the 3D Systems Application Innovation Group (AIG) (<https://www.3dsystems.com>). Once confirmed, Scalmalloy powder can be purchased directly from Toyal (<https://www.toyalgroup.net/>).



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⁶ Parts manufactured with standard parameters and protocols on a DMP Flex 350, Config B using layer thickness 30 µm and 60 µm

⁷ Thermal conductivity values are calculated by the Wiedemann-Franz law using the respective electrical resistivity values

⁸ Values adopted from APWORKS material datasheet

⁹ Minimum values based on 95% tolerance interval with a 95% confidence. Tested on specific 3DS density test coupons

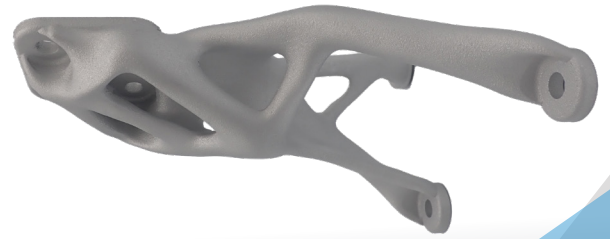
¹⁰ May deviate depending on specific part geometry

¹¹ Surface treatment performed with zirconia blasting medium at 2 bar

¹² Vertical side surface measurement along the building direction

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A6061-RAM2 bracket image courtesy of NASA Goddard Space Flight Center

Certified A6061-RAM2 (A)

Certified A6061-RAM2 (A) is an aluminum alloy offering improved strength, ductility, and as-built surface finish compared to traditional casting alloys such as AlSi10Mg in laser powder bed fusion (PBF-LB).

3D Systems offers application development and part production using the integrated additive manufacturing (AM) workflow software, 3DXpert®, and the DMP Flex 350 metal printer. 3D Systems' A6061-RAM2 parameters were developed, tested, and optimized on real applications in our AS9100/ISO9001 part production facilities, which have the unique distinction of printing more than 1,000,000 challenging metal production parts in various materials, year over year. The properties listed below provide high confidence to the user in terms of job-to-job and machine-to-machine repeatability.

For companies looking to develop new applications and processes with A6061-RAM2 please contact the 3D Systems Application Innovation Group (AIG).

Material Description

Elementum 3D's reactive additive manufacturing (RAM) process inoculates solidification and protects alloys against hot tearing and produces equiaxed fine-grained microstructure with exceptional properties. The RAM process takes advantage of chemical reactions in the melt pool to form dispersion-strengthened metal matrix composite (MMC) aluminum alloys.

A6061-RAM2 is a scandium-free aluminum alloy with chemical composition optimized for laser powder bed fusion. This general-purpose AM aluminum alloy results in properties comparable to wrought 6061-T6 with excellent strength-to-weight ratio, ductility, corrosion resistance, and electrical conductivity. On the DMP Flex 350, A6061-RAM2 parts exhibit better as-built surface finish and anodization capability than AlSi10Mg.

With proven applications in aerospace, semiconductor, and motorsports industries, A6061-RAM2 is suitable for passive radio frequency, thermal management, fluid flow, and lightweight structural components.

Mechanical Properties

DMP FLEX 350 - LT 30 ^{1,2}	TEST METHOD	METRIC	U.S.
Ultimate tensile strength (MPa ksi) Horizontal direction - XY	ASTM E8	295	43
Yield strength Rp0.2% (MPa ksi) Horizontal direction - XY		260	38
Plastic elongation (%) Horizontal direction - XY		16	16

Physical Properties

MEASUREMENT	TEST METHOD	METRIC	U.S.
Electrical conductivity ³ (S/μm)	ASTM B193 at 20°C / 68°F	13	-
Thermal conductivity ¹ (w/(m-k))	Supplier test data	162	-

¹ Modified T6 Heat Treatment.

² Tested according to ASTM E8 using round tensile test specimen type 4. Typical values, averaged over 10 coupons each.

³ Typical value measured on LT30 sample in as-printed condition.

Printed Part Properties

DENSITY ³	TEST METHOD	METRIC	U.S.
Relative density (%)	Archimedes + Optical Evaluation	> 99.6	

SURFACE ROUGHNESS ⁴	TEST METHOD	METRIC	U.S.
Vertical side surface (μm μin) Layer thickness 30 μm	ISO 25178	8	315

³ Parts manufactured with standard parameters and protocols on DMP Flex 350, Config B using layer thickness 30 μm . May deviate depending on specific part geometry.

⁴ Vertical side surface measurement along the building direction, as-built condition, typical values.

Typical Applications

- Lightweight structural parts for aerospace and automotive
- Passive radio frequency (RF) parts for satellites
- Advanced thermal management in semiconductor capital equipment
- Parts which require anodization for corrosion resistance

Application Focus: Semiconductor Wafer Table

COMPLEX CHANNEL DESIGN

Excellent as-built surface finish enables high quality internal channels not accessible to finish machining

THIN WALLS

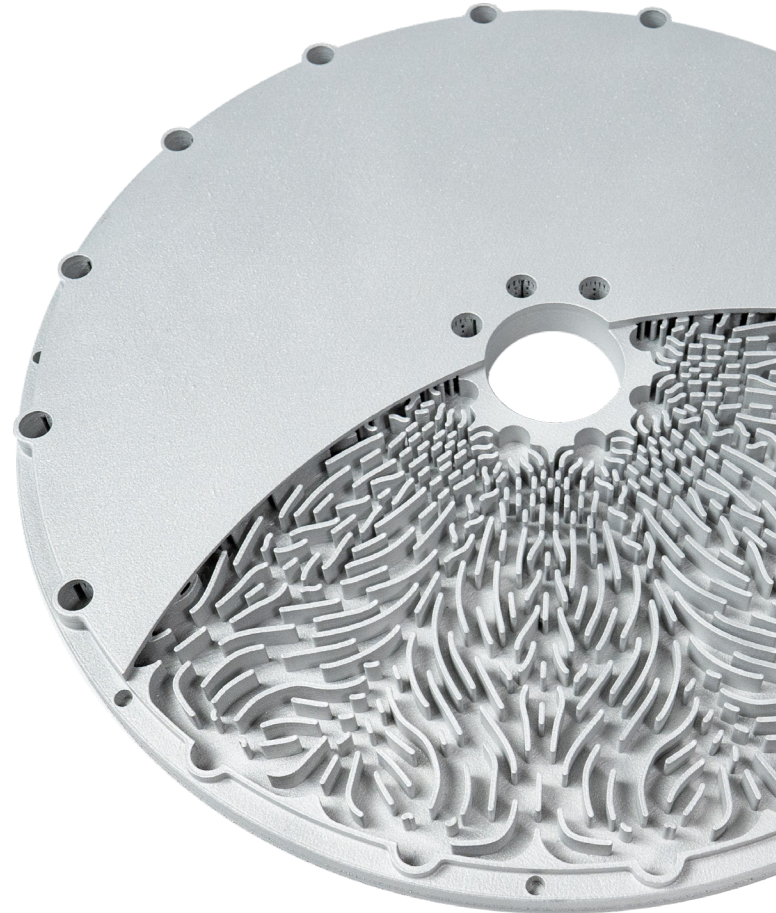
Wall thicknesses as low as 0.3 mm

ORGANIC SHAPES

Reduce turbulence and pressure drops inside the cooling system

PART COUNT REDUCTION AND IMPROVED LEAK-TIGHTNESS

Remove points of failure; simplify supply chain



To confirm the suitability of this material for your specific application, please contact the 3D Systems Application Innovation Group (AIG): <https://www.3dsystems.com/consulting/application-innovation-group>



A6061-RAM2 powder can be purchased directly from Elementum 3D: <https://www.elementum3d.com/contact/>

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LaserForm[®] CoCrF75 (A)

Cobalt-chromium-molybdenum alloy fine-tuned for use with ProX DMP 320 metal printer producing industrial parts with high corrosion and wear resistance that also require high temperature resistance. In addition to various industrial applications, LaserForm CoCrF75 (A) is also suitable for medical applications.

LaserForm CoCrF75 (A) is formulated and fine-tuned specifically for 3D Systems DMP 320 metal 3D Printers to deliver high part quality and consistent part properties. The print parameter database that 3D Systems provides together with the material has been extensively developed, tested and optimized in 3D Systems' part production facilities that hold the unique expertise of printing 500,000 challenging metal production parts in various materials year over year. And for your 24/7 production 3D Systems' thorough Supplier Quality Management System guarantees consistent, monitored material quality for reliable results.

Material Description

Cobalt-chromium-molybdenum alloys are known for their high strength and hardness and retain these properties even at elevated temperatures. In addition, they spontaneously form a protective passive film, which makes LaserForm CoCrF75 (A) both corrosion resistant and biocompatible.

These benefits make LaserForm CoCrF75 (A) the ideal material for medical tools and devices, molds and dies, industrial, high wear applications and parts requiring high strength at elevated temperatures. In biomedical applications, LaserForm CoCrF75 (A) is ideal for dental implants and prostheses.

Classification

The chemical composition of LaserForm[®] CoCr F75 conforms to the requirements of the ASTM F75, ISO 5832 and ISO 22674 standards, and is indicated in the table below in wt%.

Mechanical Properties^{1,2,3}

MEASUREMENT	CONDITION	METRIC		U.S.	
		AFTER ANNEAL	AFTER HIP	AFTER ANNEAL	AFTER HIP
Youngs modulus (GPa ksi)	ASTM E8M	225 ± 5	225 ± 5	32650 ± 730	32650 ± 730
Ultimate strength (MPa ksi)	ASTM E8M				
Horizontal direction - XY Vertical direction - Z		1030 ± 70 1000 ± 30	1020 ± 70 950 ± 40	150 ± 10 145 ± 5	150 ± 10 140 ± 5
Yield strength Rp0.2% (MPa ksi)	ASTM E8M				
Horizontal direction - XY Vertical direction - Z		540 ± 30 520 ± 30	510 ± 30 475 ± 20	80 ± 5 75 ± 5	75 ± 5 70 ± 5
Elongation at break (%)	ASTM E8M				
Horizontal direction - XY Vertical direction - Z		29 ± 6 29 ± 4	29 ± 6 23 ± 3	29 ± 6 29 ± 4	29 ± 6 23 ± 3
Hardness, Rockwell C	ASTM E18	25 ± 5	39 ± 3	25 ± 5	39 ± 3
Impact toughness ⁴ (J ft-lb)	ASTM E23	52 ± 3	NA	39±2	NA

Thermal Properties⁵

MEASUREMENT	CONDITION	METRIC	U.S.
Thermal conductivity (W/(m.K) Btu/(h.ft ² .°F))	at 20°C / 120 °F	14	8
CTE - Coefficient of thermal expansion (µm/(m.°C) µ inch/(inch. °F))	in the range of 20 to 600 °C	14	8
Melting range (°C °F)		1350 - 1430	2460 - 2610

¹ Parts manufactured with standard parameters on a ProX DMP 320, Config B
² Values based on average and standard deviation
³ HIP indicates hot isostatic pressing post treatment
⁴ Tested with Charpy V-notch impact test specimens type A at room temperature
⁵ Values based on literature
 NA = Not available



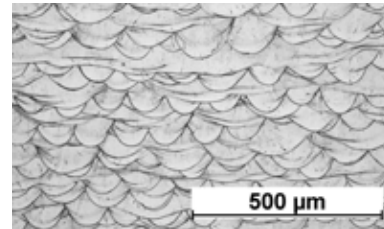
LaserForm[®] CoCrF75 (A)

Electrical Properties⁵

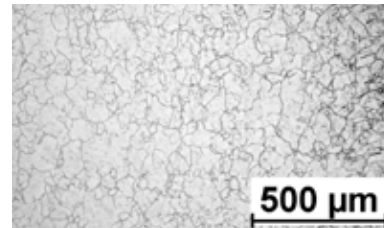
MEASUREMENT	METRIC	U.S.
Electrical resistivity (nΩ.m μΩ.in)	874	34

Physical Properties

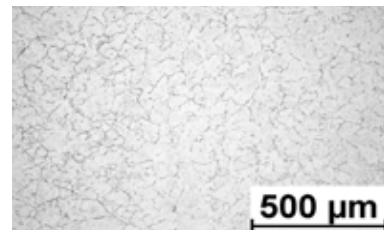
MEASUREMENT	METRIC		U.S.	
	AS BUILT AND AFTER STRESS RELIEF	AFTER HIP	AS BUILT AND AFTER STRESS RELIEF	AFTER HIP
Density				
Relative, based on pixel count ¹ (%)	>99,9	≈100	>99,9	≈100
Absolute theoretical ⁵ (g/cm ³ lb/in ³)	8.35		0.302	



Microstructure as built



Microstructure after anneal



Microstructure after HIP

Surface Quality¹

MEASUREMENT	METRIC		U.S.	
	AS BUILT	SAND BLASTED	AS BUILT	SAND BLASTED
Surface Roughness R _a				
Vertical direction (Z) (μm μin)	9 - 13	3 - 5	350 - 510	120 - 200

Chemical Composition

ELEMENT	% OF WEIGHT
Co	Bal.
Cr	27.00-30.00
Mo	5.00-7.00
Ni	≤0.50
Fe	≤0.75
C	≤0.35
Si	≤1.00
Mn	≤1.00
W	≤0.20
P	≤0.020
B, S	≤0.010
N	≤0.25
Al, Ti	≤0.10

¹ Parts manufactured with standard parameters on a ProX DMP 320, Config B

⁵ Values based on literature



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LaserForm[®] Ni625 (A)

Ni625 fine-tuned for use with ProX[®] DMP 320 metal printer producing industrial parts with high heat resistance, high strength and high corrosion resistance. LaserForm Ni626 (A) is especially resistant to crevice and pitting corrosion.

LaserForm Ni625 (A) is formulated and fine-tuned specifically for 3D Systems DMP 320 metal 3D Printers to deliver high part quality and consistent part properties. The print parameter database that 3D Systems provides together with the material has been extensively developed, tested and optimized in 3D Systems' part production facilities that hold the unique expertise of printing 500,000 challenging metal production parts in various materials year over year. And for your 24/7 production 3D Systems' thorough Supplier Quality Management System guarantees consistent, monitored material quality for reliable results.

Material Description

Ni625 is known for its combination of high strength and excellent corrosion resistance. LaserForm Ni625 (A) is the ideal material for industries where these two strengths need to come together: chemical, marine, aerospace and nuclear industry. Applications include: reaction vessels, tubing, heat exchangers, valves, engine exhaust systems, turbine seals, propeller blades, submarine fittings, propulsion motors, reactor core and control-rod components in nuclear water reactors.

Classification

The chemical composition of LaserForm Ni625 (A) corresponds to ASTM F3056, UNS N06625, Werkstoff Nr. 2.4856, DIN NiCr22Mo9Nb and AMS 5666 and is indicated in the table below in wt%.

Mechanical Properties^{1,2}

MEASUREMENT	CONDITION	METRIC			U.S.		
		AS-BUILT	AFTER STRESS RELIEF	AFTER LOW SOLUTION ANNEAL	AS-BUILT	AFTER STRESS RELIEF	AFTER LOW SOLUTION ANNEAL
Ultimate strength (MPa ksi)	ASTM E8M						
Horizontal direction - XY		1040 ± 20	1110 ± 60	1030 ± 20	150 ± 3	160 ± 9	150 ± 3
Vertical direction - Z		1030 ± 20	1050 ± 30	980 ± 20	150 ± 3	153 ± 5	142 ± 3
Yield strength Rp0.2% (MPa ksi)	ASTM E8M						
Horizontal direction - XY		770 ± 30	750 ± 60	640 ± 20	110 ± 5	110 ± 9	93 ± 3
Vertical direction - Z		730 ± 20	700 ± 40	600 ± 20	105 ± 3	100 ± 6	87 ± 3
Elongation at break (%)	ASTM E8M						
Horizontal direction - XY		22 ± 2	19 ± 3	27 ± 3	22 ± 2	19 ± 3	27 ± 3
Vertical direction - Z		33 ± 1	23 ± 3	34 ± 3	33 ± 1	23 ± 3	34 ± 3
Reduction of area (%)							
Vertical direction - Z	ASTM E8M	30 ± 2	26 ± 2	31 ± 1	30 ± 2	26 ± 2	31 ± 1
Hardness, Rockwell C	ASTM E18	29 ± 3	32 ± 3	28 ± 4	29 ± 3	32 ± 3	28 ± 4
Impact toughness ³ (J ft-lb)	ASTM E23	NA	NA	84 ± 7	NA	NA	62 ± 5

Thermal Properties⁴

MEASUREMENT	CONDITION	METRIC	U.S.
Thermal conductivity (W/(m.K) Btu/(h.ft ² .°F))	at 21 °C / 70 °F	9.8	5.7
CTE - Coefficient of thermal expansion (µm/(m.°C) µ inch/(inch . °F))	at 93 °C / 200 °F	12.8	7.1
	at 538°C / 1000°F	14.0	7.8
	at 871°C/1600°F	15.8	8.8
Melting range (°C °F)		1290 - 1350	2355 - 2465

¹ Parts manufactured with standard parameters on a ProX DMP 320, Config B

² Values based on average and standard deviation

³ Tested with Charpy V-notch impact test specimens type A at room temperature

⁴ Values based on literature

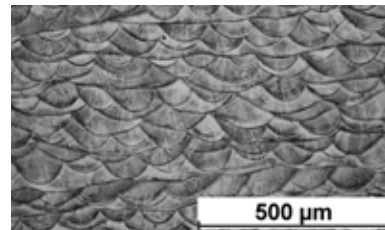
NA = Not available



LaserForm[®] Ni625 (A)

Physical Properties

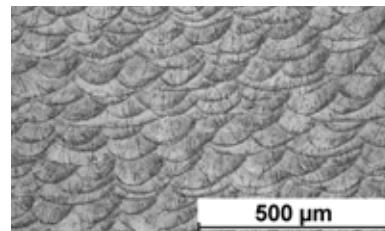
MEASUREMENT	METRIC		U.S.	
	AS BUILT AND AFTER STRESS RELIEF			
Density				
Relative, based on pixel count ¹ (%)	>99,9		>99,9	
Absolute theoretical ⁴ (g/cm ³ lb/in ³)	8.44		0.305	



Microstructure as built

Surface Quality¹

MEASUREMENT	METRIC		U.S.	
	AS BUILT	SAND BLASTED	AS BUILT	SAND BLASTED
Surface Roughness R _a				
Horizontal direction (XY) (µm µin)	4 - 7	1 - 4	160 - 275	40 - 160
Vertical direction (Z) (µm µin)	8 - 11	4 - 7	320 - 433	160 - 275

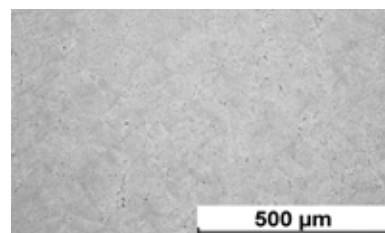


Microstructure after stress relief

Chemical Composition

The chemical composition of LaserForm Ni625 (A) corresponds to UNS N06625, Werkstoff Nr. 2.4856, DIN NiCr22Mo9Nb and AMS5 5666 and is indicated in the table below in wt%.

ELEMENT	% OF WEIGHT
Ni	≥ 58.00
Cr	20.00 - 23.00
Mo	8.00 - 10.00
Fe	≤ 5.00
Co	≤ 1.00
Nb	3.15 - 4.15
Ta	≤ 0.05
Ti	≤ 0.40
Al	≤ 0.40
Cu	≤ 0.50
Mn	≤ 0.50



Microstructure after low solution anneal



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¹ Parts manufactured with standard parameters on a ProX DMP 320, Config B

⁴ Values based on literature

LaserForm Ni718 (A)

A Nickel-based alloy fine-tuned for use with ProX® DMP 320, DMP Flex 350, DMP Factory 350 and DMP Factory 500 metal printers, producing parts for high temperature applications. LaserForm Ni718 (A) has outstanding corrosion resistance in various corrosive environments and excellent cryogenic properties.

LaserForm Ni718 (A) is formulated and fine-tuned specifically for 3D Systems ProX DMP 320, DMP Flex 350, DMP Factory 350 and DMP Factory 500 metal 3D printers to deliver highest part quality and best part properties. The print parameter database that 3D Systems provides together with the material has been extensively developed, tested and optimized in 3D Systems' part production facilities that hold the unique expertise of printing more than 1,000,000 challenging production parts year over year. Based on a multitude of test samples, the properties listed below provide high confidence to the user in terms of job-to-job and machine-to-machine repeatability. Using the LaserForm material enables the user to experience consistent and reliable part quality.

Material Description

LaserForm Ni718 (A) is a nickel-based heat resistant alloy. This precipitation-hardening nickel-chromium alloy is characterized by good tensile, fatigue, creep and rupture strength at temperatures up to 700°C. Moreover it has outstanding corrosion resistance in various corrosive environments as well as excellent cryogenic properties.

These benefits make LaserForm Ni718 (A) ideal for many high temperature applications such as gas turbine parts, instrumentation parts, power and process industry parts etc. Parts can be post-hardened over 1400 MPa Ultimate Tensile Strength (UTS) by precipitation-hardening heat treatments. The parts can be machined, spark-eroded, welded, shot-peened, polished and coated if required.

Classification

Parts built with LaserForm Ni718 Type (A) have a chemical composition that complies with ASTM F3055.

Mechanical Properties

PROX DMP 320, DMP FLEX 350, DMP FACTORY 350 - LT 30, 60 ^{1,2,3,4}	TEST METHOD	METRIC		U.S.	
		NHT	HSAA	NHT	HSAA
Ultimate Tensile Strength (MPa ksi) Horizontal direction — XY Vertical direction — Z	ASTM E8/E8M	NA	1400 ± 60	NA	203 ± 10
		930 ± 20	1340 ± 40	135 ± 6	194 ± 6
Yield strength Rp0.2% (MPa ksi) Horizontal direction — XY Vertical direction — Z	ASTM E8/E8M	NA	1230 ± 60	NA	178 ± 10
		660 ± 20	1200 ± 40	96 ± 6	174 ± 10
Elongation at break (%) Horizontal direction — XY Vertical direction — Z	ASTM E8/E8M	NA	15 ± 4	NA	15 ± 4
		30 ± 4	14 ± 8	30 ± 4	14 ± 8

DMP FACTORY 500 - LT 60 ^{5,6,7,8}	TEST METHOD	METRIC		U.S.	
		NHT	HAA	NHT	HAA
Ultimate Tensile Strength (MPa ksi) Horizontal direction — XY Vertical direction — Z	ASTM E8	1080 ± 20	1520 -40/+20	157 ± 3	220 -6/+3
		1010 ± 25	1440 -40/+20	146 ± 4	209 -6/+3
Yield strength Rp0.2% (MPa ksi) Horizontal direction — XY Vertical direction — Z	ASTM E8	790 ± 25	1350 -40/+30	115 ± 4	196 -6/+4
		660 ± 30	1280 ± 50	96 ± 4	186 ± 7
Plastic elongation (%) Horizontal direction — XY Vertical direction — Z	ASTM E8	29 ± 6	16 ± 4	29 ± 6	16 ± 4
		32 ± 4	18 ± 5	32 ± 4	18 ± 5

HIGH TEMPERATURE TENSILE PROPERTIES DMP FACTORY 500 - LT60 ⁹	TEST METHOD	METRIC		U.S.	
		NHT	HAA	NHT	HAA
Ultimate Tensile Strength (MPa ksi) Vertical direction - Z	ASTM E21, at 650°C	NA	1185 ± 25	NA	172 ± 4
Yield strength Rp0.2% (MPa ksi) Vertical direction - Z		NA	1055 ± 20	NA	153 ± 3
Plastic elongation (%) Vertical direction - Z		NA	20 ± 3	NA	20 ± 3

¹ Parts manufactured with standard parameters on a DMP Flex 350 and DMP Factory 350, Config B using layer thickness 30 µm and layer thickness 60 µm

² Values based on average and double standard deviation

³ NHT refers to non-heat-treated sample condition; HSAA refers to a modified homogenization followed with solutioning and double aging as prescribed in ASTM F3055

⁴ NHT samples tested according to ASTM E8M using round tensile test specimen type 4. HSAA samples tested according to ASTM E8 using rectangular tensile test specimen type 8

⁵ Parts manufactured with standard parameters on a DMP Factory 500, using layer thickness 60 µm (LT60)

⁶ Values based on average and 95% tolerance interval with 95% confidence

⁷ Tested according to ASTM E8 using round tensile test specimen type 4

⁸ NHT refers to non-heat-treated sample condition; HAA refers to the homogenization with double aging (HAA) heat treatment as prescribed in ASTM F3055

⁹ High temperature tensile properties based on limited sample size. For information only. Values based on average and double standard deviation

Printed Part Properties¹⁰

DENSITY	TEST METHOD	METRIC	U.S.
Theoretical density ¹¹ (g/cm ³ lb/in ³)	Value from literature	8.2	0.296
Relative density (%), ProX DMP 320, DMP Flex 350, DMP Factory 350 ^{12, 13}	Optical method (pixel count)	≥ 99.6 Typical 99.9	≥ 99.6 Typical 99.9
Relative density (%), DMP Factory 500 ^{12, 13}	Optical method (pixel count)	≥ 99.7 Typical 99.9	≥ 99.7 Typical 99.9

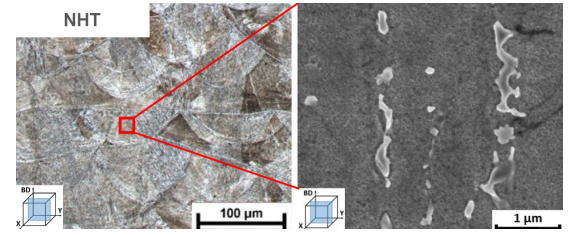
SURFACE ROUGHNESS R _a ^{12, 13, 14, 15}	TEST METHOD	METRIC	U.S.
Vertical side surface (µm µin) ProX DMP 320, DMP Flex 350, DMP Factory 350	ISO 25178	Typically, around 5	Typically, around 197
Vertical side surface (µm µin) DMP Factory 500	ISO 25178	Typically, around 5	Typically, around 197

Thermal Properties¹¹

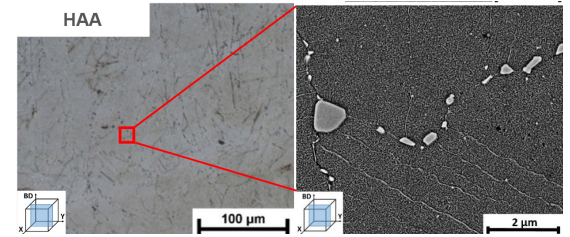
MEASUREMENT	CONDITION	METRIC	U.S.
Thermal conductivity (W/(m.K) BTU-in/h-ft ² -°F)	At 21 °C / 69.8 °F	11.4	79
	At 100°C / 212°F	18.3	127
Coefficient of Thermal Expansion (µm/m-°C µinch/(inch.°F))	At 200°C / 392°F	13.2	7.33
	At 600°C / 1112°F	13.9	7.72
Melting range (°C °F)		1260-1335	2300-2435

Chemical Composition

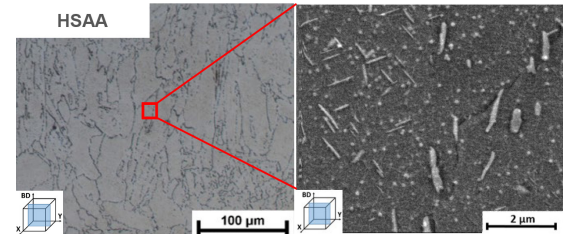
ELEMENT	% OF WEIGHT
Al	0.20-0.8
B	≤0.006
C	≤0.08
Co	≤1.00
Cr	17.00-21.00
Cu	≤0.30
Fe	Bal.
Mn,Si	≤0.35
Mo	2.80-3.30
Nb+Ta	4.75-5.50
Ni	50.00-55.00
P,S	≤0.015
Ti	0.65-1.15



Microstructure NHT



Microstructure after HAA



Microstructure after HSAA



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¹⁰ May deviate depending on specific part geometry

¹¹ Values based on literature

¹² Parts manufactured with standard parameters on a DMP Flex and Factory 350, Config B using layer thickness 30 µm and 60 µm. Parts manufactured on a DMP Factory 500, using layer thickness 60 µm

¹³ Minimum values based on 95% tolerance interval with a 95% confidence. Tested on specific 3DS test coupons

¹⁴ Surface treatment performed with Finox zirconia blasting medium at 5 bar

¹⁵ Vertical side surface measurement along the building direction



Certified HX (A)

3D Systems offers a print parameter database license for Certified HX (A) on the DMP Flex 350 and DMP Factory 500 metal 3D printers that can be applied using the integrated additive manufacturing workflow software, 3DXpert.

The print parameter database license available for nickel superalloy HX has been developed in a close collaboration between 3D Systems and GF Machining Solutions using real applications in turbomachinery and energy industrial sectors.

3D Systems' Application Innovation Group and manufacturing services bring high-quality part solutions to our customers and produce more than 1,000,000 challenging metal production parts in various materials, year over year.

Material description

Nickel-chromium-iron-molybdenum alloy with improved high temperature strength, corrosion resistance and excellent creep resistance. The service temperature of this alloy is up to 1200°C. Its composition corresponds to UNS N06002. This datasheet specifies the material properties of the parts printed on 3D Systems DMP machines using HX powder.

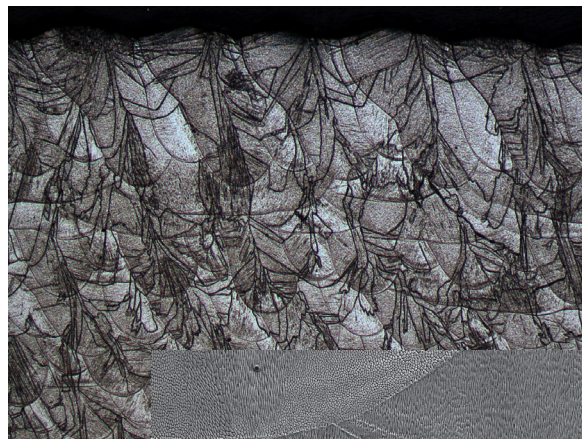
The applications for this alloy include but are not limited to:

- Jet engines and IGT turbine vanes and ducts
- Gas turbine engine combustion zone components such as transition ducts, combustor cans and spray bars
- Oil and gas components working in corrosive environments, e.g., drill bits, downhole tools and sensor casings
- Chemical processing parts such as heat exchangers, reaction vessels, evaporators, fans and fan housings

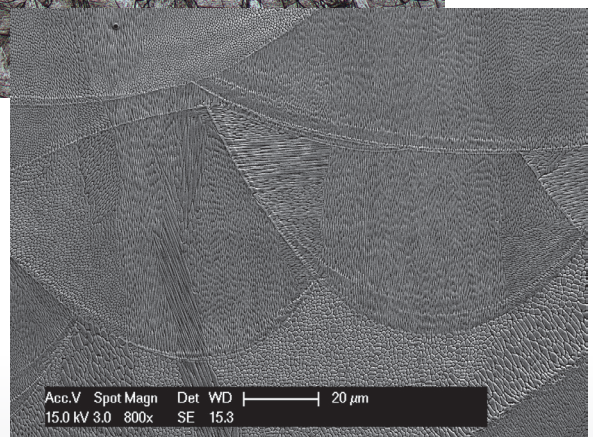
Turbine vane

The DMP technology and parameter set for Certified HX (A) allowed this large turbine vane ring (below) to print in under two days (build time 44 hours). This application is a great example of design and assembly simplification where 50+ parts are replaced by one and all joints are eliminated.

The developed parameter set for Certified HX (A) ensures the dimensional stability and repeatability of parts, delivering a superior surface quality finish ready for final processing.

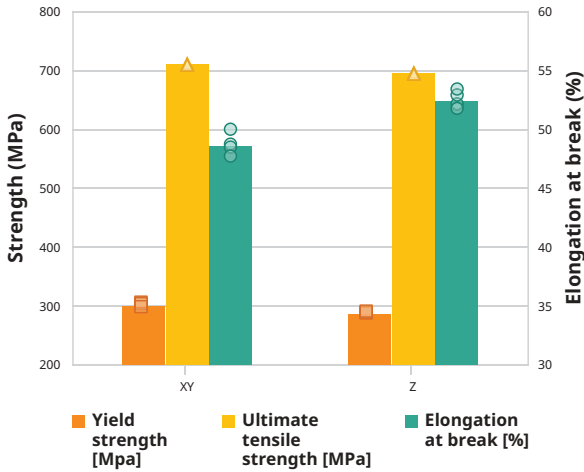


Typical density
~99.9%

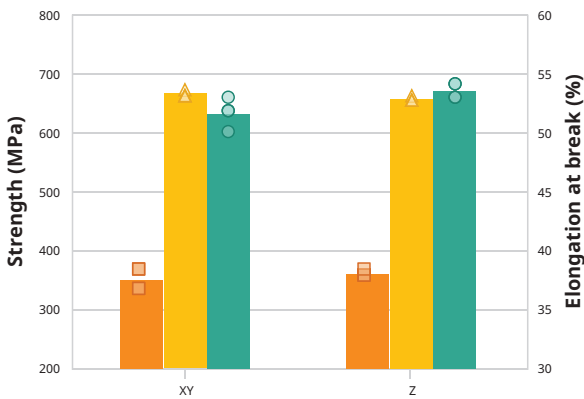


Homogeneous microstructure at higher magnification.

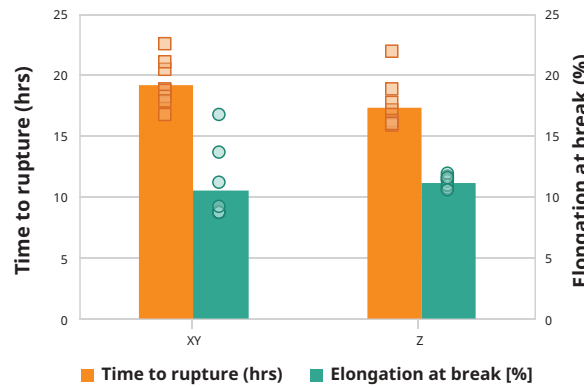
TENSILE TEST AT ROOM TEMPERATURE (ASTM E8)



TENSILE TEST AT 815°C (ASTM E21)

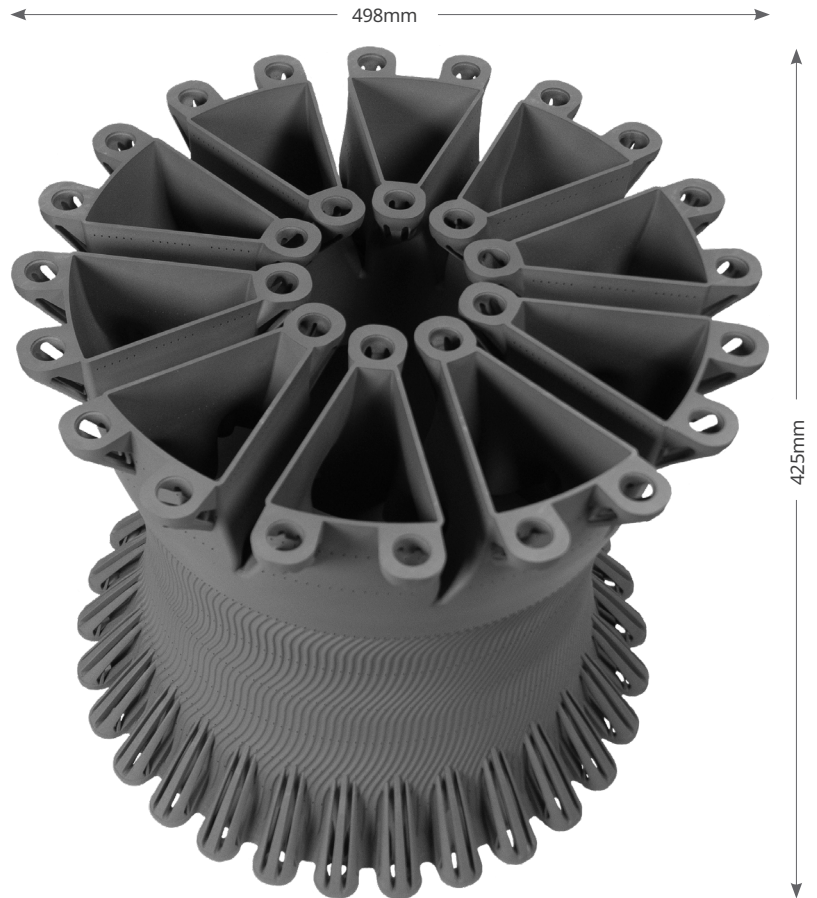


STRESS RUPTURE TESTING AT 815°C, 105MPa (ASTM E139)



Combustion chamber component:

The DMP technology and parameter set for Certified HX (A) allows complex welded assemblies of separate transition ducts and combustor casings to be transformed into a single additively manufactured component. Additional design for additive methods were applied to the flanges and complexly shaped cooling channels. Such parts are typically quite large, but in this case it was possible to fit the entire part into the DMP Factory 500's unique build envelope and allow seamless manufacturing. Total production time is 150 hours.



All specimens were stress relieved followed by HIP (~1130°C for 4hrs at 100MPa), and solution annealing (1177°C for 2hrs followed by rapid cooling below 60°C)



To confirm the suitability of this material for your specific application, please contact the 3D Systems Application Innovation Group (AIG): <https://www.3dsystems.com/consulting/application-innovation-group>

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HX powder with product reference "TruForm™ HXLC powder" can be purchased directly from Praxair: <https://www.praxairsurfacetechologies.com/en/materials-and-equipment/materials/additive-manufacturing-powders>



LaserForm[®] Maraging Steel (A)

Maraging steel fine-tuned for use with ProX[®] DMP 320 metal 3D printers to produce industrial parts and tool inserts with a combination of high-strength and excellent hardness.

LaserForm Maraging Steel (A) is formulated and fine-tuned specifically for 3D Systems DMP 320 metal 3D Printers to deliver highest part quality and best part properties. The print parameter database that 3D Systems provides together with the material has been extensively developed, tested and optimized in 3D Systems' part production facilities that hold the unique expertise of printing 500,000 challenging production parts year over year. Based on extensive testing the below listed part quality data and mechanical properties give you high planning security. For a 24/7 production operation, 3D Systems' thorough Supplier Quality Management System guarantees consistent, monitored material quality for reliable process results.

Material Description

With properties like 1.2709, this steel is easily heat-treatable in a simple age-hardening process resulting in excellent hardness and strength. LaserForm Maraging Steel (A) has good wear resistance. In regards to post-processing, the material shows good weldability and machinability. LaserForm Maraging Steel (A) is ideal for innovative tool and mold designs including conformal cooling channels for injection molding, die casting and extrusion. The material is also used for high-performance aerospace, automotive and other industrial applications which require high strength and wear resistance.

Classification

Parts built with LaserForm Maraging Steel (A) have a chemical composition that conforms to the compositional requirements of Werkstoff Nr. 1.2709.

Mechanical Properties^{1,2}

MEASUREMENT	CONDITION	METRIC			U.S.		
		AS-BUILT	AGEING 1	AGEING 2	AS-BUILT	AGEING 1	AGEING 2
Ultimate strength (MPa ksi)	ASTM E8M						
Horizontal direction - XY		1230 ± 70	2210 ± 30	2260 ± 30	178 ± 10	320 ± 5	328 ± 5
Vertical direction - Z		1220 ± 20	2120 ± 30	2160 ± 90	177 ± 3	307 ± 5	313 ± 13
Yield strength Rp0.2% (MPa ksi)	ASTM E8M						
Horizontal direction ⁴ - XY		1080 ± 90	2125 ± 30	2180 ± 40	115 ± 13	308 ± 4	316 ± 6
Vertical direction ⁵ - Z		1090 ± 50	2030 ± 60	2070 ± 80	158 ± 7	294 ± 9	300 ± 12
Elongation at break (%)	ASTM E8M						
Horizontal direction - XY		13 ± 2	5 ± 2	5 ± 2	13 ± 2	5 ± 2	5 ± 2
Vertical direction - Z		13 ± 2	5 ± 2	2 ± 1	13 ± 2	5 ± 2	2 ± 1
Hardness, Rockwell C	ASTM E18	35 ± 3	55 ± 3	55 ± 3	35 ± 3	55 ± 3	55 ± 3
Impact toughness ⁶ (J ft-lb) ³	ASTM E23	64 ± 5	8 ± 2	7 ± 2	47 ± 4	6 ± 2	5 ± 2

Thermal Properties⁴

MEASUREMENT	CONDITION	METRIC	U.S.
Thermal conductivity (W/(m.K) Btu/(h.ft ² .°F))	at 25°C / 36 °F	20.9	145
CTE - Coefficient of thermal expansion (µm/ (m.°C) µ inch/(inch. °F))	In the range of 0 to 100 °C	10.0	5.6
Melting range (°C °F)		1430-1450	2610-2640

¹ Parts manufactured with standard parameters on a ProX DMP 320, Config B

² Values based on average and double standard deviation

³ Tested with Charpy V-notch impact test specimens type A at room temperature

⁴ Values based on literature



LaserForm[®] Maraging Steel (A)

Physical Properties¹

MEASUREMENT	METRIC		U.S.	
	AS-BUILT	AGEING	AS-BUILT	AGEING
Density				
Relative, based on pixelcount (%)	> 99.8%			
Absolute theoretical (g/cm ³ lb/in ³) ¹	8.1		0.293	

Surface Quality²

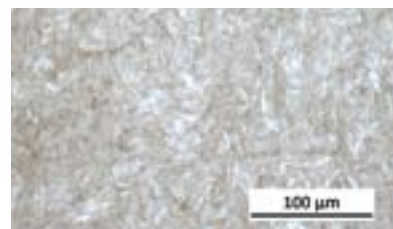
MEASUREMENT	SANDBLASTED METRIC	SANDBLASTED U.S.
Surface Roughness Ra		
Horizontal direction (XY) (µm µin)	4 - 7	157 - 276
Vertical direction (Z) (µm µin)	5 - 6	196 - 236

Chemical Composition

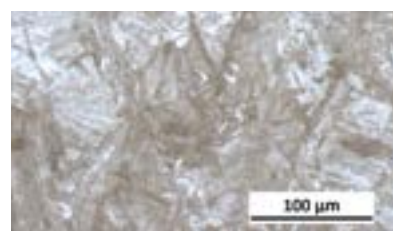
ELEMENT	% OF WEIGHT
C	≤ 0.03
Si	≤ 0.10
Mn	≤ 0.15
P	≤ 0.01
S	≤ 0.01
Cr	≤ 0.25
Mo	4.50 - 5.20
Ni	17.0 - 19.0
Ti	0.80 - 1.20
Co	8.50 - 10.0
Fe	Rest



Microstructure as built



Microstructure ageing 1



Microstructure ageing 2



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¹ Values based on literature

² Values based on minimum and maximum rangers



Certified M789 (A)

Thoroughly developed and validated print parameter sets for BÖHLER'S AMPO M789 on DMP Flex and Factory 350 as well as ProX® DMP 320 metal 3D printers. M789 is a cobalt-free steel and produces mold inserts, tools and parts with high hardness and excellent corrosion resistance.

The print parameter database license available for Certified M789 (A) in 3DXpert® all-in-one metal AM software for DMP Flex and Factory 350 as well as ProX DMP 320 metal 3d printers has been extensively developed to deliver high repeatable part quality and consistent part properties, tested and optimized by 3D Systems and GF Machining Solutions together with voestalpine BÖHLER Edelstahl and industry partners. Based on producing a multitude of test samples, geometries and endurance jobs at multiple facilities, the properties listed below provide high confidence to the user in terms of job-to-job and machine-to-machine repeatability.

Material Description

M789 combines high hardness with excellent corrosion resistance. M789 displays a broad process window on 3D Systems DMP Flex and Factory 350 and ProX DMP 320 metal printers leading to high density parts across the build plate. No preheating of the powder is required.

In the as printed and solution annealed condition, M789 reaches a hardness of around 30 HRC which allows for easy machinability. During the ageing heat treatment, intermetallic precipitates containing Ni, Ti, Al and Si are formed within the martensitic microstructure. This increases the hardness further up to 52 HRC. Unlike typical maraging steel alloys, cobalt is not needed to facilitate the ageing process. With regards to corrosion resistance M789 is comparable to and sometimes even exceeding that of PH 13-8 Mo, 17-4PH and 1.2083.

In tool and mold making M789 is used for its very high strength paired with corrosion resistance to produce mold and tool inserts with complex surfaces, fine features and conformal cooling channels for improved mold productivity. In the transportation industry typical steel components such as axel components and drive train parts can be quickly produced and reproduced in Metal AM using M789 material. For the oil and gas industry, this material enables the direct production of complex drill heads.

Mechanical Properties

PROX DMP 320, DMP FLEX 350, DMP FACTORY 350 ²	TEST METHOD	METRIC	U.S.	METRIC	U.S.
		SA + A - LT30 ^{4,5}		SA + A - LT60 ^{4,6}	
Ultimate tensile strength (MPa ksi) ¹ Horizontal direction - XY Vertical direction - Z	ASTM E8 ³	1880±25	270±4	1880±25	270±4
		1830±25	265±4	1840±20	265±3
Yield strength Rp0.2% (MPa ksi) ¹ Horizontal direction - XY Vertical direction - Z		1730±40	250±6	1740±35	250±5
		1690±40	245±6	1710±20	245±3
Plastic elongation (%) ¹ Horizontal direction - XY Vertical direction - Z		12±4		10±3	
		9±3		10±2	
Hardness, Rockwell C (HRC) ¹	ASTM E18	52±1		52±1	
Impact toughness ⁷ (J ft.lb)	ASTM E23 ⁸	6±1.5	4±1	8±2	6±1.5

Printed Part Properties

DENSITY ⁹	TEST METHOD	METRIC	U.S.
Absolute theoretical ¹⁰ (g/cm ³ lb/in ³)	Value from literature	7.715	0.2787
Relative density (%), layer thickness 30 µm ^{2,11}	Optical method (pixel count)		≥ 99.8 Typical 99.9
			≥ 99.8 Typical 99.9

¹ Values based on average and 90% tolerance interval with 90% confidence. Tested on a minimum of 6 samples

² Parts manufactured with standard parameters on DMP Flex and Factory 350, Config B using the 15-45 µm BÖHLER M789 AMPO powder

³ Tested according to ASTM E8 using round tensile test specimen type 4 with stress control (10 MPa/s) during the elastic and strain control (20%/min) during plastic regime

⁴ Solution annealing (SA) performed at 1000°C for 1 hour with subsequent rapid cooling (>75°C/min) to room temperature (<32°C), followed by ageing (A) at 500°C for 3 hours and air cooling

⁵ Layer thickness 30 µm (LT30)

⁶ Layer thickness 60 µm (LT60)

⁷ Values based on average and 2 times standard deviation. Tested on 6 samples.

⁸ Tested according to ASTM E23 using V-notch Charpy (Simple-Beam) impact test specimens, printed in the Z-direction

⁹ May deviate depending on specific part geometry

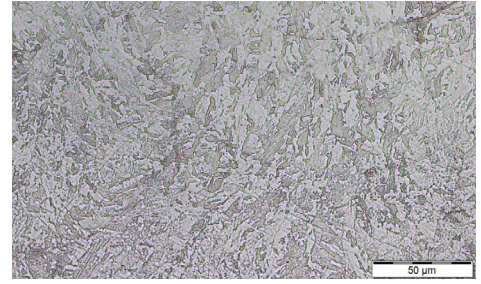
¹⁰ Values based on literature

¹¹ Minimum values based on 95% tolerance interval with 95% confidence. Tested on a minimum of 15 samples using specific 3DS test coupons.

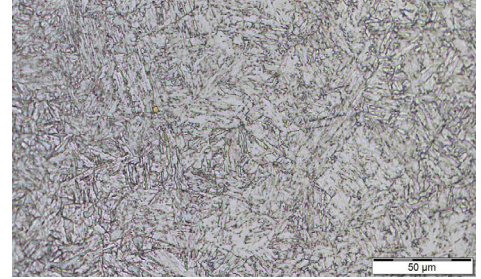
SURFACE ROUGHNESS R_a ^{2, 9, 11, 12, 13}	TEST METHOD	METRIC	U.S.
Vertical side surface (μm μin) Layer thickness 30 μm	ISO 25178	Typically, around 8	Typically, around 315
Vertical side surface (μm μin) Layer thickness 60 μm	ISO 25178	Typically, around 10	Typically, around 390

Chemical Composition

ELEMENT	TYPICAL % OF WEIGHT
C	<0.02
Si	0.5
Cr	12.2
Ni	10.0
Co	/
Mo	1.0
Al	0.6
Ti	1.0
Fe	Balance



Microstructure as build



Microstructure after solution annealing and aging

To confirm that Certified M789 (A) material is the best suited for your specific application, please contact the 3D Systems Application Innovation Group (AIG):

<https://www.3dsystems.com/consulting/application-innovation-group>

Once confirmed, Certified M789 (A) powder powder can be purchased directly from voestalpine BÖHLER Edelstahl GmbH:

<https://www.boehler-edelstahl.com/en/products/m789-ampo/>

where it is available under the name BÖHLER M789 AMPO 15-45 μm



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¹² Surface treatment performed with zirconia blasting medium at 2 bar

¹³ Vertical side surface measurement along the building direction



LaserForm[®] 17-4PH (A)

LaserForm 17-4PH (A) is fine-tuned for use with ProX[®] DMP 320 metal printer producing industrial parts with good corrosion resistance, high mechanical strength combined with excellent ductility. Mechanical properties of LaserForm 17-4PH (A) can be varied upon different heat treatments.

LaserForm 17-4PH (A) is formulated and fine-tuned specifically for 3D Systems DMP 320 metal 3D printers to deliver high part quality and consistent properties. The print parameter database that 3D Systems provides together with the material has been extensively developed, tested and optimized in 3D Systems' part production facilities that holds the unique expertise of printing 500,000 challenging metal production parts in a broad choice of materials year over year. And for your 24/7 production 3D Systems' thorough Supplier Quality Management System guarantees consistent, monitored material quality for reliable results.

Material Description

LaserForm 17-4PH (A) is known for its outstanding combination of excellent corrosion resistance and high strength with good toughness. These good mechanical properties and corrosion resistance are maintained at temperatures up to 316°C (600°F). With these characteristics, LaserForm 17-4PH (A) is ideal for surgical instruments (sterilizable), aerospace, chemical, petrochemical and general metalworking applications.

Classification

The chemical composition of LaserForm 17-4PH (A) corresponds to a stainless steel 17-4 PH alloy according to ASTM F899, A564, A693 and UNS S17400 specifications. and is indicated in the table below in wt%.

Mechanical Properties^{1,2,3}

MEASUREMENT	CONDITION	METRIC			U.S.		
		AS-BUILT	H900	H1150	AS-BUILT	H900	H1150
Ultimate strength (MPa ksi)	ASTM E8M						
Horizontal direction ⁴ - XY Vertical direction ⁵ - Z		NA 1100 ± 90	1450 ± 10 1380 ± 20	1180 ± 10 1080 ± 50	NA 160 ± 13	210 ± 2 200 ± 3	170 ± 2 155 ± 8
Yield strength Rp0.2% (MPa ksi)	ASTM E8M						
Horizontal direction ⁴ - XY Vertical direction ⁵ - Z		NA 830 ± 110	1280 ± 30 1260 ± 100	1130 ± 20 1020 ± 170	NA 120 ± 16	185 ± 5 180 ± 15	165 ± 3 145 ± 25
Elongation at break (%)	ASTM E8M						
Horizontal direction ⁴ - XY Vertical direction ⁵ - Z		NA 19 ± 4	11 ± 1 12 ± 2	12 ± 1 16 ± 4	NA 19 ± 4	11 ± 1 12 ± 2	12 ± 1 16 ± 4
Hardness, Rockwell C	ASTM E18	32 ± 4	40 ± 2	35 ± 3	32 ± 4	40 ± 2	35 ± 3
Impact toughness ⁶ (J ft-lb)	ASTM E23	71 ± 20	7 ± 2	11 ± 5	52 ± 15	5 ± 2	8 ± 4

Thermal Properties⁷

MEASUREMENT	CONDITION	METRIC	U.S.
Thermal conductivity (W/(m.K) Btu/(h.ft ² .°F))	at 100°C / 212 °F	18.3	10.6
CTE - Coefficient of thermal expansion (µm/ (m.°C) µ inch/(inch. °F))	at 0°C	11.6	6.4
Melting range (°C °F)		1400 - 1450	2550 - 2640

¹ Parts manufactured with standard parameters on a ProX DMP 320, Config B

² Values based on average and double standard deviation

³ H900 and H1150 indicate heat treatments targeting resp. H900 and H1150 conditions

⁴ Tested on ASTM E8M specimen with rectangular cross sections

⁵ Tested on ASTM E8M specimen with circular cross sections type 4

⁶ Tested with Charpy V-notch impact test specimens type A at room temperature

⁷ Values based on literature

NA = Not available



LaserForm[®] 17-4PH (A)

Magnetic Properties¹

MEASUREMENT	METRIC	U.S.
Relative magnetic permeability	100	100

Physical Properties

MEASUREMENT	METRIC	U.S.
Density		
Relative, based on pixel count ² (%)	>99.9	>99.9
Absolute theoretical ¹ (g/cm ³ lb/in ³)	7.75	0.28

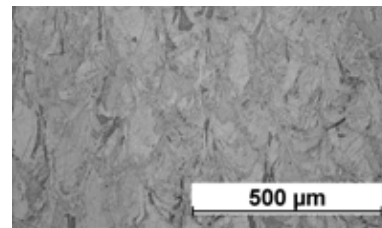
Surface Quality²

MEASUREMENT	METRIC		U.S.	
	AS BUILT	SAND BLASTED	AS BUILT	SAND BLASTED
Surface Roughness R _a				
Horizontal direction (XY) (µm µin)	5 - 7	4 - 7	195 - 275	155 - 275
Vertical direction (Z) (µm µin)	6 - 8	4 - 8	236 - 315	155 - 315

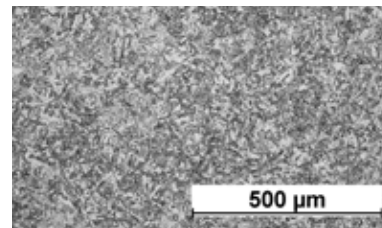
Chemical Composition

ELEMENT	% OF WEIGHT
Fe	Bal.
C	<0.07
Mn	<1.00
P	<0.040
S	<0.030
Si	<1.00
Cr	15.00-17.50
Ni	3.00-5.00
Cu	3.00-5.00
Nb+Ta	0.15-0.45

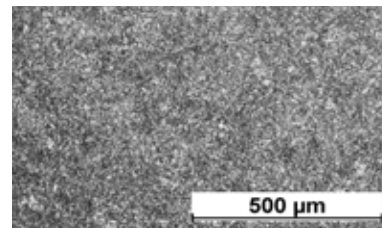
¹ Values based on literature
² Parts manufactured with standard parameters on a ProX DMP 320, Config B



Microstructure as built



Microstructure after H900



Microstructure after H1150



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LaserForm[®] 316L (A)

Extra low-carbon grade Stainless Steel which is fine-tuned for use with the ProX[®] DMP 320, producing parts with high corrosion resistance and sterilisability. LaserForm 316L (A) yields crack free and completely dense parts for all your applications.

LaserForm 316L (A) is formulated and fine-tuned specifically for 3D Systems DMP 320 metal 3D Printers to deliver highest part quality and best part properties. The print parameter database that 3D Systems provides together with the material has been extensively developed, tested and optimized in 3D Systems' part production facilities that hold the unique expertise of printing 500,000 challenging production parts year over year. Based on over 1000 test samples the below listed part quality data and mechanical properties give you high planning security. And for a 24/7 production 3D Systems' thorough Supplier Quality Management System guarantees consistent, monitored material quality for reliable process results.

Material Description

Austenitic stainless steel type LaserForm 316L is the extra low carbon grade of 316. This steel is used as a general purpose material with excellent mechanical and corrosion properties at room temperature. Its chloride resistance makes this specific grade of stainless steel suitable for marine applications. 316L stainless steel is also the preferred material for use in hydrogen atmospheres or for hydrogen piping / cooling applications. Furthermore 316L retains good mechanical properties at sub-zero and even cryogenic temperatures and is suitable for structural components in low-temperature applications.

Classification

Parts built with LaserForm 316L alloy have a chemical composition that conforms to the compositional requirements of DIN X2CrNiMo 17-12-2 or Werkstoff Nr. 1.4404.

Mechanical Properties^{1,3}

MEASUREMENT	CONDITION	METRIC		U.S.	
		AFTER STRESS RELIEF	FULL ANNEAL	AFTER STRESS RELIEF	FULL ANNEAL
Youngs modulus (GPa ksi)					
Horizontal direction — XY		180 ± 15	180 ± 15	27600 ± 1500	27600 ± 1500
Ultimate Strength (MPa ksi)	ASTM E8M				
Horizontal direction — XY		660 ± 20	610 ± 30	96 ± 3	89 ± 5
Vertical direction — Z		570 ± 30	540 ± 30	83 ± 5	78 ± 5
Yield strength Rp0.2% (MPa ksi)	ASTM E8M				
Horizontal direction — XY		530 ± 20	370 ± 30	77 ± 3	54 ± 5
Vertical direction — Z		440 ± 20	320 ± 20	63 ± 3	47 ± 3
Elongation at break (%)	ASTM E8M				
Horizontal direction — XY		39 ± 5	51 ± 5	39 ± 5	51 ± 5
Vertical direction — Z		49 ± 5	66 ± 5	49 ± 5	66 ± 5
Reduction of area (%)	ASTM E8M				
Horizontal direction — XY		65 ± 5	61 ± 5	65 ± 5	61 ± 5
Vertical direction — Z		65 ± 5	62 ± 5	65 ± 5	62 ± 5
Hardness, Rockwell B (HRB)	ASTM E18	90 ± 6	83 ± 4	90 ± 6	83 ± 4
Impact toughness ² (J/cm ² lb.ft)	ASTM E23	215 ± 15	220 ± 15	158 ± 10	162 ± 10

Thermal Properties⁴

MEASUREMENT	CONDITION	METRIC	U.S.
Thermal conductivity (W/(m.K) Btu/(h.ft ² .°F))	At 20 °C / 68 °F	15	9
Coefficient of Thermal Expansion (µm/m.°C µin/in.°F)	In the range of 20 - 600°C / 68-1112°F	19.0	10.6
Melting range (°C °F)		1370-1400	2500-2550

¹ Parts manufactured with standard parameters on a ProX DMP 320, Config B

² Tested with Charpy V-notch toughness test, DMV probe

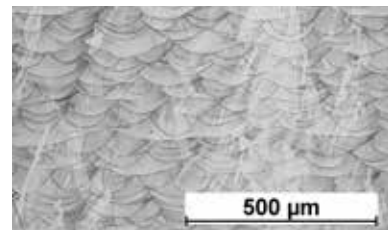
³ Values based on average and standard deviation

⁴ Values based on literature

LaserForm[®] 316L (A)

Physical Properties ⁴

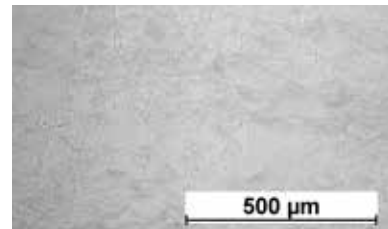
MEASUREMENT	METRIC		U.S.	
	AS BUILT AND AFTER STRESS RELIEF	AFTER FULL ANNEAL	AS BUILT AND AFTER STRESS RELIEF	AFTER FULL ANNEAL
Density — Absolute theoretical ⁵ (g/cm ³ lb/in ³)	8.0		0.286	



Microstructure after stress relief

Surface Quality

MEASUREMENT	METRIC	U.S.
	SANDBLASTED	SANDBLASTED
Surface Roughness Vertical direction (Z) (μm μin)	5-10	200-400



Microstructure after full anneal

Chemical Composition

ELEMENT	% OF WEIGHT
Fe	bal.
Cr	16.50-18.50
Ni	10.00-13.00
C	≤0.030
Mn	≤2.00
Mo	2.00-2.50
N	≤0.11
Si	≤1.00
P	≤0.045
S	≤0.030

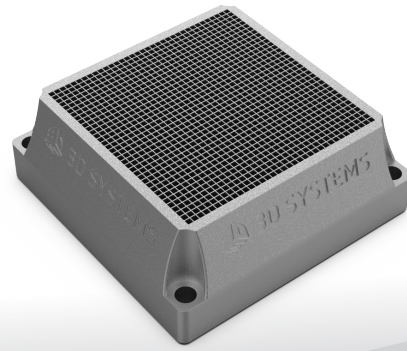


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⁴ Values based on literature



Tungsten (A)

3D Systems offers a print parameter database license for Tungsten (A) on the DMP Flex 350 metal 3D printer that can be applied using the integrated additive manufacturing workflow software, 3DXpert®.

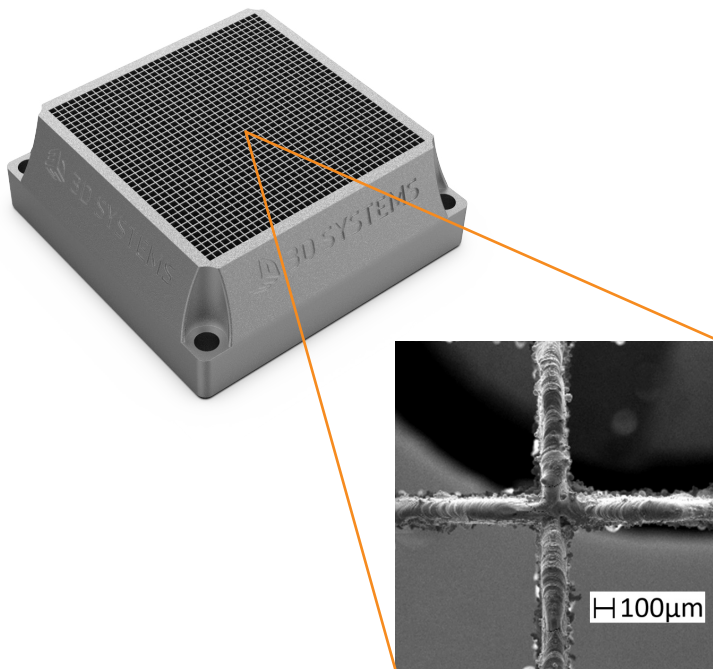
Material Description

The high-tech and semiconductor industries benefit from this material's excellent radiation shielding capabilities for manufacturing high-precision components used in imaging equipment (e.g., collimators). Tungsten's high-temperature properties are deployed in plasma environments such as in ion generation equipment (e.g., arc slits, beam targets, anodes, and cathodes). In the nuclear industry, tungsten components are used to withstand extreme high-temperature and corrosive working environments.

Commercially pure tungsten, W1 (W > 99.9%), is a high-density refractory metal exhibiting the highest melting point (3422°C) among all metals. Tungsten yields excellent radiation absorption properties (X-ray, gamma radiation) combined with an outstanding resistance against heat and corrosion.

Application Focus: Collimator

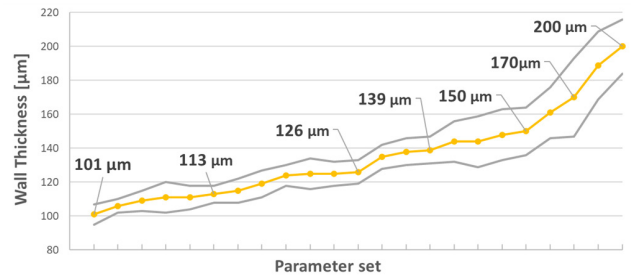
The DMP technology and parameter set for Tungsten (A) allows for manufacturing high-precision components such as thinly-walled anti-scatter grid structures, used in medical and industrial imaging equipment. The high material density (19.25 g/cc) provides excellent X-ray and gamma radiation shielding capabilities. The thinly-walled anti-scatter grid structures can be additively manufactured in a cost-effective manner, avoiding extensive conventional post-process machining steps.



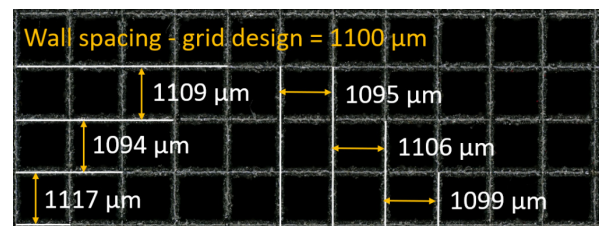
Direct metal printing (DMP) with a low-oxygen printing environment is essential for producing highly dense pure tungsten DMP parts. Superior part density of pure tungsten can be achieved thanks to the best-in-class vacuum technology of the DMP Flex 350.

Indicative part properties - Layer thickness 30 µm

Property	Test method	Metric	US
Relative density	Optical method (pixel count)	97%	
Electrical resistivity	ASTM B193 at 20°C / 68°F	9.7 µΩ.cm	3.8 µΩ.in
Roughness Ra Vertical side surface ¹	ISO 25178	5.7 µm	225 µin



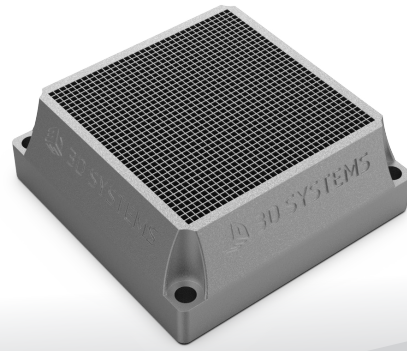
Extensive parameter database for **customizable wall thickness** reliable down to 100 µm.²



AM allows for accurate wall spacing.

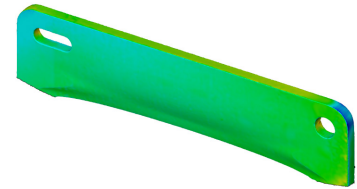
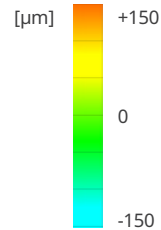
¹ Surface treatment performed with zirconia blasting medium at 2 bar.

² Measurements done on top surface of the grid, based on analysis of 80x and 250x magnification SEM imaging.

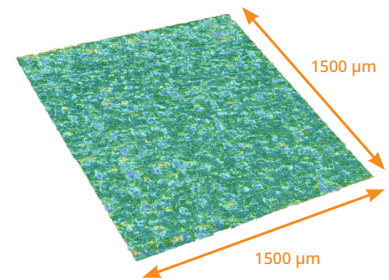
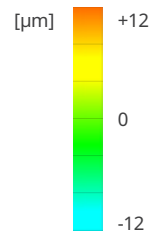


Application Focus: Arc Slit

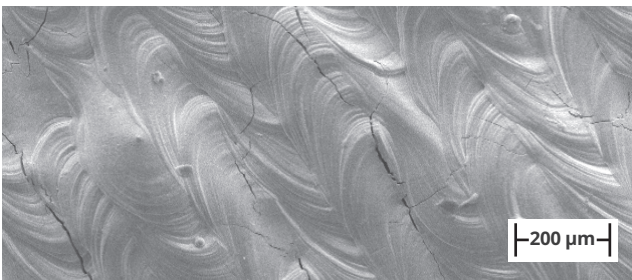
DMP pure tungsten arc slits yield excellent performance in high-temperature or plasma environments such as in ion generation equipment. The freedom of design in additive manufacturing offers a cost-efficient alternative to machined tungsten components.



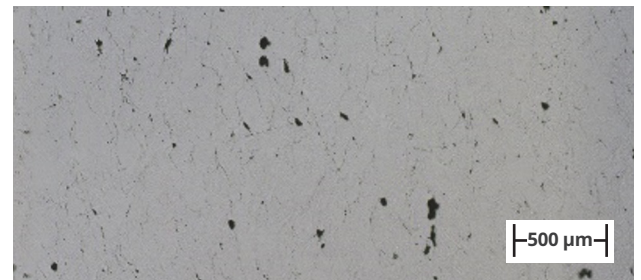
High accuracy after support removal and sandblasting as measured by a 3D scan.



Smooth surface as measured by a Keyence microscope, with an Ra down to 5.7 μm .



DMP Flex 350 allows **fully molten tungsten** material. Additively manufactured pure tungsten does contain micro cracks and is brittle, limiting its use for mechanically loaded components.



Superior part density thanks to best-in-class vacuum technology.



To confirm the suitability of this material for your specific application, please contact the 3D Systems Application Innovation Group (AIG): <https://www.3dsystems.com/consulting/application-innovation-group>

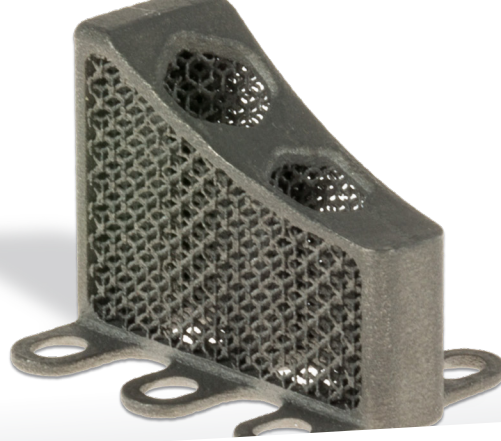


Tungsten powder with reference "TEKMAT™ W-25" can be purchased directly from Tekna: <http://www.tekna.com/spherical-powders/tungsten>

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LaserForm[®] Ti Gr1 (A)

Commercially pure titanium fine-tuned for use with ProX[®] DMP 320 and DMP 350 printers; metal powder perfectly suited for medical applications and implants as LaserForm Ti Gr1 (A) is the purest Ti grade, known for its excellent biocompatibility and high ductility.

LaserForm Ti Gr1 (A) is formulated and fine-tuned specifically for 3D Systems ProX DMP 320 and DMP 350 metal 3D Printers to deliver highest part quality and best part properties. The print parameter database that 3D Systems provides together with the material has been extensively developed, tested and optimized in 3D Systems' part production facilities that hold the unique expertise of printing 500,000 challenging production parts year over year. Based on over 1000 test samples the below listed part quality data and mechanical properties give you high planning security. And for a 24/7 production 3D Systems' thorough Supplier Quality Management System guarantees consistent, monitored material quality for reliable process results.

Material Description

Commercially pure titanium is perfectly suited for medical applications because of its low stiffness and excellent biocompatibility. Grade 1 titanium is the most ductile medical titanium grade, rendering it ideal for implants, such as bone plates and other fixation devices, which need to be molded manually during surgery to fit the patient. Similar to other titanium grades, Grade 1 titanium has excellent corrosion resistance, including chloride and cavitation corrosion resistance.

Classification

Parts built with LaserForm Ti Gr1 Alloy have a chemical composition that complies with ASTM F3302, ASTM F67, ASTM B265, ASTM B348 (grade 1), ISO 5832-2, ISO 13782 and Werkstoff Nr. 3.7025 standards.

Mechanical Properties^{1,2,3}

MEASUREMENT	CONDITION	METRIC		U.S.	
		AFTER STRESS RELIEF 1	AFTER HIP	AFTER STRESS RELIEF 1	AFTER HIP
Young's modulus (GPa ksi)	ASTM E8M	105-120	105-120	15000-17500	15000-17500
Ultimate Strength (MPa ksi)	ASTM E8M				
Horizontal direction — XY		500 ± 30	460 ± 30	73 ± 4	67 ± 4
Vertical direction — Z		500 ± 30	460 ± 30	73 ± 4	67 ± 4
Yield strength Rp0.2% (MPa ksi)	ASTM E8M				
Horizontal direction — XY		380 ± 30	340 ± 20	55 ± 4	49 ± 3
Vertical direction — Z		380 ± 30	340 ± 20	55 ± 4	49 ± 3
Elongation at break (%)	ASTM E8M				
Horizontal direction — XY		29 ± 5	36 ± 5	29 ± 5	36 ± 5
Vertical direction — Z		30 ± 5	36 ± 5	30 ± 5	36 ± 5
Reduction of area (%)	ASTM E8M				
Horizontal direction — XY		53 ± 5	58 ± 10	53 ± 5	58 ± 10
Vertical direction — Z		53 ± 6	60 ± 10	53 ± 6	60 ± 10
Hardness, Rockwell B (HRB)	ASTM E18	85 ± 5	80 ± 5	85 ± 5	80 ± 5

Thermal Properties⁴

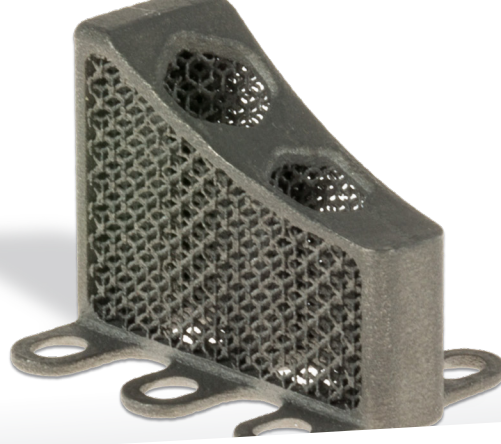
MEASUREMENT	CONDITION	METRIC	U.S.
Thermal conductivity (W/(m.K) btu.in/(h.ft.°F))	At 50 °C / 120 °F	16	9.25
Coefficient of Thermal Expansion (µm/m.°C µin/(in.°F))	In the range of 20 to 600 °C	7.17	3.98
Melting point (°C °F)		1668	3070

¹ Parts manufactured with standard parameters on a ProX DMP 320, Config A

² Values based on average and double standard deviation

³ Surface condition of test samples: Horizontal samples (XY) tested in machined surface condition only, vertical (Z) tested in as-printed and machined surface condition

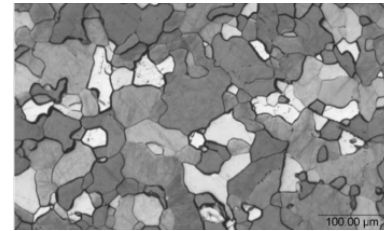
⁴ Values based on literature



LaserForm[®] Ti Gr1 (A)

Physical Properties

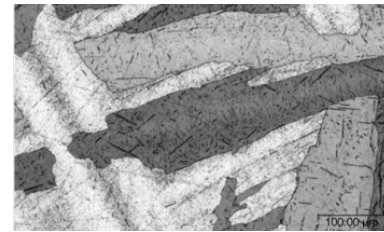
MEASUREMENT	CONDITION	METRIC		U.S.	
		AS BUILT AND AFTER STRESS RELIEF	AFTER HIP	AS BUILT AND AFTER STRESS RELIEF	AFTER HIP
Density — Relative, based on pixelcount (%) ^{1,2}	Optical method	> 99.6 typical 99.8		> 99.6 typical 99.8	
Density — Absolute theoretical ³ (g/cm ³ lb/in ³)		4.51		0.163	



Microstructure after stress relief 1

Surface Quality^{4,5}

MEASUREMENT	CONDITION	METRIC		U.S.	
		SANDBLASTED		SANDBLASTED	
Surface Roughness Ra Top surface ⁶ (µm µin) Vertical side surface ⁷ (µm µin)	ISO 25178	4-8		160-310	
		4-8		160-310	



Microstructure after HIP

Chemical Composition

Ti	Bal.
N	≤0.03
C	≤0.08
H	≤0.015
Fe	≤0.20
O	≤0.18
Residuals (each)	≤0.1
Residuals (total)	≤0.4

¹ Minimum value based on 95% confidence interval
Tested on typical density test shapes

² May deviate depending on specific part geometry

³ Values based on literature

⁴ Parts manufactured with standard parameters on a ProX DMP 320, Config A

⁵ Sand blasting performed with zirconia blasting medium at 2 bar

⁶ Top surface measurements along the 2 perpendicular axes of the reference square geometry

⁷ Vertical side surface measurement along the building direction



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LaserForm[®] Ti Gr5 (A)

Titanium alloy fine-tuned for use with ProX[®] DMP 320 and DMP 350 metal printers. This alloy is used in technical and medical applications because of its high strength, low density and excellent biocompatibility. The essential difference between Ti6Al4V ELI (grade 23) and Ti6Al4V (grade 5) is the allowed higher oxygen and iron content in Ti Gr5. This confers improved strength.

LaserForm Ti Gr5 (A) is formulated and fine-tuned specifically for 3D Systems ProX DMP 320 and DMP 350 metal 3D printers to deliver highest part quality and best part properties. The print parameter database that 3D Systems provides together with the material has been extensively developed, tested and optimized in 3D Systems' part production facilities that hold the unique expertise of printing 500,000 challenging production parts year over year. Based on over 1000 test samples the below listed part quality data and mechanical properties give you high planning security. And for a 24/7 production 3D Systems' thorough Supplier Quality Management System guarantees consistent, monitored material quality for reliable process results.

Material Description

This titanium alloy is commonly used for lightweight and high-strength components such as aerospace and motor sports applications. Because of its excellent biocompatibility Ti Gr5 (A) is also very well suited for medical implants, tools and devices and dental prostheses. The essential difference between Ti6Al4V ELI (grade 23) and Ti6Al4V (grade 5) is the allowed higher oxygen and iron content in Ti Gr5. This confers improved strength while slightly reducing ductility.

These benefits make LaserForm Ti Gr5 (A) the ideal material for light-weight, high-strength components as required for a broad scope of parts in aerospace, sports and marine products. Its high strength and biocompatibility make it the material of choice for medical tools and devices.

Classification

Parts built with LaserForm Ti Gr5 Alloy have a chemical composition that meets the requirements of ASTM B265, B348 (grade 5), F2924, F3302, ISO 5832-3 and Werkstoff Nr. 3.7165.

Mechanical Properties^{1,2,3}

MEASUREMENT	CONDITION	METRIC		U.S.	
		AFTER STRESS RELIEF 1	AFTER HIP	AFTER STRESS RELIEF 1	AFTER HIP
Youngs modulus (GPa ksi) ⁴	ASTM E8M	105-120	105-120	15000-17500	15000-17500
Ultimate strength (MPa ksi)	ASTM E8M				
Horizontal direction — XY		1180 ± 30	1000 ± 30	171 ± 5	145 ± 4
Vertical direction — Z		1160 ± 50	1020 ± 50	168 ± 8	148 ± 8
Yield strength Rp0.2% (MPa ksi)	ASTM E8M				
Horizontal direction — XY		1090 ± 30	910 ± 30	158 ± 5	132 ± 5
Vertical direction — Z		1080 ± 50	930 ± 30	157 ± 8	134 ± 5
Elongation at break (%)	ASTM E8M				
Horizontal direction — XY		9 ± 2	15 ± 3	9 ± 2	15 ± 3
Vertical direction — Z		9 ± 2	14 ± 3	9 ± 2	14 ± 3
Hardness, Rockwell C (HRC)	ASTM E18	40 ± 2	36 ± 2	40 ± 2	36 ± 2

Thermal Properties⁴

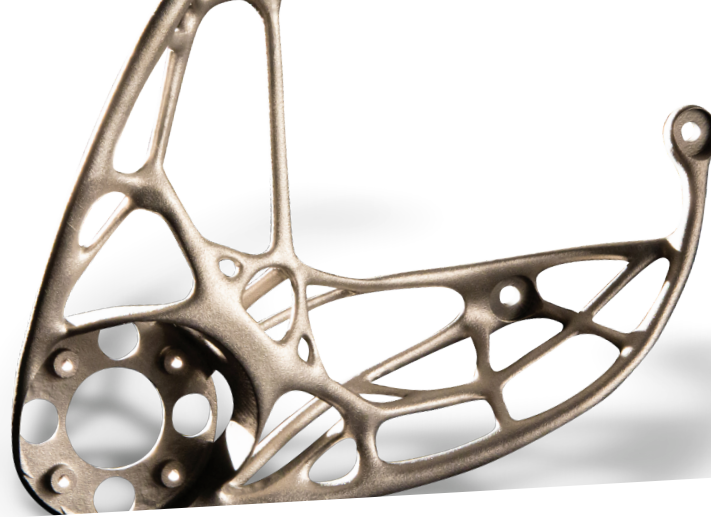
MEASUREMENT	CONDITION	METRIC	U.S.
Thermal conductivity (W/(m.K) Btu in/(h.ft.°F)	At 50 °C/ 120 °F	6.7	3.9
Coefficient of thermal expansion (µm/m·°C / µin/(in.°F)	In the range of 20 to 100 °C	8.6	4.8
Melting range (°C °F)		1692-1698	3046-3056

¹ Parts manufactured with standard parameters on a ProX DMP 320, Config A

² Values based on average and double standard deviation

³ Surface condition of test samples: Horizontal samples (XY) tested in machined surface condition only, vertical (Z) tested in as-printed and machined surface condition

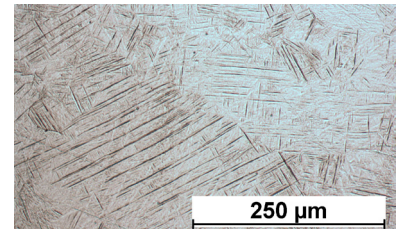
⁴ Values based on literature



LaserForm[®] Ti Gr5 (A)

Physical Properties

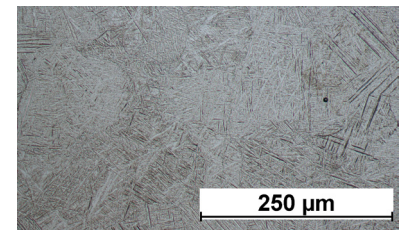
MEASUREMENT	CONDITION	METRIC		U.S.	
		AS BUILT AND AFTER STRESS RELIEF	AFTER HIP	AS BUILT AND AFTER STRESS	AFTER HIP
Density — Relative, based on pixelcount ^{1,2} (%)	Optical method	> 99.6 typical 99.8		> 99.6 typical 99.8	
Density — Absolute theoretical ³ (g/cm ³ lb/in ³)		4.42		0.159	



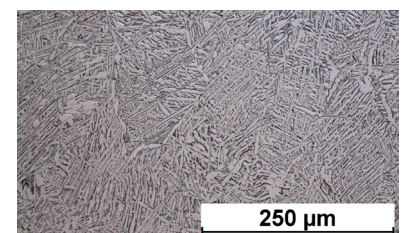
Microstructure as built

Surface Quality

MEASUREMENT	CONDITION	SANDBLASTED METRIC	SANDBLASTED U.S.
Surface Roughness R _a ^{4,5}	ISO 25178		
Layer thickness 30µm and 60µm Top surface ⁶ (µm µin) Vertical side surface ⁷ (µm µin)		typical 3-8 typical 5-7	typical 120-320 typical 200-280
Layer thickness 90µm Top surface ⁶ (µm µin) Vertical side surface ⁷ (µm µin)		typical 13-19 typical 6-12	typical 500-750 typical 240-480



Microstructure after stress relief



Microstructure after HIP

Chemical Composition

Ti	bal.
N	≤0.05
c	≤0.08
H	≤0.015
Fe	≤0.30
O	≤0.20
Al	5.50-6.75
V	3.50-4.50
Y	≤0.005
residuals each	≤0.10
residuals total	≤0.40

¹ Minimum value based on 95% confidence interval. Tested on typical density test coupons

² May deviate depending on specific part geometry

³ Values based on literature

⁴ Parts manufactured with standard parameters on a ProX DMP 320, Config A

⁵ Sand blasting performed with zirconia blasting medium at 5 bar

⁶ Top surface measurements along the 2 perpendicular axes of the reference square geometry

⁷ Vertical side surface measurement along the building direction



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LaserForm Ti Gr23 (A)

Titanium alloy fine-tuned for use with DMP Flex 100, ProX® DMP 320, DMP Flex 350, DMP Factory 350 and DMP Factory 500 metal printers. Metal powder producing technical and medical parts with a combination of high specific strength and excellent biocompatibility. LaserForm Ti Gr23 (A) is ELI (Extra Low Interstitial) grade with lower iron, carbon, and oxygen content and is known for higher purity than LaserForm Ti Gr5 (A) resulting in improved ductility and fracture toughness.

LaserForm Ti Gr23 (A) is formulated and fine-tuned specifically for 3D Systems' DMP Flex 100, ProX DMP 320, DMP Flex 350, DMP Factory 350 and DMP Factory 500 metal 3D printers to deliver highest part quality and best part properties. The print parameter database that 3D Systems provides together with the material has been extensively developed, tested and optimized in 3D Systems' part production facilities that hold the unique expertise of printing more than 1,000,000 challenging production parts year over year. Based on a multitude of test samples, the properties listed below provide high confidence to the user in terms of job-to-job and machine-to-machine repeatability. Using the LaserForm material enables the user to experience consistent and reliable part quality.

Material Description

This titanium alloy is commonly used in aerospace and medical applications because of its high strength, low density, excellent biocompatibility. The essential difference between Ti6Al4V ELI (grade 23) and Ti6Al4V (grade 5) is the reduction of oxygen content to 0.13% (maximum) in grade 23. This confers improved ductility and fracture toughness, with some reduction in strength.

These benefits make LaserForm TiGr23 (A) the most used titanium grade for medical and aerospace applications. It can be used in biomedical applications such as surgical implants, orthodontic appliances or in-joint replacements, as well as in aerospace applications such as lightweight brackets, engine rotor/stator parts or heat exchangers.

Classification

Parts built with LaserForm Ti Gr23 (A) Alloy have a chemical composition that complies with ASTM F3001, ASTM F3302, ISO 5832-3, ASTM F136 and ASTM B348 standards.

Mechanical Properties

PROX DMP 320, DMP FLEX 350, DMP FACTORY 350 - LT 30, 60, 90 ^{1,2,3,4,6}	TEST METHOD	METRIC		U.S.	
		SR ⁵	HIP	SR ⁵	HIP
Ultimate Tensile Strength (MPa ksi) Horizontal direction — XY Vertical direction — Z	ASTM E8M	1070 ± 30	980 ± 50	155 ± 4	142 ± 7
		1070 ± 30	980 ± 70	155 ± 4	142 ± 10
Yield strength Rp 0.2% (MPa ksi) Horizontal direction — XY Vertical direction — Z	ASTM E8M	970 ± 30	890 ± 50	141 ± 4	129 ± 7
		1000 ± 60	890 ± 90	145 ± 9	129 ± 13
Plastic elongation (%) Horizontal direction — XY Vertical direction — Z	ASTM E8M	13 ± 2	14 ± 2	13 ± 2	14 ± 2
		13 ± 3	14 ± 2	13 ± 3	14 ± 2
Reduction of area (%) Horizontal direction — XY Vertical direction — Z	ASTM E8M	45 ± 15	45 ± 5	45 ± 15	45 ± 5
		45 ± 15	45 ± 5	45 ± 15	45 ± 5
Fatigue (MPa ksi)	ASTM E466	Typical 640	-	Typical 92	-

DMP FACTORY 500 - LT 60 ^{2,6,7,8}	TEST METHOD	METRIC		U.S.	
		NHT	SR	NHT	SR
Ultimate Tensile Strength (MPa ksi) Horizontal direction — XY Vertical direction — Z	ASTM E8	1310 ± 20	1060 ± 15	190 ± 3	154 ± 2
		1290 ± 40	1060 ± 25	187 ± 6	154 ± 4
Yield strength Rp 0.2% (MPa ksi) Horizontal direction — XY Vertical direction — Z	ASTM E8	1150 ± 20	960 ± 15	167 ± 3	139 ± 2
		1150 +30/-55	950 ± 30	167 +4/-8	138 ± 4
Plastic elongation (%) Horizontal direction — XY Vertical direction — Z	ASTM E8	9 ± 3	17 ± 2	9 ± 3	17 ± 2
		11 ± 2	18 ± 3	11 ± 2	18 ± 3
Reduction of area (%) Horizontal direction — XY Vertical direction — Z	ASTM E8	23 ± 11	49 ± 5	23 ± 11	49 ± 5
		32 ± 4	52 ± 4	32 ± 4	52 ± 4

¹ Parts manufactured with standard parameters on a ProX DMP 320, DMP Flex and Factory 350, Config A

² Values based on average and 95% tolerance interval with 95% confidence

³ Tested according to ASTM E8M using round tensile test specimen type 4

⁴ Force-controlled axial fatigue testing (R=0.1). Endurance limit at 5 x 10⁶ cycles. Fatigue samples with machined surface. Values based on limited samples, for information only

⁵ Parts manufactured using layer thickness 30 µm and 60 µm only

⁶ NHT: Non-heat treated condition; SR: Stress-relieved condition; HIP: Hot isostatically pressed condition

⁷ Tested according to ASTM E8 using round tensile test specimen type 4

⁸ Parts manufactured with standard parameters on a DMP Factory 500, using layer thickness 60 µm (LT60)

Mechanical Properties

DMP FLEX 100 - LT30 ^{3, 6, 9, 10}	TEST METHOD	METRIC			U.S.		
		NHT	SR	HIP	NHT	SR	HIP
Ultimate strength (MPa ksi) Horizontal direction - XY Vertical direction - Z	ASTM E8M	1310 ± 150	1060 ± 60	1020 ± 60	190 ± 22	154 ± 9	148 ± 9
		1280 ± 70	1040 ± 30	1020 ± 60	186 ± 10	151 ± 4	148 ± 9
Yield strength Rp 0.2% (MPa ksi) Horizontal direction - XY Vertical direction - Z	ASTM E8M	1130 ± 140	960 ± 40	930 ± 60	164 ± 20	139 ± 6	135 ± 9
		1070 ± 70	930 ± 40	930 ± 60	155 ± 10	135 ± 6	135 ± 9
Plastic elongation (%) Horizontal direction - XY Vertical direction - Z	ASTM E8M	8 ± 2	12 ± 4	14 ± 4	8 ± 2	12 ± 4	14 ± 4
		8 ± 2	14 ± 4	14 ± 4	8 ± 2	14 ± 4	14 ± 4
Reduction of area (%) Horizontal direction - XY Vertical direction - Z	ASTM E8M	35 ± 20	50 ± 10	40 ± 10	35 ± 20	50 ± 10	40 ± 10
		35 ± 10	50 ± 10	40 ± 10	35 ± 10	50 ± 10	40 ± 10

Density

MEASUREMENT	TEST METHOD	METRIC	U.S.
Theoretical density ¹¹ (g/cm ³ lb/in ³)	Value from literature	4.42	0.16
DMP Flex 100			
Relative density (%), layer thickness 30 μm ^{9, 12, 13}	Optical method (pixel count)	≥ 99.4 Typical 99.9	≥ 99.4 Typical 99.9
ProX DMP 320, DMP Flex 350, DMP Factory 350, DMP Factory 500			
Relative density (%), layer thickness 30 μm ^{1, 12, 13}	Optical method (pixel count)	≥ 99.6 Typical 99.8	≥ 99.6 Typical 99.8
Relative density (%), layer thickness 60 μm ^{1, 8, 12, 13}	Optical method (pixel count)	≥ 99.6 Typical 99.8	≥ 99.6 Typical 99.8

Surface Roughness R_a

MEASUREMENT ^{12, 13, 15, 16}	TEST METHOD	METRIC	U.S.
DMP Flex 100^{9, 14}			
Top surface (μm μin) Vertical side surface (μm μin) Layer thickness 30 μm	NF EN ISO 4288	Typically, around 6 Typically, around 9	Typically, around 236 Typically, around 354
ProX DMP 320, DMP Flex 350, DMP Factory 350, DMP Factory 500¹⁷			
Vertical side surface (μm μin) ¹ Layer thickness 30 μm	ISO 25178	Typically, around 7	Typically, around 276
Vertical side surface (μm μin) ^{1, 8} Layer thickness 60 μm	ISO 25178	Typically, around 9	Typically, around 354

Electrical and Thermal Properties

MEASUREMENT	CONDITION	METRIC	U.S.
Electrical conductivity ¹⁸ (S/m) [x10 ⁵]	Four point contact ASTM B193 at 20°C 68°F	5.9 ± 0.1	5.9 ± 0.1
Thermal conductivity ¹¹ (W/(m.K) BTU inch/(hr.ft ² .°F))	at 20°C 68 °F	6.70	46.5
Coefficient of thermal expansion ¹¹ (μm/(m.°C) μ inch/(inch.°F))	In the range of 20 to 100 °C	8.6	4.8
Melting range ¹¹ (°C °F)		1604 - 1660	2919 - 3020

⁹ Parts manufactured with standard parameters on a DMP Flex 100, using layer thickness 30 μm (LT30)

¹⁰ Values based on average and double standard deviation

¹¹ Values based on literature

¹² May deviate depending on specific part geometry

¹³ Minimum value based on 95% tolerance interval with 95% confidence. Tested on typical density test shapes

¹⁴ Results obtained in as-printed condition

¹⁵ Surface measurements performed on the top surface plane, which is perpendicular to the building direction

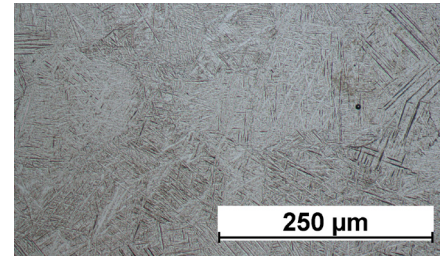
¹⁶ Vertical side surface measurement along the building direction

¹⁷ Surface treatment performed with zirconia blasting medium at 5 bar

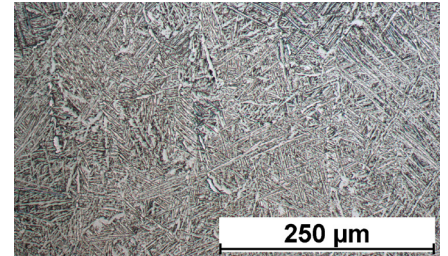
¹⁸ Results are based on limited sample size printed on ProX DMP 320, not statistically representative

Chemical Composition

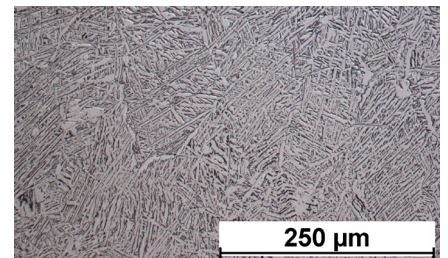
ELEMENT	% OF WEIGHT
Ti	Bal.
N	≤ 0.03
C	≤ 0.08
H	≤ 0.012
Fe	≤ 0.25
O	≤ 0.13
Al	5.50 - 6.50
V	3.50 - 4.50
Y	≤ 0.005
Other (each)	≤ 0.10
Other (total)	≤ 0.40



Microstructure without heat treatment (NHT)



Microstructure after stress relief (SR)



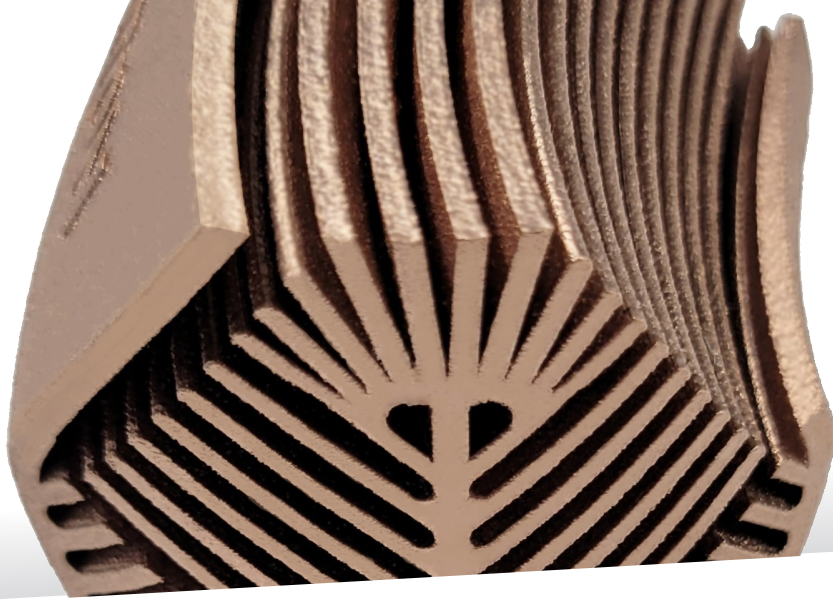
Microstructure after hot isostatic pressing (HIP)



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Certified CuCr2.4 (A)

Certified CuCr2.4 (A) is copper alloy offering improved strength, ductility, and as-built surface finish compared to commercially pure copper while retaining high thermal and electrical conductivity. 3D Systems offers application development and part production using the integrated additive manufacturing (AM) workflow software, 3DXpert®, and the DMP Flex and Factory 350 metal 3D printer. 3D Systems' CuCr2.4 parameters were developed, tested, and optimized on real applications in our AS9100/ISO9001 part production facilities, which have the unique distinction of printing more than 1,000,000 challenging metal production parts in various materials, year over year.

The final part properties can be tailored by different heat treatments, balancing mechanical properties and conductivity based on application needs. For companies looking to develop new applications and processes with CuCr2.4, our AIG experts can support and accelerate application development as well as tune the heat treatment to the application needs.

Material Description

CuCr2.4 is a precipitation hardenable copper alloy with increased strength over pure copper while retaining very high electrical and thermal conductivity. At the same time, CuCr2.4 also exhibits good corrosion resistance. It is also easy to process thanks to the high percentage of chromium.

These properties render the material ideal for heat management or electrical applications, especially when there is a combined structural function. CuCr2.4 is ideal for applications such as heat exchangers, cooling components and heat sinks to induction coils and electrical components.



Part height: 61 mm
Print time: 7h 49m 21s, batch size 1

Mechanical Properties

DMP FLEX 350 , DMP FACTORY 350 – LT60	TEST METHOD	HT - 500 °C		HT - 1000 °C	
		METRIC	U.S.	METRIC	U.S.
Ultimate tensile strength (MPa ksi) Horizontal direction – XY	ASTM E8	799	115	270	39
Yield strength Rp0.2% (MPa ksi) Horizontal direction – XY		729	105	136	20
Plastic elongation (%) Horizontal direction – XY		13		46	
Electrical conductivity (% IACS) ² Horizontal direction – XY	ASTM B193	~61		~93	
Relative density (%) – LT60	Optical method (pixel count)	99.9			

¹ No surface treatment applied, measured in as printed condition.

² International Annealed Copper Standard.

Layer thickness 60 μm – Theoretical productivity 19 cc/h

Heat Exchanger

A variable double gyroid creates two separate fluid domains while baffles prevent blending. External ribs provide additional strength. CuCr2.4 is ideal at enabling a thermal conductivity up to 93% IACS after heat treatment.

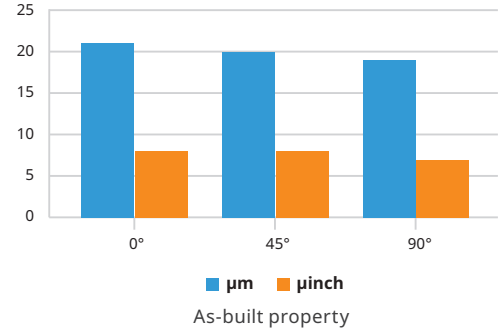


As-built surface quality with no post-finishing

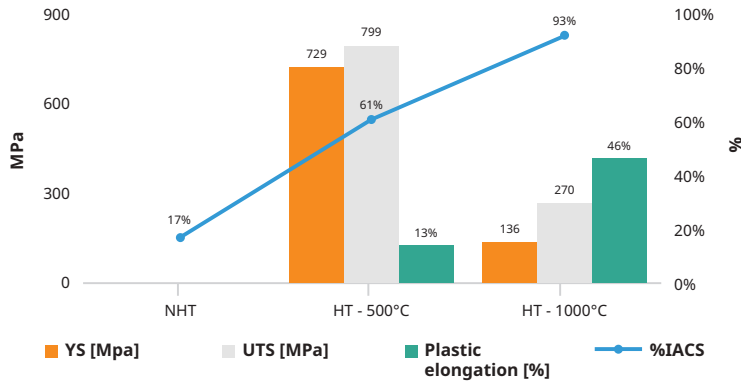
Typical Applications Include:

- Heat Exchangers
- Heat Sinks
- Cooling Components
- Connectors
- Induction Coils
- Electrodes
- Circuit breaker parts

SURFACE ROUGHNESS RA¹ - LT60 ISO 25178

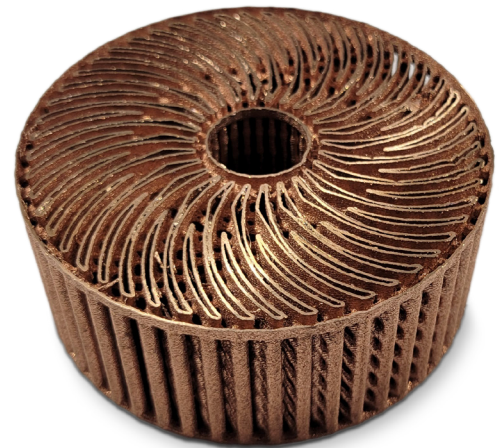


MECHANICAL PROPERTIES & CONDUCTIVITY



Heat Exchanger

The surface-area-to-volume ratio maximizes drive thermal transfer efficiency, combined with CoCr2.4 to utilize high thermal conductivity up to 93%IACS.



Part height: 34.5 mm
 Print time: 4.5h, batch size 1
 Layer thickness: 60um
 As-built surface quality with no post-finishing

To confirm the suitability of this material for your specific application, please contact the 3D Systems Application Innovation Group (AIG): <https://www.3dsystems.com/consulting/application-innovation-group>

CuCr2.4 powder with product reference MA-CCR25H can be purchased directly from Mitsui-Kinzoku: kinoufun@mitsui-kinzoku.com



Certified CuNi30 (A)

CuNi30 is a low-conductive copper alloy offering excellent corrosion resistance in salt water, good strength and ductility, and exhibiting stable material properties in cryogenic environments. Powder chemistry is in accordance with UNS 96400.

3D Systems offers a print parameter database license for Certified CuNi30 (A) on the DMP Flex and Factory 350 metal 3D printers that can be applied using the integrated additive manufacturing workflow software, 3DXpert. The print parameter database license available for CuNi30 has been developed in a close collaboration between 3D Systems and Huntington Ingalls Industries' Newport News Shipbuilding division.

For companies looking to develop new applications and processes with CuNi30, please contact the 3D Systems Application Innovation Group (AIG).

Material Description

This copper alloy with 30 wt.% nickel (UNS 96400) exhibits excellent corrosion resistance especially in salt water, steam, and acidic environments. CuNi30 exhibits stable mechanical, physical, and thermal properties ranging from high temperatures (400 °C) to cryogenic temperatures (-270 °C).

CuNi30 is a single-phase material, in which the high solubility of nickel in copper results in outstanding corrosion resistance with low conductivity properties. The high nickel content improves the printability of the copper alloy. The additions of Fe and Nb ensures an excellent combination of strength and ductility.

Typical Mechanical Properties

DMP FLEX 350, DMP FACTORY 350 – LT 30 ^{1,2,3}	TEST METHOD	METRIC	US	UNS 96400
Ultimate tensile strength (MPa ksi ksi)	ASTM E8	515	75	60
Yield strength Rp0.2% (MPa ksi ksi)		440	64	32
Plastic elongation (%)		28	28	20

Typical Printed Part Properties

DMP FLEX 350, DMP FACTORY 350 – LT 30 ³	TEST METHOD	METRIC	US
Relative density (%)	Optical method (pixel count)	99.8	99.8
Surface Roughness - Vertical side surface (µm µin)	Contact profilometer	10, typical	393, typical
Hardness (Rockwell B)	ASTM E18	82.3	

¹ No Heat Treatment.

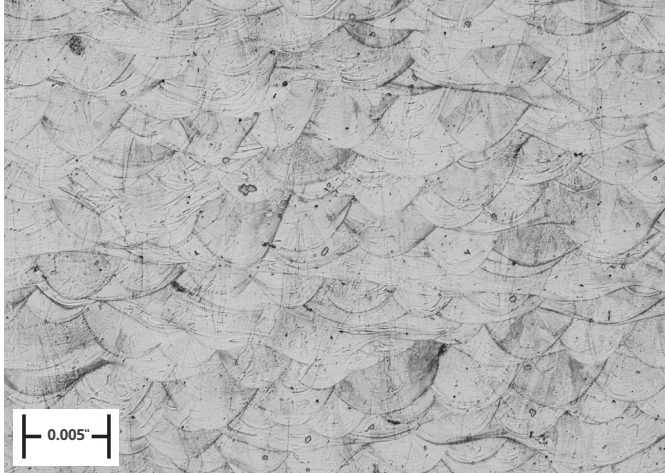
² Machined and tested according to ASTM E8 using round tensile test specimen type 4. Typical values, averaged over 3 vertical and 3 horizontal tensile coupons.

³ Parts manufactured with standard parameters and protocols on DMP ProX 320, Config B using layer thickness 30 µm. May deviate depending on specific part geometry.

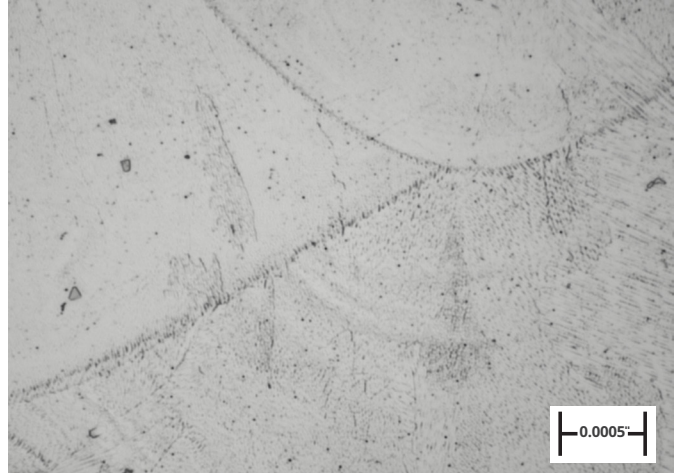
The standard part parameters are compatible with DMP Flex 350, DMP Factory 350 and DMP ProX 320 machines. The standard parameters are targeting maritime applications.

As-Printed Microstructure:

Homogeneous, fine-grained microstructure yielding outstanding corrosion resistance and excellent strength exceeding UNS 96400 requirements.



100x magnification



1000x magnification

Application Focus:

MARITIME, SHIPBUILDING & REPAIR — PIPE FITTINGS & FLANGES

CuNi30 is a well-known reference material for marine applications, thanks to its outstanding corrosion resistance in salt water and anti-algae properties. Direct Metal Printing (DMP) drastically reduces the lead time for small-volume or repair components such as pipe reducers, pipe couplings, and pipe elbows.

OFFSHORE OIL & GAS — PUMPS & VALVES

CuNi30 offers excellent corrosion resistance in salt water, petroleum and corrosive gases.

CRYOGENIC, CHEMICAL & NUCLEAR EQUIPMENT — COOLING TUBES & GUIDES

Exploit the stress-corrosion resistance and stable mechanical, physical, and thermal properties of the CuNi30 alloy, ranging from high temperatures (400 °C) to cryogenic temperatures (-270 °C).

SIMPLIFIED ASSEMBLY IN 3DXPERT

Benefit from the 3DXpert automated nesting features to simplify assembly during build file preparation of cylindrical and ring-shaped components, such as pipe fittings.



To confirm the suitability of this material for your specific application, please contact the 3D Systems Application Innovation Group (AIG): <https://www.3dsystems.com/consulting/application-innovation-group>

3D Systems thanks Huntington Ingalls Industries' Newport News Shipbuilding Division for this fruitful, application-driven collaboration