LaserForm® AlSi7Mg0.6 (A)

AlSi7Mg0.6 (A) fine-tuned for use with DMP Flex / Factory 350 and DMP Flex 350 Triple metal printers to produce industrial parts with a combination of good mechanical properties and improved thermal conductivity.

AlSi7Mg0.6 (A) is formulated and fine-tuned 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

AlSi7Mg0.6 (A) 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 strenght 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.

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[1,2,3,4]

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

Thermal Properties[4]

MEASUREMENT	CONDITION	METRIC			U.S.		
		NHT	SR	DA	NHT	SR	DA
Thermal conductivity[5,6] (W/(m.K) | Btu.in/(h.ft².°F))	at 20°C / 68°F	120-140	180-190	150-170	70-80	105-110	85-100
CTE - Coefficient of thermal expansion[7] (μm/(m.°C) | μ inch/(inch.°F))	in the range of 20 to 100 °C	typical 21.4			typical 11.9		
Melting range[7] (°C | °F)		typical 557 - 613			typical 1035-1135		

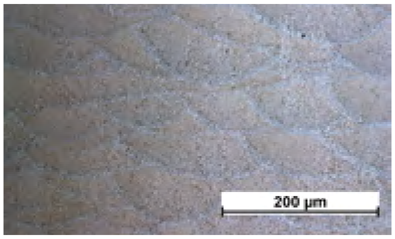
1 Parts manufactured with standard parameters on a ProX DMP 320, Config B ; values also indicative for DMP Flex / Factory 350 and DMP Flex 350 Triple
2 Values based on average and double standard deviation
3 Surface condition of test samples: Horizontal samples (XY) tested in machined surface condition only, vertical (Z) tested in as-printed and machined surface condition
4 NHT is non-heat treated sample condition; SR refers to a stress relief; DA refers to a direct ageing
5 Thermal conductivity values are calculated via the Wiedemann-Franz law using the measured electrical resistivity values
6 Results are based on limited sample size, not statistically representative
7 Values based on literature

Electrical Properties[4,6,8]

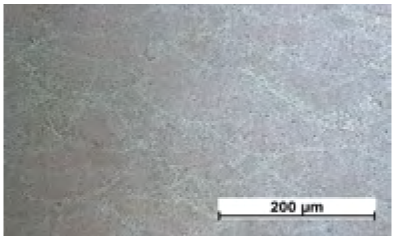
MEASUREMENT	CONDITION	METRIC			U.S.		
		NHT	SR	DA	NHT	SR	DA
Electrical conductivity (10^6 S/m)	ASTM B193 at 20°C / 68°F	17-19	25-27	22-24	17-19	25-27	22-24

Physical Properties

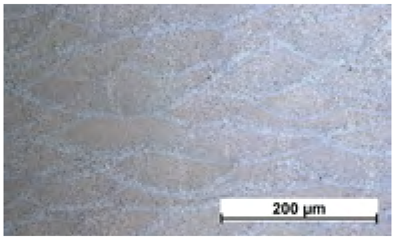
MEASUREMENT	TEST METHOD	METRIC	U.S.
Density			
Relative, based on pixel count[1,9,10] (%)	Optical method	> 99.2 tpical 99.8	> 99.2 tpical 99.8
Absolute theoretical[7] (g/cm^3 | lb/in^3)		2.67	0.096



Microstructure NHT



Microstructure after SR



Microstructure after DA

Surface Quality[1,11]

MEASUREMENT	TEST METHOD	METRIC	U.S.
Surface Roughness R_a	ISO 25178		
Layer Thickness 30µm (µm | µin) Vertical side surface[12]		typical 5-7	typical 200-280
Layer Thickness 60µm (µm | µin) Vertical side surface[12]		typical 10-20	typical 400-800

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	6.5-7.5
Mg	0.50-0.70
Fe	≤0.15
Cu	≤0.03
Mn	≤0.10
Zn	≤0.07
Ti	≤0.18
Other (each)	≤ 0.03
Other (total)	≤ 0.10

8 Electrical resistivity measurements are based on the four point contact method according to ASTM B193
9 Minimum value based on 95% confidence interval. Tested on typical density test coupons
10 May deviate depending on specific part geometry
11 Sand blasting performed with zirconia blasting medium at 2 bar
12 Vertical side surface measurement along the building direction

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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LaserForm AlSi10Mg (A)

AlSi10Mg (A) is fine-tuned for use with the following listed printers producing industrial parts with a combination of good mechanical properties and good thermal conductivity*:

- DMP Flex/Factory 350
- DMP Flex/Factory 350 Dual
- DMP Flex 350 Triple
- DMP Factory 500

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.

LaserForm AlSi10Mg (A) is formulated and fine-tuned 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.

Mechanical Properties

DMP FLEX 350, DMP FACTORY 350, DMP FLEX 350 DUAL, DMP FACTORY 350 DUAL – LT 30[1, 2, 3, 4]	TEST METHOD	METRIC			U.S.		
		NHT	SR1	SR2	NHT	SR1	SR2
Ultimate tensile strength (MPa | ksi)	ASTM E8						
Horizontal direction - XY		460 ± 20	290 ± 15	400 ± 20	67 ± 3	42 ± 3	58 ± 3
Vertical direction - Z		465 ± 30	300 ± 15	425 ± 20	67 ± 5	43 ± 3	61 ± 3
Yield strength Rp0.2% (MPa | ksi)							
Horizontal direction - XY		275 ± 20	185 ± 15	270 ± 20	39 ± 3	27 ± 3	39 ± 3
Vertical direction - Z		250 ± 25	185 ± 15	250 ± 10	36 ± 4	27 ± 3	36 ± 2
Plastic elongation (%)							
Horizontal direction - XY		12.5 ± 5.1	16.7 ± 3.3	10.1 ± 3.0	12.5 ± 5.1	16.7 ± 3.3	10.1 ± 3.0
Vertical direction - Z		7.9 ± 4.1	15.7 ± 2.8	5.7 +3.4	7.9 ± 4.1	15.7 ± 2.8	5.7 ± 3.4

DMP FLEX 350, DMP FACTORY 350, DMP FLEX 350 DUAL, DMP FACTORY 350 DUAL – LT 60[2, 3, 4, 5]	TEST METHOD	METRIC			U.S.		
		NHT	SR1	SR2	NHT	SR1	SR2
Ultimate tensile strength (MPa | ksi)	ASTM E8						
Horizontal direction - XY		435 ± 30	285 ± 15	390 ± 25	63 ± 5	41 ± 3	57 ± 4
Vertical direction - Z		425 ± 55	290 ± 15	400 ± 40	62 ± 8	42 ± 3	58 ± 6
Yield strength Rp0.2% (MPa | ksi)							
Horizontal direction - XY		250 ±25	170 ± 15	260 ± 30	36 ± 4	25 ± 3	37 ± 5
Vertical direction - Z		225 ± 20	160 ± 20	235 ± 10	33 ± 3	23 ± 3	34 ± 2
Plastic elongation (%)							
Horizontal direction - XY		9.5 ± 5.2	13.9 ± 3.0	8.4 ± 3.1	9.5 ± 5.2	13.9 ± 3.0	8.4 ± 3.1
Vertical direction - Z		7.2 ± 4.9	12.9 ± 4.8	5.3 ± 2.8	7.2 ± 4.9	12.9 ± 4.8	5.3 ± 2.8

DMP FLEX 350 TRIPLE - LT 60[2, 4, 6, 7]	TEST METHOD	METRIC			U.S.		
		NHT	SR1	SR2	NHT	SR1	SR2
Ultimate tensile strength (MPa | ksi)	ASTM E8						
Horizontal direction - XY		435 ± 5	285 ± 5	NA	63 ± 1	41 ± 1	NA
Vertical direction - Z		435 ± 25	295 ± 5		63 ± 4	43 ± 1	
Yield strength Rp0.2% (MPa | ksi)							
Horizontal direction - XY		245 ± 5	175 ± 5	NA	35 ± 1	25 ± 1	NA
Vertical direction - Z		225 ± 5	175 ± 5		33 ± 1	25 ± 1	
Plastic elongation (%)							
Horizontal direction - XY		12.1 ± 2.4	18.7 ± 2.6	NA	12.1 ± 2.4	18.7 ± 2.6	NA
Vertical direction - Z		8.7 ± 3.8	11.9 ± 3.0		8.7 ± 3.8	11.9 ± 3.0	

High productive parameter set using a layer thickness of 90 µm (LT90) is also available on DMP 350 depending on requirements. Typical application fields for LT90 are Electrical motor casing, pump casing, heat exchangers and automotive prototyping.

* Also applicable for ProX® DMP 320, former 3D Systems printer

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

[2] 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

[3] Values based on average and 95% tolerance interval with 95% confidence

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

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

[6] Parts manufactured with standard parameters on a DMP Flex 350 Triple, using layer thickness 60 µm (LT60)

[7] Values based on average and standard deviation, 5 samples tested for each condition

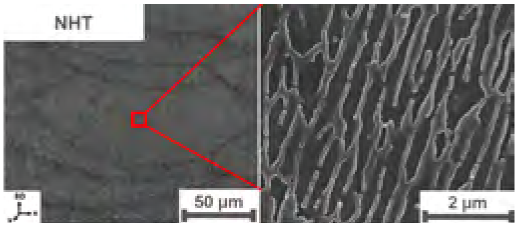
Mechanical Properties

DMP FACTORY 500 – LT 60[2, 3, 4, 8]	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 ± 20 300 ± 20	405 ± 20 420 +20/-60	NA	42 ± 3 44 ± 3	59 ± 3 61 +3/-9
Yield strength Rp0.2% (MPa | ksi) Horizontal direction - XY Vertical direction - Z		NA	170 ± 20 180 ± 20	270 +15/-30 250 ± 20	NA	25 ± 3 26 ± 3	39 +2/-4 36 ± 3
Plastic elongation (%) Horizontal direction - XY Vertical direction - Z		NA	17.5 ± 4.9 13.3 ± 5.7	9.4 ± 5.5 5.8 ± 3.4	NA	17.5 ± 4.9 13.3 ± 5.7	9.4 ± 5.5 5.8 ± 3.4

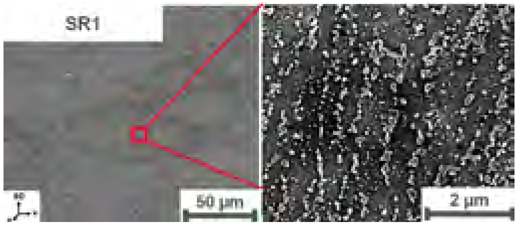
Printed Part Properties[9]

DENSITY	TEST METHOD	METRIC	U.S.
Theoretical density (g/cm^3 | lb/in^3)	Value from literature	2.68	0.097
Relative density (%) Layer thickness 30 µm [1, 10] and 60 µm [6, 10]	Optical method (pixel count)	≥ 99.7 Typical 99.9	≥ 99.7 Typical 99.9
Relative density (%) Layer thickness 60 µm [5, 8, 10]	Optical method (pixel count)	≥ 99.5 Typical 99.8	≥ 99.5 Typical 99.8
Relative density (%) Layer thickness 90 µm [10, 11]	Optical method (pixel count)	≥ 98.6 Typical 99.3	≥ 98.6 Typical 99.3

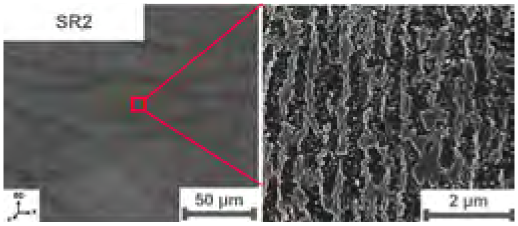
SURFACE ROUGHNESS R_a[12, 13]	TEST METHOD	METRIC	U.S.
Vertical side surface (µm | µin) Layer thickness 30 µm	ISO 25178	Typically, around 8	Typically, around 315
Vertical side surface (µm | µin) Layer thickness 60 µm	ISO 25178	Typically, around 15	Typically, around 591
Vertical side surface (µm | µin) Layer thickness 90 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[14,15] (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[16] (µm/(m.°C) | µ inch/(inch . °F))	in the range of 20 to 100 °C	typical 20.9			typical 11.6		
Melting range[16] (°C | °F)		typical 557 - 596			typical 1035 - 1105		

Electrical Properties[15,17]

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

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

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

[8] Parts manufactured with standard parameters and protocols on a DMP Factory 500, using layer thickness 60 µm (LT60)
[9] May deviate depending on specific part geometry
[10] Minimum values based on 95% tolerance interval with 95% confidence. Tested on specific 3DS density test coupons
[11] Parts manufactured with standard parameters and protocols on a DMP Flex 350 Dual, Config B, using layer thickness 90 µm (LT90)
[12] Surface treatment performed with zirconia blasting medium at 2 bar
[13] Vertical side surface measurement along the building direction
[14] Thermal conductivity values are calculated by the Wiedemann-Franz law using the respective electrical resistivity values
[15] Results are based on limited sample size, not statistically representative. Samples printed on a ProX DMP 320, Config B
[16] Values based on literature
[17] Electrical resistivity measurements are based on four point contact method according to ASTM B193

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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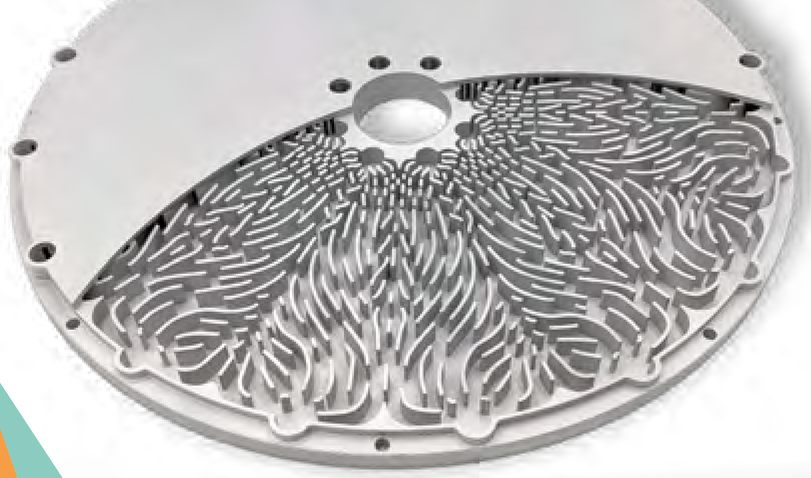


A6061-RAM2 bracket image courtesy of NASA Goddard Space Flight Center

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®, the DMP Flex 350 and DMP Flex 350 Triple 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 meltpool 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

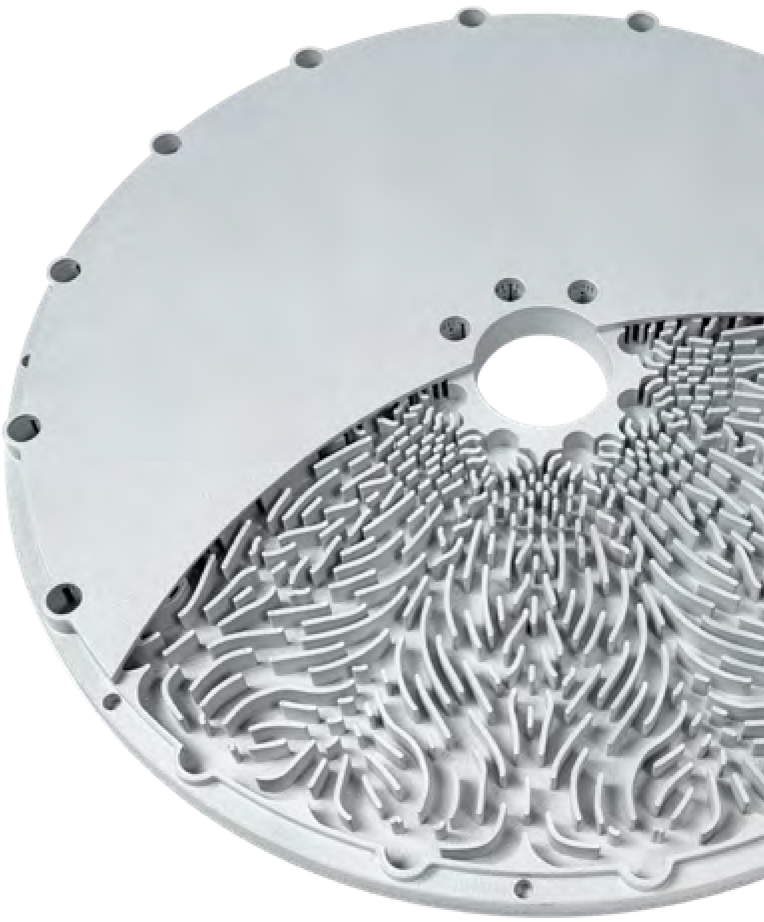
DENSITY[4]	TEST METHOD	METRIC	U.S.
Relative density (%)	Archimedes + Optical Evaluation	> 99.6	

SURFACE ROUGHNESS[5]	TEST METHOD	METRIC	U.S.
Vertical side surface (μm | μin) Layer thickness 30 μm	ISO 25178	8	315

[4] 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.
[5] 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

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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

ELEMENTUM 3D

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

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Certified Scalmalloy® (A)

Thoroughly developed print parameters and certification process support for APWORKS Scalmalloy material on 3D Systems DMP Flex and Factory 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 and Factory 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 and Factory 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, DMP FACTORY 350 - LT 30[1,3,4,5]	TEST METHOD	METRIC	U.S.
		SR	SR
Ultimate tensile strength (MPa | ksi)	ASTM E8		
Horizontal direction - XY		520 ± 10	75 ± 2
Vertical direction - Z		520 ± 15	75 ± 2
Yield strength Rp0.2% (MPa | ksi)			
Horizontal direction - XY		490 ± 10	71 ± 2
Vertical direction - Z		490 ± 15	71 ± 2
Plastic elongation (%)			
Horizontal direction - XY		15.8 ± 2.7	15.8 ± 2.7
Vertical direction - Z		15.8 ± 2.6	15.8 ± 2.6

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

[1] Parts manufactured with standard parameters and protocols on a DMP Flex and Factory 350, Config B, using layer thickness 30 µm (LT30)
[2] Parts manufactured with standard parameters and protocols on a DMP Flex and Factory 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 Properties[6]

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 Properties[6]

DENSITY	TEST METHOD	METRIC	U.S.
Theoretical density[8] (g/cm³ | lb/in³)	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 with reference SCALMA40B5 can be purchased directly from Toyal (https://toyal-europe.com).

APWORKS Toyal

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[6] Parts manufactured with standard parameters and protocols on DMP Flex and Factory 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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PN 10123B 02-22

Aheadd® CP1

High print quality at high productivity rates for Constellium's Aheadd® CP1 on 3D Systems DMP Flex 350 Triple printer. Aheadd CP1 is an Al-Fe-Zr alloy offering improved strength, thermal stability, and good corrosion resistance.

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' Aheadd CP1 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 Aheadd CP1, please contact the 3D Systems Application Innovation Group (AIG).

Material description

Aheadd CP1 by Constellium is specifically designed for the L-PBF process resulting in a superior DMP process stability enabling higher productivity, thin wall capability and excellent surface quality.

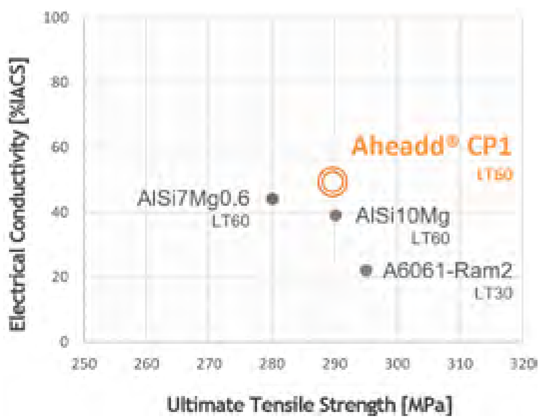
Both the Fe as well the Zr contribute to the higher strength through two mechanisms. The refining effect of Zr during the solidification as well as the formation of Fe-Al intermetallic particles will strengthen the material. The low levels of alloying elements ensures a good thermal conductivity which can be further increased by applying a heat treatment. Lastly, the absence of silicon in contrast to the traditional casting alloys such as AlSi10Mg in laser powder bed fusion (PBF-LB) allows for various surface finishing options such chemical polishing, Decorative anodizing (type II) or Hard anodizing (type III).

Chemical Composition

ELEMENT	% OF WEIGHT
Al	Balance
Fe	0.8 - 1.4
Zr	0.9 - 1.4

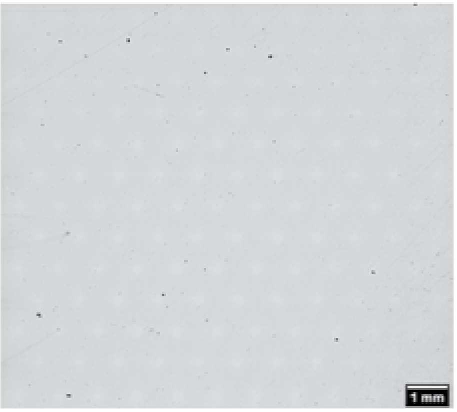
Typical Properties[1, 2, 3]

DMP FLEX 350 TRIPLE	NHT	SR
Ultimate tensile strength (MPa)	190	330
Yield strength Rp0.2% (MPa)	130	290
Plastic elongation (%)	30	20
Electrical conductivity (MS/m)	18	28



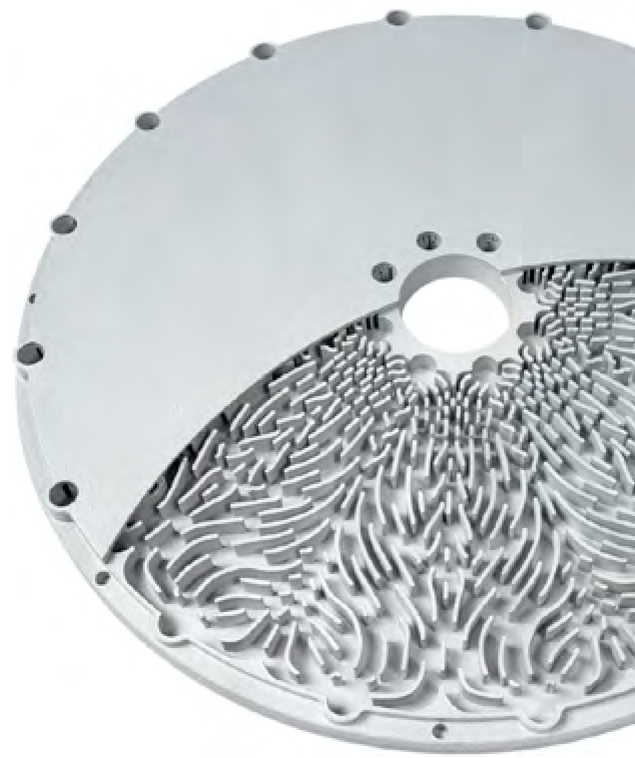
[1] Samples tested in non-heat treated (NHT) and stress relief (SR) condition. Stress relief treatment was performed for 4h at 400°C under air and then air cooling
[2] Mechanical properties tested using machined horizontally and vertically oriented ASTM E8 type 4 specimens printed with layer thickness 60 µm (LT60)
[3] Values based on a limited sample population (<10)
[4] Electrical Conductivity measured according to ASTM B193. IACS = International Annealed Copper Standard. Values based on a limited sample population (<10)

Layer thickness: 60µm
Typical relative density[5]: 99.9%



Application Focus: Semiconductor Wafer Table

The high-conductivity and corrosion resistance properties of Aheadd® CP1 are well-aligned to maximize heat transferefficiency and improve semiconductor capital equipmentthroughput and accuracy. Optimized cooling channelsand surface patterns dramatically improve surfacetemperatures and thermal gradients while reducingtime constants. At the same time, assembly consolidationreduces part count which increases reliability.



COMPLEX CHANNEL DESIGN
Excellent as-built surface finish enables high quality internal channels not accessible to finish machining.

THINS 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.

[5] Relative density values shown are typical values from density test coupons and may deviate depending on specific part geometry

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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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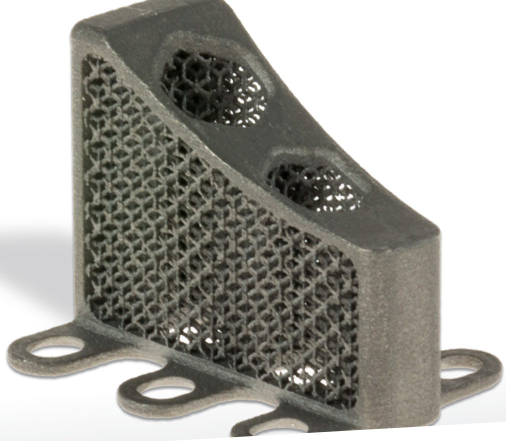


LaserForm® Ti Gr1 (A)

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.

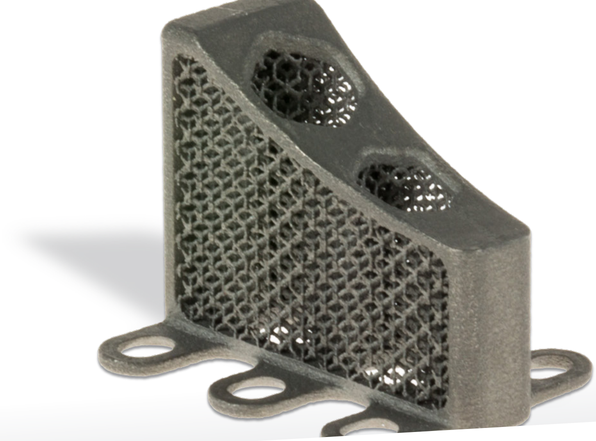
Mechanical Properties [1,2,3]

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

Thermal Properties[4]

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

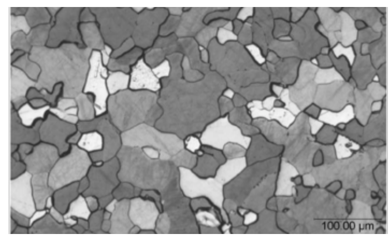
[1] Parts manufactured with standard parameters on a ProX DMP 320, Config A
[2] Values based on average and double standard deviation
[3] Surface condition of test samples: Horizontal samples (XY) tested in machined surface condition only, vertical (Z) tested in as-printed and machined surface condition
[4] Values based on literature



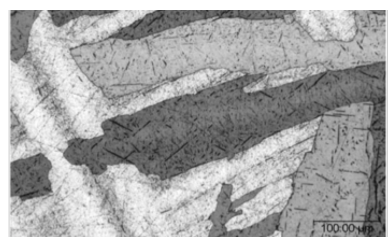
LaserForm® Ti Gr1 (A)

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/cm³ | lb/in³)		4.51		0.163	



Microstructure after stress relief 1



Microstructure after HIP

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 4-8	 160-310 160-310

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 Vertical direction — Z		1180 ± 30 1160 ± 50	1000 ± 30 1020 ± 50	171 ± 5 168 ± 8	145 ± 4 148 ± 8
Yield strength Rp0.2% (MPa | ksi)	ASTM E8M				
Horizontal direction — XY Vertical direction — Z		1090 ± 30 1080 ± 50	910 ± 30 930 ± 30	158 ± 5 157 ± 8	132 ± 5 134 ± 5
Elongation at break (%)	ASTM E8M				
Horizontal direction — XY Vertical direction — Z		9 ± 2 9 ± 2	15 ± 3 14 ± 3	9 ± 2 9 ± 2	15 ± 3 14 ± 3
Hardness, Rockwell C (HRC)	ASTM E18	40 ± 2	36 ± 2	40 ± 2	36 ± 2

Thermal Properties[4]

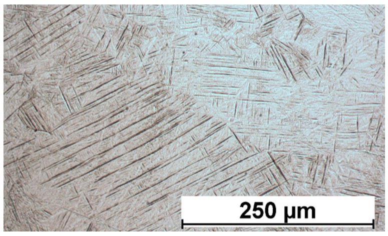
MEASUREMENT	CONDITION	METRIC	U.S.
Thermal conductivity (W/(m.K) | Btu in/(h.ft.°F)	At 50 °C/ 120 °F	6.7	3.9
Coefficient of thermal expansion (µm/m-°C / µin/(in.°F)	In the range of 20 to 100 °C	8.6	4.8
Melting range (°C | °F)		1692-1698	3046-3056

[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

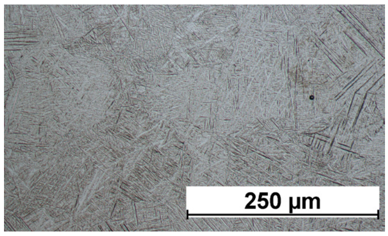
LaserForm® Ti Gr5 (A)

Physical Properties

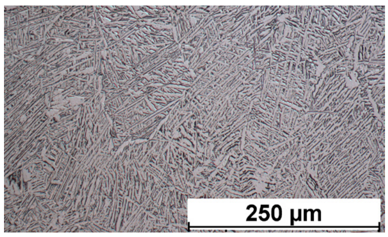
MEASUREMENT	CONDITION	METRIC		U.S.	
		AS BUILT AND AFTER STRESS RELIEF	AFTER HIP	AS BUILT AND AFTER STRESS	AFTER HIP
Density — Relative, based on pixelcount[1,2] (%)	Optical method	> 99.6 typical 99.8		> 99.6 typical 99.8	
Density — Absolute theoretical[3] (g/cm^3 | lb/in^3)		4.42		0.159	



Microstructure as built



Microstructure after stress relief



Microstructure after HIP

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

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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PN 10107C

07-20

LaserForm Ti Gr23 (A)

Titanium alloy fine-tuned for use with 3D Systems' DMP Flex 100, DMP Flex 200, DMP Flex 350, DMP Factory 350, DMP Flex 350 Dual, DMP Factory 500 and DMP Factory 350 Dual 3D metal printers. Produces 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 to deliver the 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, which have 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 LaserForm materials 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 and 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 medical and aerospace titanium grade. It can be used in biomedical applications such as surgical implants, orthodontic appliances and in-joint replacements due to its biocompatibility.

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

DMP FLEX 350, DMP FACTORY 350 - LT 30, 60, 90[1, 4, 5, 6, 7]	TEST METHOD	METRIC		U.S.	
		SR[3]	HIP[2]	SR[3]	HIP[2]
Ultimate tensile strength (MPa | ksi) Horizontal direction — XY Vertical direction — Z	ASTM E8M	 1060 ± 15 1060 ± 15	 990 ± 25 990 ± 30	 154 ± 2 154 ± 2	 144 ± 4 144 ± 4
Yield strength Rp 0.2% (MPa | ksi) Horizontal direction — XY Vertical direction — Z	ASTM E8M	 970 ± 15 960 ± 20	 890 ± 30 900 ± 50	 141 ± 2 139 ± 3	 129 ± 4 130 ± 7
Plastic elongation (%) Horizontal direction — XY Vertical direction — Z	ASTM E8M	 15 ± 3 15 ± 2	 17 ± 3 17 ± 4	 15 ± 3 15 ± 2	 17 ± 3 17 ± 4
Reduction of area (%) Horizontal direction — XY Vertical direction — Z	ASTM E8M	 40 ± 8 44 ± 7	 46 ± 9 48 ± 6	 40 ± 8 44 ± 7	 46 ± 9 48 ± 6
Fatigue (MPa | ksi)	ASTM E466	Typical 640	NA	Typical 92	-

DMP FLEX 350 DUAL, DMP FACTORY 350 DUAL - LT 30, 60, 90[5, 7, 8]	TEST METHOD	METRIC		U.S.	
		SR[2]	HIP[3]	SR[2]	HIP[3]
Ultimate tensile strength (MPa | ksi) Horizontal direction — XY Vertical direction — Z	ASTM E8	 1045 ± 15 1040 ± 10	 955 ± 20 960 ± 20	 152 ± 2 152 ± 2	 138± 3 139 ± 3
Yield strength Rp 0.2% (MPa | ksi) Horizontal direction — XY Vertical direction — Z	ASTM E8	 940 ± 20 950 ± 40	 845 ± 20 835 ± 20	 135 ± 3 137 ± 4	 123 ± 3 121 ± 3
Plastic elongation (%) Horizontal direction — XY Vertical direction — Z	ASTM E8	 19 ± 4 19 ± 3	 17 ± 4 19 ± 3	 19 ± 4 18 ± 3	 17 ± 4 19 ± 3
Reduction of area (%) Horizontal direction — XY Vertical direction — Z	ASTM E8	 50 ± 10 50 ± 10	 45 ± 5 45 ± 5	 50 ± 10 50 ± 10	 45 ± 5 45 ± 5

[1] Parts manufactured with standard parameters on a DMP Flex and Factory 350, Config A
[2] Values based on average and 95% tolerance interval with 95% confidence
[3] Values based on limited dataset
[4] Tested according to ASTM E8M using round tensile test specimen type 4
[5] Tested according to ASTM E8 using round tensile test specimen type 4
[6] Force- controlled axial fatigue testing (R=0.1). Endurance limit at 5 x10^6 cycles. Fatigue samples with machined surface. Values based on limited samples, for information only
[7] NHT: Non-heat treated condition; SR: Stress-relieved condition; HIP: Hot isostatically pressed condition
[8] Parts manufactured with standard parameters on a DMP Flex and Factory 350 Dual, Config A, using layer thickness 30, 60 and 90 µm
[9] Parts manufactured with standard parameters on a DMP Factory 500, using layer thickness 60 µm (LT60)

Mechanical properties

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

DMP FLEX 100 - LT30[4, 7, 10, 11]	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 1280 ± 70	1060 ± 60 1040 ± 30	1020 ± 60 1020 ± 60	190 ± 22 186 ± 10	154 ± 9 151 ± 4	148 ± 9 148 ± 9
Yield strength Rp 0.2% (MPa | ksi) Horizontal direction - XY Vertical direction - Z	ASTM E8M	1130 ± 140 1070 ± 70	960 ± 40 930 ± 40	930 ± 60 930 ± 60	164 ± 20 155 ± 10	139 ± 6 135 ± 6	135 ± 9 135 ± 9
Plastic elongation (%) Horizontal direction - XY Vertical direction - Z	ASTM E8M	8 ± 2 8 ± 2	12 ± 4 14 ± 4	14 ± 4 14 ± 4	8 ± 2 8 ± 2	12 ± 4 14 ± 4	14 ± 4 14 ± 4
Reduction of area (%) Horizontal direction - XY Vertical direction - Z	ASTM E8M	35 ± 20 35 ± 10	50 ± 10 50 ± 10	40 ± 10 40 ± 10	35 ± 20 35 ± 10	50 ± 10 50 ± 10	40 ± 10 40 ± 10

DMP FLEX 200 - LT30[2, 5, 7, 16]	TEST METHOD	METRIC	U.S.
		SR	SR
Ultimate strength (MPa | ksi) Horizontal direction - XY Vertical direction - Z	ASTM E8	1120 ± 40 1130 ± 55	162 ± 6 164 ± 8
Yield strength Rp 0.2% (MPa | ksi) Horizontal direction - XY Vertical direction - Z	ASTM E8	1025 ± 40 1040 ± 75	149 ± 6 151 ± 11
Plastic elongation (%) Horizontal direction - XY Vertical direction - Z	ASTM E8	13 ± 4 15 ± 7	13 ± 4 15 ± 7
Reduction of area (%) Horizontal direction - XY Vertical direction - Z	ASTM E8	30 ± 10 40 ± 25	30 ± 10 40 ± 25

Density

MEASUREMENT	TEST METHOD	METRIC	U.S.
Theoretical density[12] (g/cm³ | lb/in³)	Value from literature	4.42	0.16
DMP Flex 100			
Relative density (%), layer thickness 30 µm[10, 13, 14]	Optical method (pixel count)	≥ 99.4 Typically 99.9	≥ 99.4 Typically 99.9
DMP Flex 200			
Relative density (%), layer thickness 30 µm[13, 14, 16]	Optical method (pixel count)	≥ 99.5 Typically 99.9	≥ 99.5 Typically 99.9
DMP Flex/Factory 350, DMP Flex/Factory 350 Dual, DMP Factory 500			
Relative density (%), layer thickness 30 µm[1, 8, 13, 14]	Optical method (pixel count)	≥ 99.6 Typically 99.8	≥ 99.6 Typically 99.8
Relative density (%), layer thickness 60 µm[1, 8, 9, 13, 14]	Optical method (pixel count)	≥ 99.6 Typically 99.8	≥ 99.6 Typically 99.8
Relative density (%), layer thickness 90 µm[8, 13, 14]	Optical method (pixel count)	≥ 99.6 Typically 99.8	≥ 99.6 Typically 99.8

[10] Parts manufactured with standard parameters on a DMP Flex 100, using layer thickness 30 µm (LT30)
[11] Values based on average and double standard deviation
[12] Values based on literature
[13] May deviate depending on specific part geometry
[14] Minimum value based on 95% tolerance interval with 95% confidence; tested on typical density test shapes
[15] Results obtained in as-printed condition
[16] Parts manufactured with standard parameters on a DMP Flex 200, using layer thickness 30µm (LT30)
[17] Vertical side surface measurement along the building direction
[18] Surface treatment performed with zirconia blasting medium at 5 bar

Surface roughness R_a

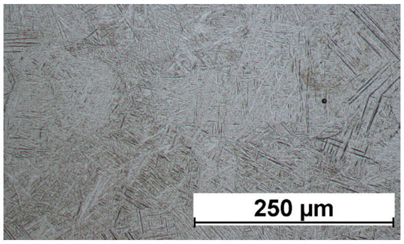
MEASUREMENT[13]	TEST METHOD	METRIC	U.S.
DMP Flex 100, DMP Flex 200[10, 15, 16, 17]			
Vertical side surface (μm | μin) Layer thickness 30 μm	NF EN ISO 4288	Typically 9	Typically 354
DMP Flex/Factory 350, DMP Flex/Factory 350 Dual, DMP Factory 500[17,18]			
Vertical side surface (μm | μin)[1, 8] Layer thickness 30 μm	ISO 25178	Typically 7	Typically 276
Vertical side surface (μm | μin)[1, 8] Layer thickness 60 μm	ISO 25178	Typically 9	Typically 354
Vertical side surface (μm | μin)[8] Layer thickness 90 μm	ISO 25178	Typically 10	Typically 394

Electrical and thermal properties

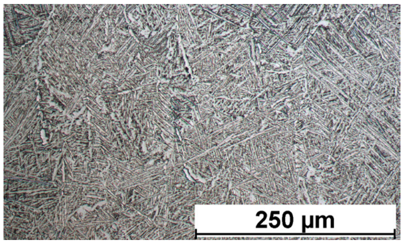
MEASUREMENT	CONDITION	METRIC	U.S.
Electrical conductivity[3] ((S/m) [x10^5])	Four point contact ASTM B193 at 20°C | 68°F	5.9 ± 0.1	5.9 ± 0.1
Thermal conductivity[12] (W/(m.K) | BTU inch/(hr.ft^2.°F))	at 20°C | 68 °F	6.70	46.5
Coefficient of thermal expansion[12] (μm/(m.°C) | μ inch/(inch.°F))	In the range of 20 to 100 °C	8.6	4.8
Melting range[12] (°C | °F)		1604 - 1660	2919 - 3020

Chemical composition

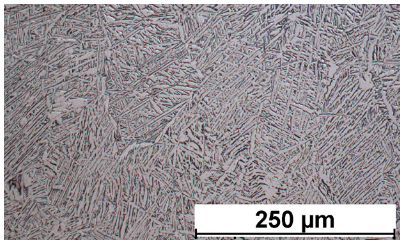
ELEMENT	% OF WEIGHT
Ti	Bal.
N	≤ 0.03
C	≤ 0.08
H	≤ 0.012
Fe	≤ 0.25
O	≤ 0.13
Al	5.50 - 6.50
V	3.50 - 4.50
Y	≤ 0.005
Other (each)	≤ 0.10
Other (total)	≤ 0.40



Microstructure without heat treatment (NHT)



Microstructure after stress relief (SR)



Microstructure after hot isostatic pressing (HIP)

Chemical composition requirements (weight %)[A]

Material	Carbon, max	Oxygen, max	Nitrogen, max	Hydrogen, max	Iron, max	Aluminum	Vanadium	Yttrium, max	Other Elements, max, each[B]	Other Elements, max, total[B]
CP[C] TI	0.08	0.35	0.05	0.015	0.30	—	—	—	0.10	0.40
Ti-6Al-4V	0.08	0.20	0.05	0.015	0.30	5.50 - 6.75	3.50 - 4.50	0.005	0.10	0.40
Ti-6Al-4V ELI[D]	0.08	0.13	0.05	0.012	0.25	5.50 - 6.50	3.50 - 4.50	0.005	0.10	0.40

[A] The percentage of titanium content by difference is not required to be determined or certified.

[B] Other elements need not be reported unless the concentration level is greater than 0.1% each, or 0.4% total. Other elements shall not be added intentionally. Other elements may be present in titanium alloys in small quantities and are inherent to the manufacturing process. In titanium these elements typically include tin, chromium, molybdenum, niobium, zirconium, hafnium, bismuth, ruthenium, palladium, copper, silicon, cobalt, tantalum, nickel, boron, manganese and tungsten.

[C] CP (commercially pure) titanium in this standard is similar to UNS R50550 or Grade 3 titanium.

[D] ELI (extra low interstitial) denotes chemical composition restrictions from the original Ti-6Al-4V alloy for elements known to affect material performance.

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LaserForm 316L (A)

Extra low-carbon grade stainless steel fine-tuned for use with the DMP Flex/Factory 350, DMP Flex/Factory 350 Dual and DMP Flex 350 Triple producing parts with high corrosion resistance and sterilisability. LaserForm 316L (A) yields crack-free, dense parts for all your applications.

LaserForm 316L (A) is formulated and fine-tuned specifically for 3D Systems' 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

Austenitic stainless steel type LaserForm 316L (A) 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.

LaserForm 316L stainless steel is also the preferred material for use in hydrogen atmospheres or for hydrogen piping / cooling applications. It retains good mechanical properties at sub-zero and even cryogenic temperatures and is suitable for structural components in low-temperature applications.

Mechanical properties[1,2]

DMP FLEX/FACTORY 350[3] PROX DMP 320	**TEST METHOD**	**METRIC**		**U.S.**	
		SR	**FA**	**SR**	**FA**
Ultimate tensile strength (MPa ǀ ksi) Horizontal direction — XY Vertical direction — Z	ASTM E8M	660 ± 20 570 ± 30	610 ± 30 540 ± 30	96 ± 3 83 ± 5	89 ± 5 78 ± 5
Yield strength Rp0.2% (MPa ǀ ksi) Horizontal direction — XY Vertical direction — Z	ASTM E8M	530 ± 20 440 ± 20	370 ± 30 320 ± 20	77± 3 63 ± 3	54 ± 5 47 ± 3
Elongation at break (%) Horizontal direction — XY Vertical direction — Z	ASTM E8M	39 ± 5 49 ± 5	51 ± 5 66 ± 5	39 ± 5 49 ± 5	51 ± 5 66 ± 5
Reduction of area (%) Horizontal direction — XY Vertical direction — Z	ASTM E8M	65 ± 5 65 ± 5	61 ± 5 62 ± 5	65 ± 5 65 ± 5	61 ± 5 62 ± 5
Hardness, Rockwell B	ASTM E18	90 ± 6	83 ± 4	90 ± 6	83 ± 4
Impact toughness[4] (J/cm^2 ǀ lb.ft)	ASTM E23	215 ± 15	220 ± 15	158 ± 10	162 ± 10

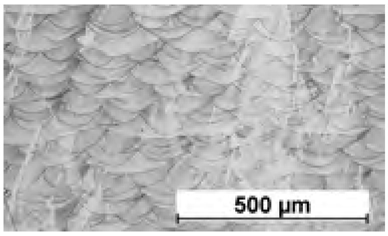
DMP FLEX / FACTORY 350 DUAL[5,6]	**TEST METHOD**	**FA**			
		METRIC		**U.S.**	
		LT30	**LT60**	**LT30**	**LT60**
Ultimate tensile strength (MPa ǀ ksi) Horizontal direction — XY Vertical direction — Z	ASTM E8	660 ± 20 570 ± 20	640 ± 20 590 ± 20	99 ± 3 85 ± 2	93 ± 3 85 ± 2
Yield strength Rp0.2% (MPa ǀ ksi) Horizontal direction — XY Vertical direction — Z	ASTM E8	405 ± 5 390 ± 5	390 ± 30 360 ± 20	59± 5 56 ± 3	56 ± 5 52 ± 3
Elongation at break (%) Horizontal direction — XY Vertical direction — Z	ASTM E8	48 ± 5 62 ± 5	50 ± 5 56 ± 5	39 ± 5 49 ± 5	51 ± 5 66 ± 5
Reduction of area (%) Horizontal direction — XY Vertical direction — Z	ASTM E8	63 ± 5 76 ± 5	64 ± 5 70 ± 5	65 ± 5 65 ± 5	61 ± 5 62 ± 5

[1] Values based on average and standard deviation
[2] NHT SR refers to a stress relief heat treatment ; FA refers to a full annealing
[3] Parts manufactured with standard parameters on a ProX DMP 320
[4] Tested with charpy V-notch toughness test, DMV probe
[5] Parts manufactured with standard parameters on DMP Flex / Factory 350 Dual, config B, using layer thickness 30 µm (LT30) and 60 µm (LT60)
[6] Tested according ASTM E8 using round testing test specimen type 4
[7] For each condition, values based on a limited sample population (<10)

DMP FLEX 350 TRIPLE - LT60[6,7,8]	TEST METHOD	METRIC		U.S.	
		NHT	FA	NHT	FA
Ultimate tensile strength (MPa ǀ ksi)	ASTM E8				
Horizontal direction — XY		705 ± 5	665 ± 5	102 ± 1	97 ± 1
Vertical direction — Z		655 ± 10	625 ± 10	95 ± 1	91 ± 1
Yield strength Rp0.2% (MPa ǀ ksi)					
Horizontal direction — XY		580 ± 10	395 ± 30	84 ± 1	57 ± 4
Vertical direction — Z		525 ± 15	380 ± 30	76 ± 2	55 ± 4
Elongation at break (%)					
Horizontal direction — XY		40 ± 5	45 ± 5	40 ± 5	45 ± 5
Vertical direction — Z		45 ± 5	55 ± 5	45 ± 5	55 ± 5
Reduction of area (%)					
Horizontal direction — XY		68 ± 5	63 ± 5	68 ± 5	63 ± 5
Vertical direction — Z		74 ± 5	69 ± 5	74 ± 5	69 ± 5

Thermal properties[9]

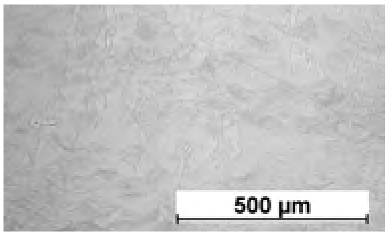
MEASUREMENT	CONDITION	METRIC	U.S.
Thermal conductivity (W/(m.K) ǀ Btu.in/(h.ft.°F))	At 20 °C/ 68 °F	15	9
Coefficient of thermal expansion (µm/m-°C ǀ µin/in-°F)	In the range of 20 - 600°C / 68-1112°F	19.0	10.6
Melting range (°C ǀ °F)		1370-1400	2500-2550



Microstructure after SR

Density[3,8]

MEASUREMENT	TEST METHOD	METRIC	U.S.
Theoretical density (g/cm^3 J lb/in^3)	Value from literature	8.0	0.286
Relative density (%)	Optical method (pixel count)	≥ 99.9 Typical 99.95	≥ 99.9 Typical 99.95



Microstructure after FA

Chemical composition

Parts built with LaserForm 316L (A) have a chemical composition that complies to the compositional requirements of ASTM F3184-16.

ELEMENT	% OF WEIGHT
Fe	Bal.
Cr	16.00-18.00
Ni	10.00-14.00
C	≤0.030
Mn	≤2.00
Mo	2.00-3.00
Si	≤1.00
P	≤0.045
S	≤0.030

[8] Parts manufactured with standard parameters on a DMP Flex 350 Triple, using layer thickness 60 µm (LT60)
[9] Values based on literature

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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 Properties[7]

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 Properties[1]

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

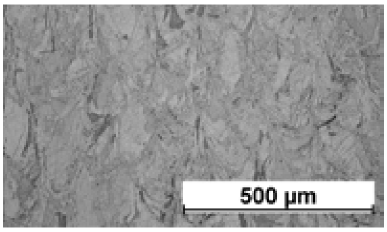
Surface Quality[2]

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

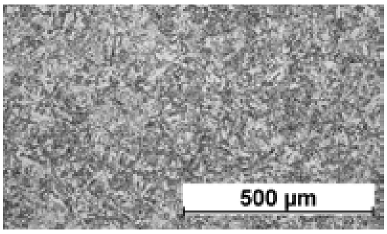
Chemical Composition

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

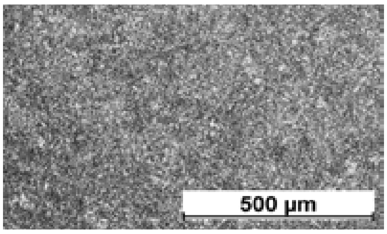
[1] Values based on literature
[2] Parts manufactured with standard parameters on a ProX DMP 320, Config B



Microstructure as built



Microstructure after H900



Microstructure after H1150

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LaserForm® 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 Vertical direction - Z		1230 ± 70 1220 ± 20	2210 ± 30 2120 ± 30	2260 ± 30 2160 ± 90	178 ± 10 177 ± 3	320 ± 5 307 ± 5	328 ± 5 313 ± 13
Yield strength Rp0.2% (MPa | ksi)	ASTM E8M						
Horizontal direction[4] - XY Vertical direction[5] - Z		1080 ± 90 1090 ± 50	2125 ± 30 2030 ± 60	2180 ± 40 2070 ± 80	115 ± 13 158 ± 7	308 ± 4 294 ± 9	316 ± 6 300 ± 12
Elongation at break (%)	ASTM E8M						
Horizontal direction - XY Vertical direction - Z		13 ± 2 13 ± 2	5 ± 2 5 ± 2	5 ± 2 2 ± 1	13 ± 2 13 ± 2	5 ± 2 5 ± 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 Properties [4]

MEASUREMENT	CONDITION	METRIC	U.S.
Thermal conductivity (W/(m.K) | Btu/(h.ft².°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 Properties[1]

MEASUREMENT	METRIC		U.S.	
	AS-BUILT	AGEING	AS-BUILT	AGEING
Density				
Relative, based on pixelcount (%)	> 99.8%			
Absolute theoretical (g/cm³ | lb/in3) [1]	8.1		0.293	

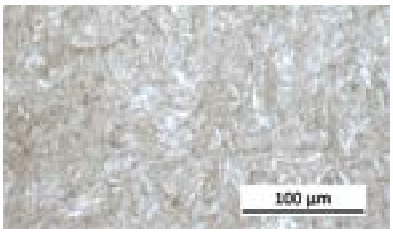
Surface Quality[2]

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

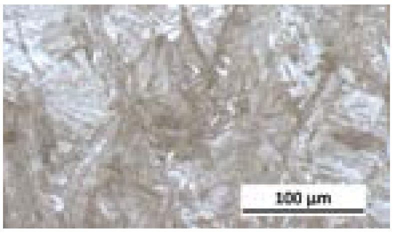
Chemical Composition

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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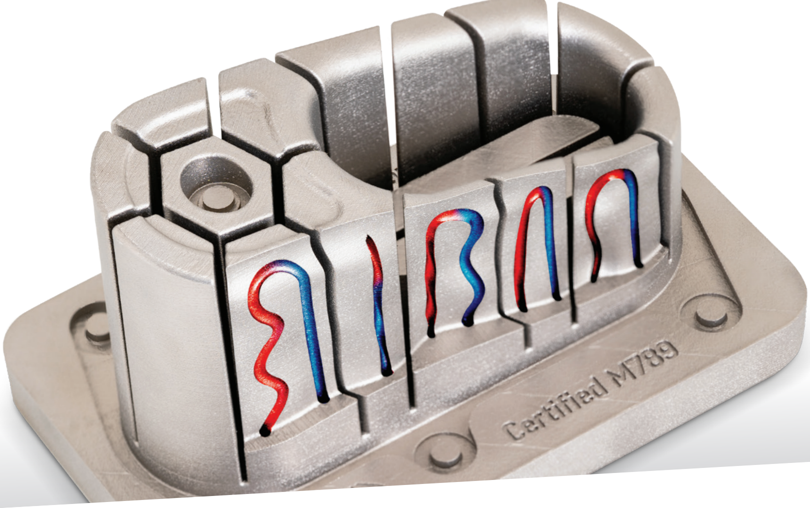
[1] Values based on literature
[2] Values based on minimum and maximum rangers

PN 10115A 11-03



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

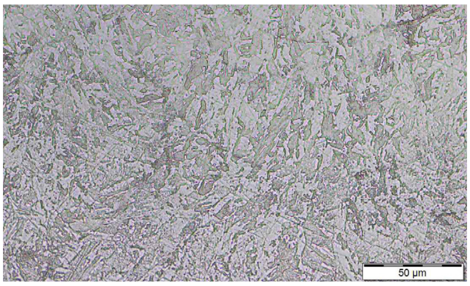
PROX DMP 320, DMP FLEX 350, DMP FACTORY 350[2]	TEST METHOD	METRIC	U.S.	METRIC	U.S.
		SA + A – LT30[4,5]		SA + A – LT60[4,6]	
Ultimate tensile strength (MPa | ksi)[1] Horizontal direction - XY Vertical direction - Z	ASTM E8[3]	1880±25 1830±25	270±4 265±4	1880±25 1840±20	270±4 265±3
Yield strength Rp0.2% (MPa | ksi)[1] Horizontal direction - XY Vertical direction - Z		1730±40 1690±40	250±6 245±6	1740±35 1710±20	250±5 245±3
Plastic elongation (%)[1] Horizontal direction - XY Vertical direction - Z		12±4 9±3		10±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/cm³ | lb/in³)	Value from literature	7.715	0.2787
Relative density (%), layer thickness 30 µm[2,11]	Optical method (pixel count)	≥ 99.8 Typical 99.9	
Relative density (%), layer thickness 60 µm[2,11]		≥ 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.

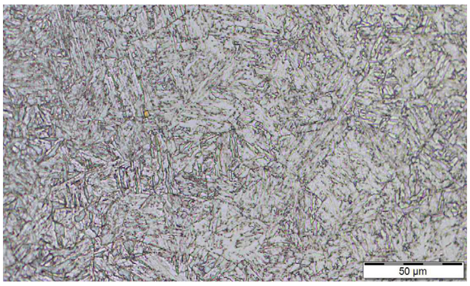
SURFACE ROUGHNESS R_a [2, 9, 11, 12, 13]	TEST METHOD	METRIC	U.S.
Vertical side surface (µm | µin) Layer thickness 30 µm	ISO 25178	Typically, around 8	Typically, around 315
Vertical side surface (µm | µin) Layer thickness 60 µm	ISO 25178	Typically, around 10	Typically, around 390



Microstructure as build

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 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.bohler-edelstahl.com/en/products/m789-ampo/
where it is available under the name BÖHLER M789 AMPO 15-45 µm

BÖHLER AMPO

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[12] Surface treatment performed with zirconia blasting medium at 2 bar
[13] Vertical side surface measurement along the building direction

PN 10124A 09-21

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 CoCr75 (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 CoCr75 (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 Properties[5]

MEASUREMENT	CONDITION	METRIC	U.S.
Thermal conductivity (W/(m.K) | Btu/(h.ft².°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 Properties[5]

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

Physical Properties

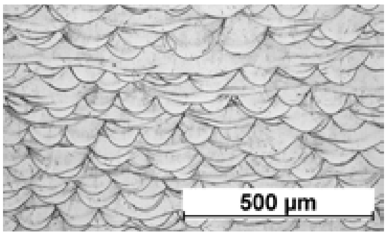
MEASUREMENT	METRIC		U.S.	
	AS BUILT AND AFTER STRESS RELIEF	AFTER HIP	AS BUILT AND AFTER STRESS RELIEF	AFTER HIP
Density				
Relative, based on pixel count[1] (%)	>99,9	≈100	>99,9	≈100
Absolute theoretical[5] (g/cm^3 | lb/in^3)	8.35		0.302	

Surface Quality[1]

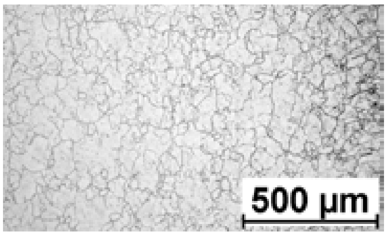
MEASUREMENT	METRIC		U.S.	
	AS BUILT	SAND BLASTED	AS BUILT	SAND BLASTED
Surface Roughness R_a				
Vertical direction (Z) (μm | μin)	9 - 13	3 - 5	350 - 510	120 - 200

Chemical Composition

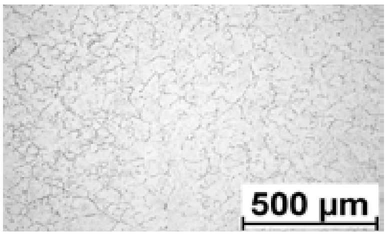
ELEMENT	% OF WEIGHT
Co	Bal.
Cr	27.00-30.00
Mo	5.00-7.00
Ni	≤0.50
Fe	≤0.75
C	≤0.35
Si	≤1.00
Mn	≤1.00
W	≤0.20
P	≤0.020
B, S	≤0.010
N	≤0.25
Al, Ti	≤0.10



Microstructure as built



Microstructure after anneal



Microstructure after HIP

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

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LaserForm Ni718 (A)

Ni718 (A) is fine-tuned for use with DMP Flex/Factory 350, DMP Flex/Factory 350 Dual, DMP Flex 350 Triple 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 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

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.

Mechanical Properties

DMP FLEX/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 930 ± 20	1400 ± 60 1340 ± 40	NA 135 ± 6	203 ± 10 194 ± 6
Yield strength Rp0.2% (MPa | ksi) Horizontal direction — XY Vertical direction — Z	ASTM E8/E8M	NA 660 ± 20	1230 ± 60 1200 ± 40	NA 96 ± 6	178 ± 10 174 ± 10
Elongation at break (%) Horizontal direction — XY Vertical direction — Z	ASTM E8/E8M	NA 30 ± 4	15 ± 4 14 ± 8	NA 30 ± 4	15 ± 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 1010 ± 25	1520 -40/+20 1440 -40/+20	157 ± 3 146 ± 4	220 -6/+3 209 -6/+3
Yield strength Rp0.2% (MPa | ksi) Horizontal direction — XY Vertical direction — Z	ASTM E8	790 ± 25 660 ± 30	1350 -40/+30 1280 ± 50	115 ± 4 96 ± 4	196 -6/+4 186 ± 7
Plastic elongation (%) Horizontal direction — XY Vertical direction — Z	ASTM E8	29 ± 6 32 ± 4	16 ± 4 18 ± 5	29 ± 6 32 ± 4	16 ± 4 18 ± 5

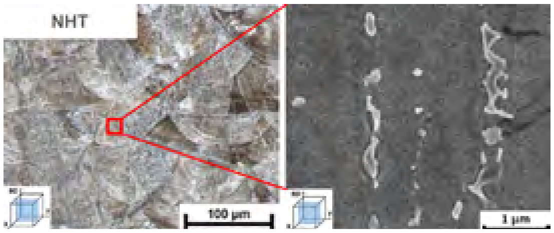
HIGH TEMPERATURE TENSILE PROPERTIES DMP FACTORY 500 – LT605[5,9]	TEST METHOD	METRIC		U.S.	
		NHT	HAA	NHT	HAA
Ultimate Tensile Strength (MPA | ksi) Vertical direction – Z	ASTM E21, at 650°C	NA	1185 ± 25	NA	172 ± 4
Yield strength Rp0.2% (MPa| ksi) Vertical direction – Z		NA	1055 ± 20	NA	153 ± 3
Plastic elongation (%) Vertical direction – Z		NA	20 ± 3	NA	20 ± 3

[1] Parts manufactured with standard parameters on a DMP Flex/Factory 350, Config B using layer thickness 30 µm (LT30) and 60 µm (LT60) ; values are also indicative for DMP Flex/Factory Dual and DMP Flex 350 Triple
[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] 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

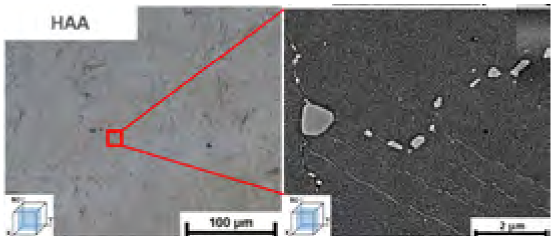
Printed Part Properties[1,5]

DENSITY	TEST METHOD	METRIC	U.S.
Theoretical density (g/cm³ | lb/in³)	Value from literature	8.2	0.296
Relative density (%)[10,11] DMP Flex/Factory 350	Optical method (pixel count)	≥ 99.6 Typical 99.9	≥ 99.6 Typical 99.9
Relative density (%)[10,11] DMP Factory 500	Optical method (pixel count)	≥ 99.7 Typical 99.9	≥ 99.7 Typical 99.9

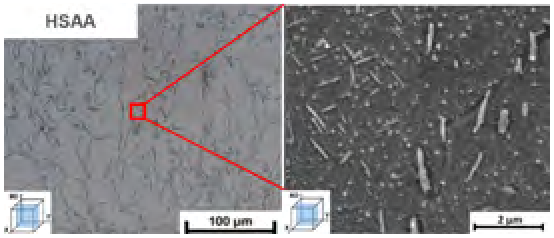
SURFACE ROUGHNESS R_a[11,12,13]	TEST METHOD	METRIC	U.S.
Vertical side surface (µm | µin)	ISO 25178	Typically, around 5	Typically, around 197



Microstructure NHT



Microstructure after HAA



Microstructure after HSAA

Thermal Properties[14]

MEASUREMENT	CONDITION	METRIC	U.S.
Thermal conductivity (W/(m.K) | BTU.in/h.ft².°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 | µin/(in.°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

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

ELEMENT	% OF WEIGHT
Al	0.20-0.8
B	≤0.006
C	≤0.08
Co	≤1.0
Cr	17.00-21.00
Cu	≤0.3
Fe	Bal.
Mn	≤0.35
Mo	2.80-3.30
Nb+Ta	4.75-5.50
Ni	50.00-55.00
P	≤0.015
S	≤0.015
Si	≤0.35
Ti	0.65-1.15

[10] May deviate depending on specific part geometry
[11] Minimum values based on 95% tolerance interval with a 95% confidence. Tested on specific 3DS test coupons
[12] Surface treatment performed with Finox zirconia blasting medium at 5 bar
[13] Vertical side surface measurement along the building direction
[14] Values based on literature

To confirm the suitability of this material for your specific application, please contact the 3D Systems Application Innovation Group (AIG):
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LaserForm® Ni625 (A)

Ni625 (A) is fine-tuned for use with DMP Flex/Factory 350, DMP Flex/Factory 350 Dual and DMP Flex 350 Triple metal printers producing industrial parts with high heat resistance, high strength strength and high corrosion resistance. LaserForm Ni625 (A) is especially resistant to crevice and pitting corrosion.

Ni625 (A) is formulated and fine-tuned 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

Ni625 (A) 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.

Mechanical Properties[1,2,3]

MEASUREMENT	CONDITION	METRIC			U.S.		
		NHT	SR	LSA	NHT	SR	LSA
Ultimate strength (MPa | ksi)	ASTM E8M						
Horizontal direction - XY Vertical direction - Z		1040 ± 20 1030 ± 20	1110 ± 60 1050 ± 30	1030 ± 20 980 ± 20	150 ± 3 150 ± 3	160 ± 9 153 ± 5	150 ± 3 142 ± 3
Yield strength Rp0.2% (MPa | ksi)	ASTM E8M						
Horizontal direction - XY Vertical direction - Z		770 ± 30 730 ± 20	750 ± 60 700 ± 40	640 ± 20 600 ± 20	110 ± 5 105 ± 3	110 ± 9 100 ± 6	93 ± 3 87 ± 3
Elongation at break (%)	ASTM E8M						
Horizontal direction - XY Vertical direction - Z		22 ± 2 33 ± 1	19 ± 3 23 ± 3	27 ± 3 34 ± 3	22 ± 2 33 ± 1	19 ± 3 23 ± 3	27 ± 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[4] (J | ft-lb)	ASTM E23	NA	NA	84 ± 7	NA	NA	62 ± 5

Thermal Properties[5]

MEASUREMENT	CONDITION	METRIC	U.S.
Thermal conductivity (W/(m.K) | Btu.in/(h.ft².°F))	at 21 °C / 70 °F	9.8	68
CTE - Coefficient of thermal expansion (μm/(m.°C) | μ in/(in . °F))	at 93 °C / 200 °F at 538°C / 1000°F at 871°C/1600°F	12.8 14.0 15.8	7.1 7.8 8.8
Melting range (°C | °F)		1290 - 1350	2355 - 2465

[1] Parts manufactured with standard parameters on a ProX DMP 320, Config B. Values also indicative for DMP Flex/Factory 350 and DMP Flex 350 Triple
[2] Values based on average and standard deviation
[3] NHT refers to non-heat treated sample condition, SR refers to a stress-relief, LSA refers to a low-solution annealing
[4] Tested with Charpy V-notch impact test specimens type A at room temperature
[5] Values based on literature
NA = Not available

Physical Properties

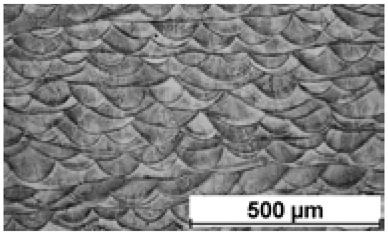
DENSITY	TEST METHOD	METRIC	U.S.
Theoretical density (g/cm³ | lb/in³)	Value from litterature	8.44	0.305
Relative density[1] (%)	Optical method	>99,9	>99,9

SURFACE ROUGHNESS R_A [1]	METRIC		U.S.	
	AS BUILT	SAND BLASTED	AS BUILT	SAND BLASTED
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

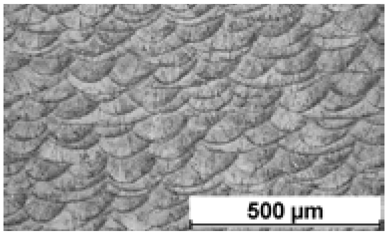
Chemical Composition

Parts built with LaserForm Ni625 (A) have a chemical composition that complies with ASTM F3056, UNS N06625, Werkstoff Nr. 2.4856, DIN NiCr22Mo9Nb and AMS5 5666.

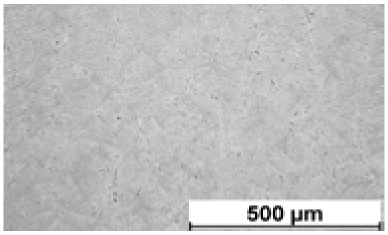
ELEMENT	% OF WEIGHT
Ni	Bal.
Cr	20.00 - 23.00
Mo	8.00 - 10.00
Fe	≤ 5.00
Co	≤1.00
Nb	3.15 - 4.15
Ta	≤ 0.05
Ti	≤ 0.40
Al	≤ 0.40
Cu	≤ 0.50
Mn	≤ 0.50
C	≤ 0.10
P	≤ 0.015
S	≤ 0.015
Si	≤ 0.50



Microstructure NHT



Microstructure after SR



Microstructure after LSA

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Certified HX (A)

3D Systems offers a print parameter database license for Certified HX (A) on the DMP Flex 350, DMP Flex 350 Triple 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:

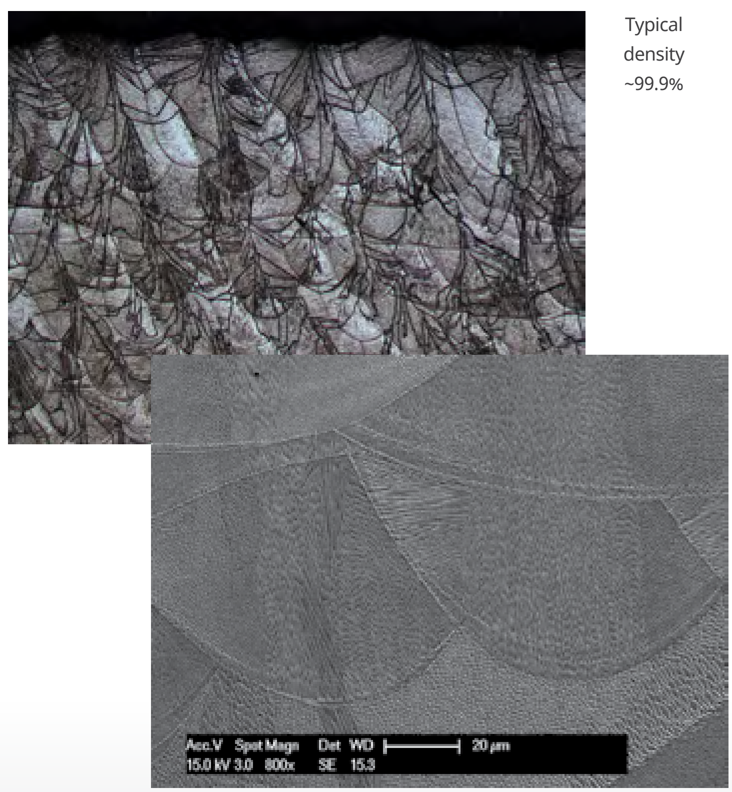
- Jet engines and IGT turbine vanes and ducts
- Gas turbine engine combustion zone components such as transition ducts, combustor cans and spray bars
- Oil and gas components working in corrosive environments, e.g., drill bits, downhole tools and sensor casings
- Chemical processing parts such as heat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

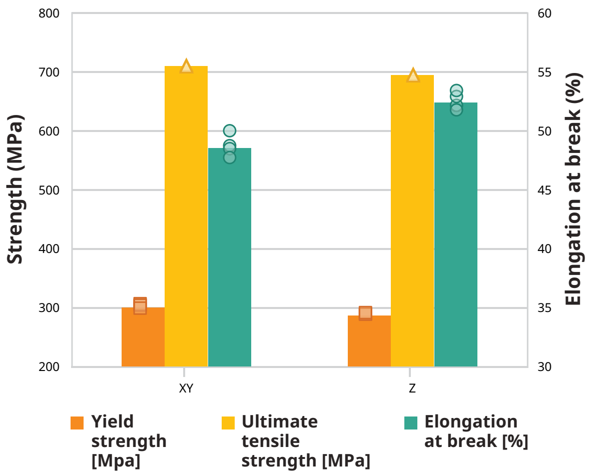
490mm



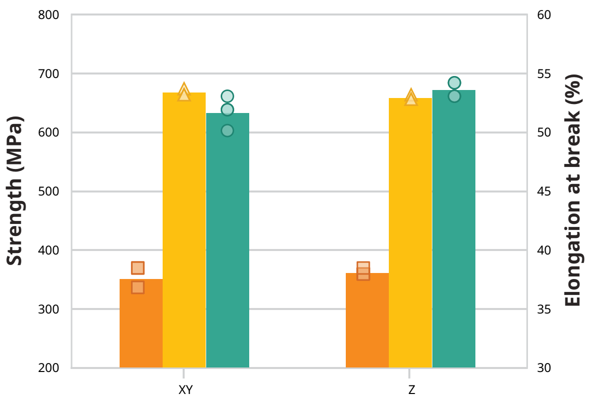
Typical density ~99.9%

Homogeneous microstructure at higher magnification.

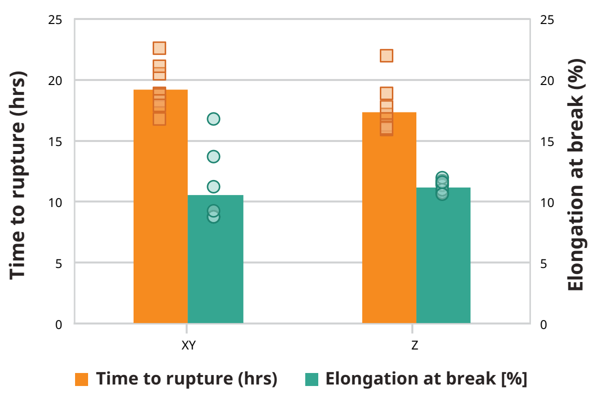
TENSILE TEST AT ROOM TEMPERATURE (ASTM E8)



TENSILE TEST AT 815°C (ASTM E21)

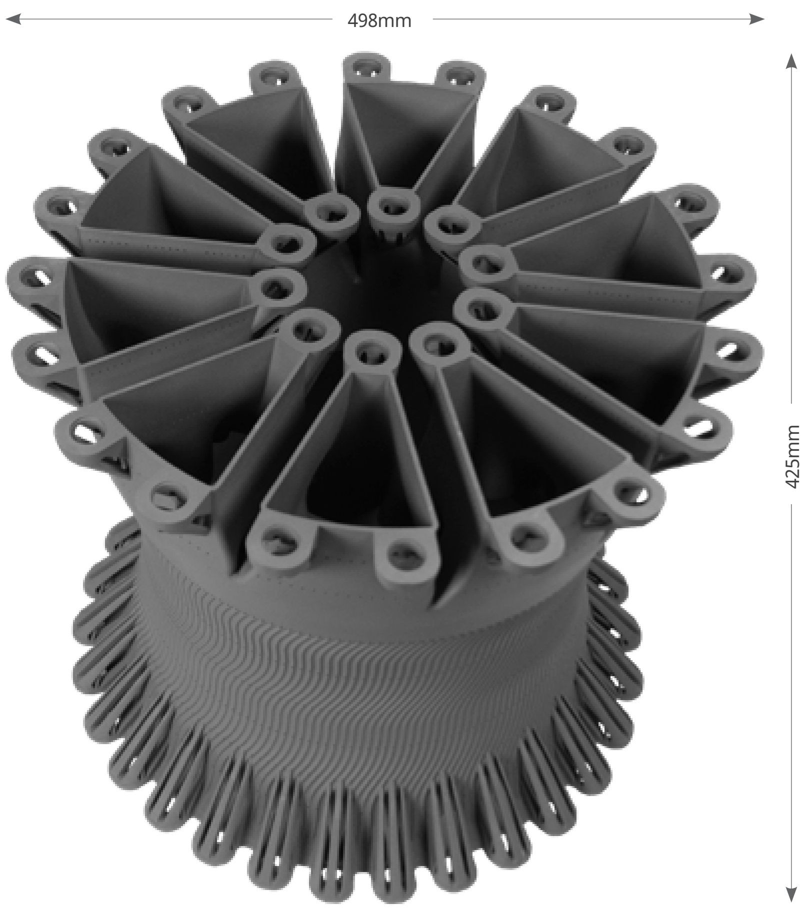


STRESS RUPTURE TESTING AT 815°C, 105MPA (ASTM E139)



Combustion chamber component:

The DMP technology and parameter set for Certified HX (A) allows complex welded assemblies of separate transitions 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)

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ABOUT GF MACHINING SOLUTIONS

When all you need is everything, it's good to know that there is one company that you can count on to deliver complete solutions and services. From unmatched Electrical Discharge Machining (EDM), Laser texturing, Laser micromachining, Additive Manufacturing and first-class Milling and Spindles to Tooling and Automation, all of our solutions are backed by unrivaled Customer Services and expert GF Machining Solutions training. https://www.gfms.com/com/en/machines/additive-manufacturing.html

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GRX-810 (A)

GRX-810 (A) is a Nickel-based superalloy developed by NASA. It is specifically developed for additive manufacturing with the aim to deliver a material with high ductility, excellent strength and creep resistance properties at high temperatures. The target properties were carefully selected with specific target applications in mind, namely combustor components and nozzle operating above 1093°C (2000°F). As a reference, GRX-810 (A) outperforms both Ni718 and Ni625 in terms of strength and creep resistance at this temperature.

3D Systems offers GRX-810 (A) through the Application Innovation Group (AIG) for evaluation purposes. This service is limited to customers inside the United States. 3D Systems GRX-810 (A) evaluation services using the integrated additive manufacturing (AM) workflow software, 3DXpert®, and the DMP Flex/Factory 350 metal 3D printers. 3D Systems' uses optimized parameters for GRX-810 (A) that were developed, tested, and optimized in cooperation with Velontra and 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.

For companies inside the United States looking to evaluate GRX-810 (A), our AIG in the United States can support and accelerate this survey.

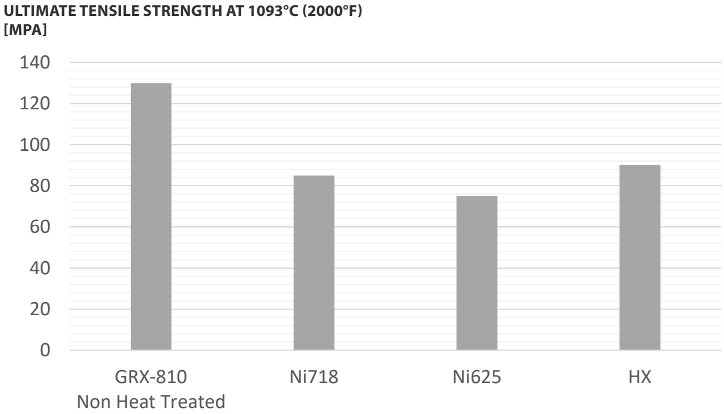
Material Description

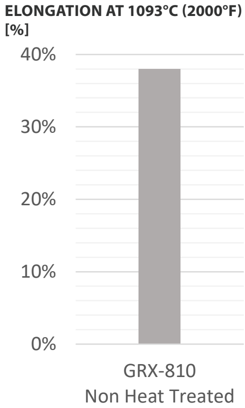
GRX-810 (A) is a Ni-Co-Cr alloy that because of its oxide dispersion strengthening mechanism has exceptional creep resistance, a failure mode that occurs in many turbine and combustion components. GRX-810 (A) was first manufactured by NASA with fuel injection nozzles that suffer from creep failure and have high mechanical requirements at high temperatures in mind. GRX-810 (A) has a high service temperature between 1000°C and 1200°C and is capable of withstanding high stresses around 50% higher than Inconel at these elevated temperatures.

3D Systems is uniquely positioned to support evaluation surveys on this material and is the first entity other than NASA to verify the elevated temperature tensile and creep properties of GRX-810 (A). In this exercise, 3D Systems successfully replicated the mechanical performance at 1093°C (2000°F).

3D Systems offers evaluation services only through AIG located in the United States on this unique alloy for additive manufacturing. Availability is also limited to customers inside the United States. The 3D Systems build volume reducer accessory for the DMP Flex or Factory 350 DMP systems reduces the required amount of powder to load in the printer and allows for cost-efficient evaluation exercises on GRX-810 (A).

Typical Properties[1, 2, 3]

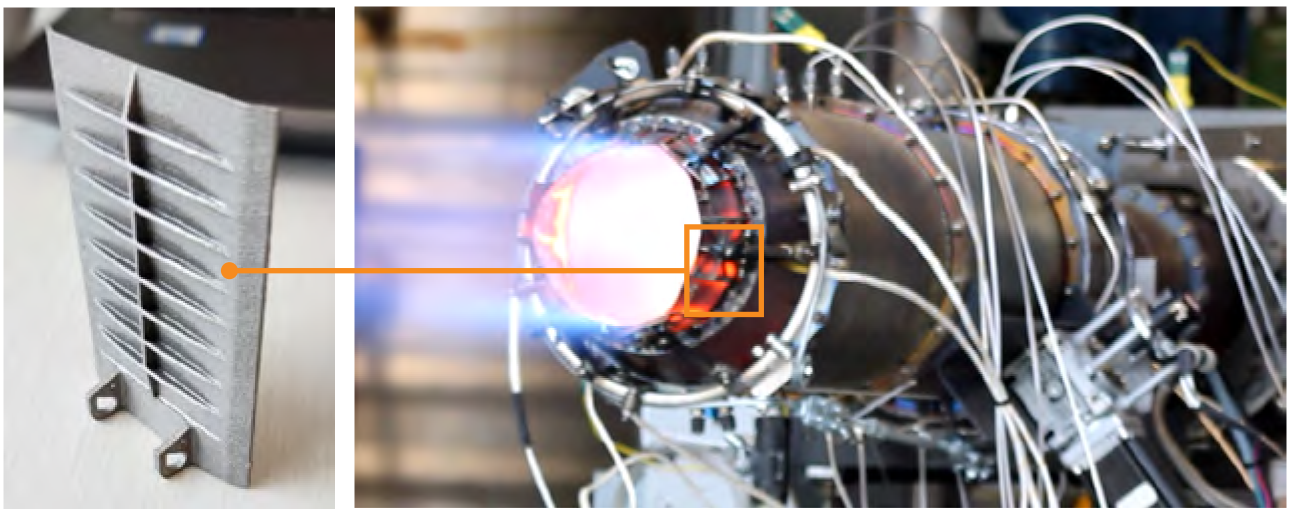




[1] Parts manufactured with a standard parameters and protocols on DMP Flex/Factory 350 using layer thickness 60 μm (LT60)
[2] Sampled machined and tested according to ASTM E8 using round tensile test specimen type 4
[3] Typical values, average of 3 vertical tensile coupons

Layer thickness: 60µm
Typical relative density[4]: 99.9%

Application Focus:
Exhaust Nozzle Flap



PART HEIGHT	57 mm
PRINT TIME	6 h
BATCH SIZE	2
LAYER THICKNESS	60 µm

The exhaust nozzle flap in GRX-810 (A) was built with the DMP Flex 350 printer using the DMP Flex 350 Ø100x160mm build volume reducer insert. It was subsequently tested by Velontra and passed hot fire testing under extreme temperature conditions

[4] Values based on a limited sample population (<15). Values shown are typical values from density test coupons, may deviate depending on specific part geometry

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VELONTRA

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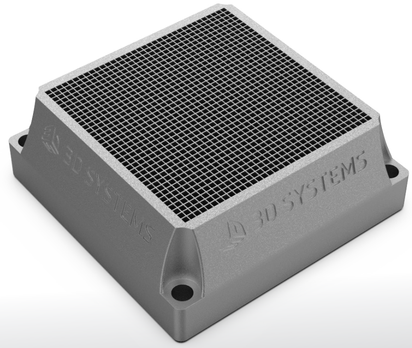


Tungsten (A)

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.

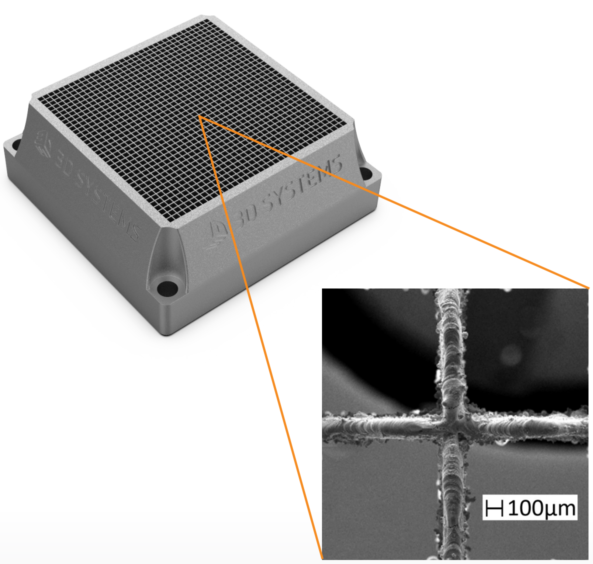
Direct metal printing (DMP) with a low-oxygen printing environment is essential for producing highly dense pure tungsten DMP parts. Superior part density of pure tungsten can be achieved thanks to the best-in-class vacuum technology of the DMP Flex 350.

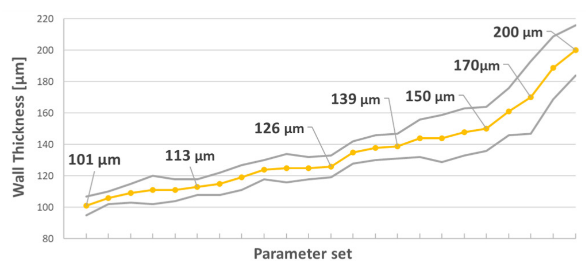
Indicative part properties - Layer thickness 30 μm

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

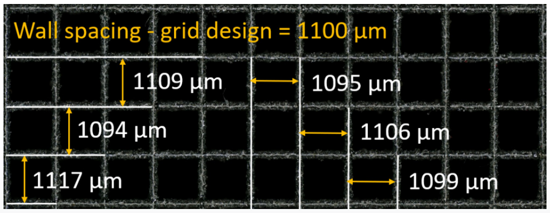
Application Focus: Collimator

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.





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



AM allows for accurate wall spacing.

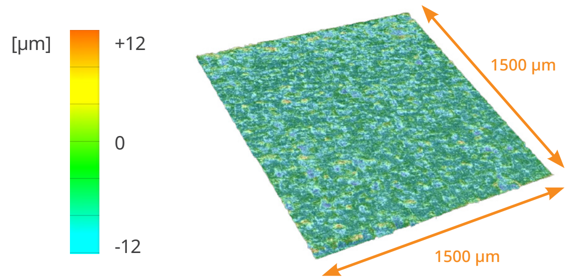
[1] Surface treatment performed with zirconia blasting medium at 2 bar.

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

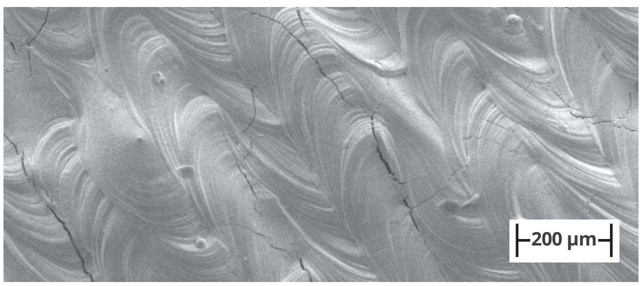
Application Focus: Arc Slit

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.

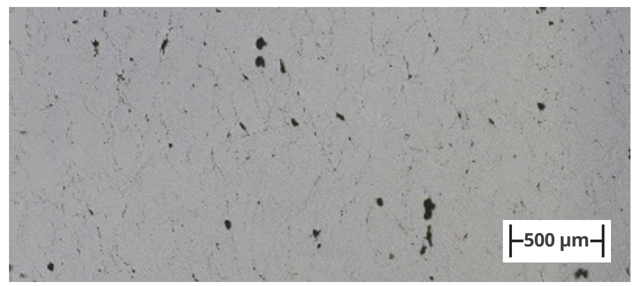
High accuracy after support removal and sandblasting as measured by a 3D scan.



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.

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6K ADDITIVE

Tungsten powder with reference “6K-Wpwd525-3DS” can be purchased directly from 6K Additive:

Contact:
Francois Bonjour
fbonjour@6kadditive.com
Ph: +33 6 79 72 75 75

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Certified C-103 (A)

Certified C-103 (A) is a niobium alloy with hafnium and titanium alloying elements. It is a refractory material specifically designed for high-temperature and high-corrosive operating applications. Parts in C-103 can operate reliably up to a service temperature of approximately 1480°C. For example, at a temperature of 1093°C, C-103 has more than double the strength of Ni718 or Ni625.

3D Systems offers application development and part production using the integrated additive manufacturing (AM) workflow software, 3DXpert®, and the DMP Flex/Factory 350 metal 3D printers. 3D Systems' Certified C-103 parameters were developed, tested, and optimized in cooperation with 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.

For companies looking to develop new applications and processes with Certified C-103, our Application Innovation Group (AIG) can support and accelerate this development.

Material description

Certified C-103 is a niobium-hafnium-titanium alloy. C-103 was used for the first time in the Apollo manned lunar module rocket engine in 1965. It has since been adopted for various ultra-high temperature applications, such as rocket nozzles, jet propulsion, and thrust augmenter flaps.

3D Systems offers this standard alloy now as a solution for additive manufacturing. The extremely low oxygen environment of the DMP Flex and Factory 350 vacuum chamber architecture minimizes oxygen pickup, ensuring the best conductivity properties. In effect, the DMP Flex and Factory 350 Architecture allows indefinite storage of C-103 powder under low oxygen conditions. Moreover, with the DMP Factory 350 system, the entire powder handling cycle can be done under an inert environment.

Finally, the 3D Systems build volume reducer accessory for the DMP Flex or Factory 350 DMP systems reduces the required amount of powder to load in the printer and allows for cost-efficient pilot application development and pilot production.

Typical Properties[1,2,3]

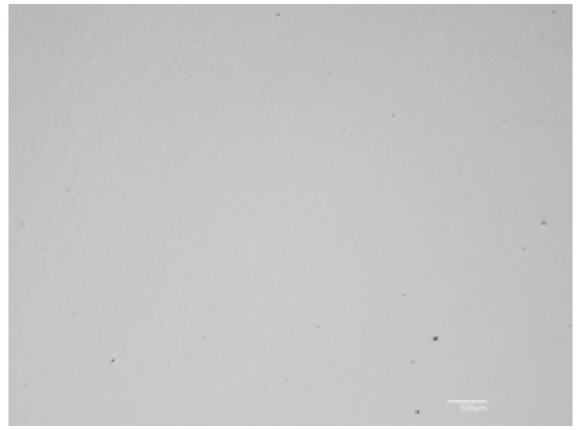
DMP FLEX/FACTORY 350 – LT 60	TEST METHOD	TEST CONDITION	NON HEAT TREATED (NHT)
Ultimate tensile strength (MPa | ksi)			574 | 83
Yield strength Rp0.2% (MPa | ksi)	ASTM E8	Room Temp 22˚C	461 | 67
Elongation (%)			28
Ultimate tensile strength (MPa | ksi)			269 | 39
Yield strength Rp0.2% (MPa | ksi)	ASTM E21	Elevated Temp 1093˚C	216 | 31
Elongation (%)			13

[1] Parts manufactured with a standard parameters and protocols on DMP Flex/Factory 350 using layer thickness 60 μm (LT60)
[2] Sampled machined and tested according to ASTM E8 using round tensile test specimen type 4
[3] Typical values, average of 3 vertical tensile coupons

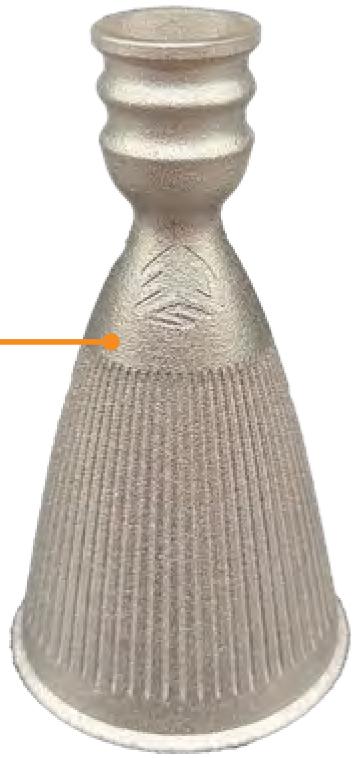
Typical Applications

- High temperature (aero) space propulsion and satellite components
- Steering nozzles, high-thrust nozzles
- Thrust chambers, turbine blades, jet engine afterburner flap sections
- Burst disks test stands components

Layer thickness: 60µm
Typical relative density[4]: 99.6-99.7%



Roughness Ra[5]
8-12 µm



Satellite Truster

PART HEIGHT	57 mm
PRINT TIME	6 h
LAYER THICKNESS	60 µm

Application Focus:

SPACE – NOZZLES AND THRUST CHAMBERS
C-103 has a high service temperature between 1200°C and 1400°C. It is capable of withstanding high stresses at these elevated temperatures, rendering it particularly suited for use in propulsion systems. In addition, Because of its low ductile-to-brittle transition temperature, C-103 has excellent resistance to high-frequency vibrations at cryogenic temperatures, as occurs in many satellite or space applications.

JUGGLE COMPLEXITY AND SIMPLIFY ASSEMBLY IN 3DXPERT
Benefit from the 3DXpert design features to generate surface lattice and cooling channels with unlimited complexity. Analyze your design inside the same software environment. Leverage the power of additive manufacturing to simplify assemblies by integrating additional functions such as structural elements and fixtures into a single part.

[4] Values based on a limited sample population (<15). Values shown are typical values from density test coupons, may deviate depending on specific part geometry
[5] No surface treatment applied, measured in as printed condition according with a Keyence microscope. Values based on a limited sample population (<5)

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H.C.Starck
High Performance Metal Solutions

3D Systems works with C-103 powders sourced from H.C. Starck Solutions
Contact info:
Web: www.hcstarcksolutions.com
Mail: info@hcstarcksolutions.com

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Certified CuCr1Zr (A)

Certified CuCr1Zr (A) is a high strength copper alloy with electrical conductivity that can exceed 90% IACS when applying the appropriate heat treatment.

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 printers. 3D Systems' Certified CuCr1Zr parameters were developed, tested, and optimized on real heat management applications in cooperation with 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.

For companies looking to develop new applications and processes with Certified CuCr1Zr, our Application Innovation Group (AIG) can support and accelerate application development.

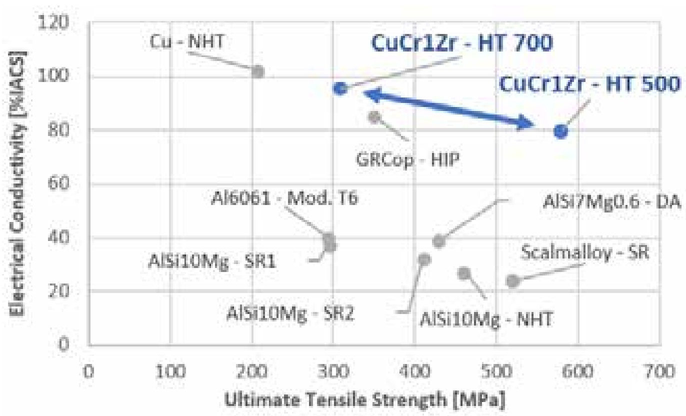
Material Description

Certified CuCr1Zr is a standard alloy that has been used in traditional manufacturing for a long time. The addition of chromium improves the mechanical properties by precipitation strengthening. Zirconium is reported to enhance the resistance to stress relaxation of the Cu–Cr alloy.

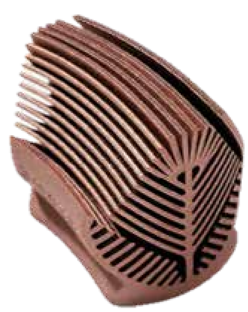
3D Systems offers this standard alloy, compliant to UNS C18150 and EN CW106C requirements, now as a solution for additive manufacturing. The extremely low oxygen environment of the DMP Flex and Factory 350 vacuum chamber architecture minimizes oxygen pickup, ensuring the best conductivity properties.

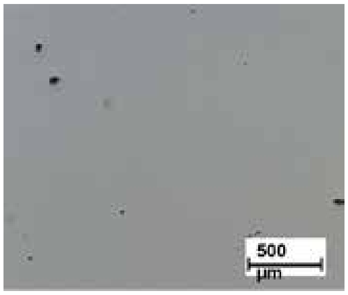
Different heat treatments can be applied for balancing strength and conductivity. Our AIG professionals have the experience to select the appropriate heat treatment to meet your application requirements.

Electrical Conductivity exceeding 90% IACS[1]



Layer Tickness 30 Relative Density Typically 99.7%[2]





Part height	39 mm
Print time	6 h (Batch size: 1)
Layer thickness	30 µm
Surface roughness Ra	Typically 20 µm for vertical surfaces[3]

Typical Applications

- Heat management and cooling systems
- Conductive contacts
- Induction coils
- Combustion chambers
- Structural engine parts
- Other high-conductivity applications

1. Electrical Conductivity measured according to ASTM B193. IACS = International Annealed Copper Standard. Values based on a limited sample population (<10).
2. Relative density values shown are typical values from density test coupons and may deviate depending on specific part geometry. Values based on a limited sample population (<10).

Part height	33 mm
Print time	2.5 h (Batch size: 1)
Layer thickness	30 µm

Mechanical Properties can be Finetuned

DMP FLEX 350, DMP FACTORY 350 - LT30[1,4]	TEST METHOD	HEAT TREATEMENT 500°C	HEAT TREATEMENT 700°C
Ultimate tensile strength (MPa | ksi)	ASTM E8	580 | 84	305 | 44
Yield strength Rp0.2% (MPa | ksi)	ASTM E8	490 | 71	170 | 24
Plastic elongation (%)	ASTM E8	25	35
Electrical conductivity (% IACS)	ASTM B193	80	94

Increase System Efficiency with 3DXpert Designs

3D printing is a versatile production process that enables the creation of complex shapes with high surface area-to-volume ratios. This flexibility, together with the high thermal and electrical conductivity of Certified CuCr1Zr, maximizes the efficiency for different types applications:

HEAT EXCHANGERS

3DXpert has features specifically developed for the design of heat exchanger systems with complex internal geometries. Define patterns or structures and generate baffles automatically. Tie these definitions to separate volumes, define inlets and outlets and optimize via integrated analysis along volumes, areas or sections.

INDUCTION COILS

Design induction coils that simultaneously benefit from the high thermal conductivity and 3D printing design freedom to optimize internal cooling channels and maximize coil performance.

ELECTRICAL CONTACTS

Marrying strength and electrical conductivity renders Certified CuCr1Zr an ideal solution for complex electrical contacts or small series production.

3DXpert

Part height	76 mm
Print time	4 h (Batch size: 1)
Layer thickness	30 µm

4 Mechanical properties tested using horizontally oriented ASTM E8 type 4 specimens printed with layer thickness 30 µm. Values based on a limited sample population (<5).

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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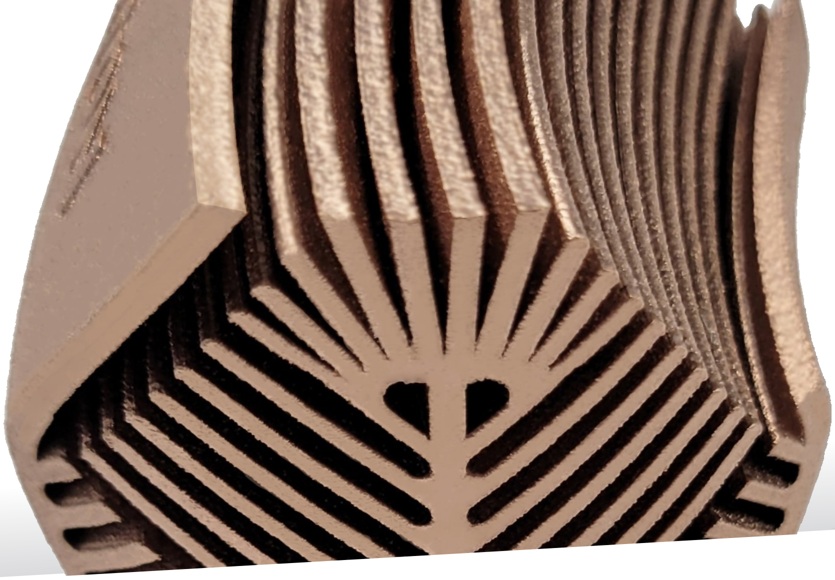


Certified CuCr2.4 (A)

Certified CuCr2.4 (A) is a copper alloy offering improved strength and printability 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 DMP Factory 350 metal 3D printers. 3D Systems' Certified 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.

For companies looking to develop new applications and processes with Certified CuCr2.4, our Application Innovation Group (AIG) can support and accelerate application development as well as tune the heat treatment to the application needs.

Theoretical Build Rate of 19 cc/hour

Part height	61 mm
Print time	7.8 h (Batch size: 1)
Layer thickness	60 µm
Surface roughness Ra	Steady value of 20 µm for angled surfaces ranging from 0° to 90° [2]

Typical Applications

- Heat management and cooling systems
- Conductive contacts
- Induction coils
- Combustion chambers
- Structural engine parts
- Other high-conductivity applications

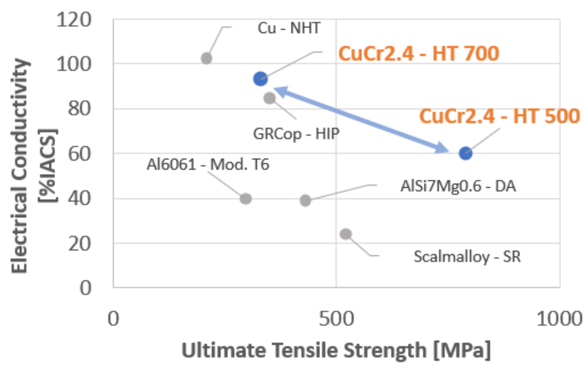
Material Description

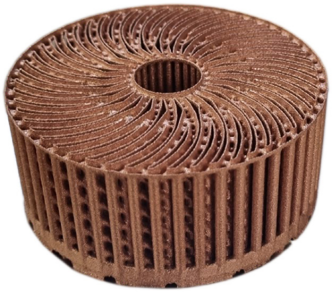
Certified CuCr2.4 is a precipitation hardenable copper alloy. It is stronger than pure copper, also at elevated temperatures, while retaining very high electrical and thermal conductivity.

The addition of chromium to copper increases the laser absorptivity and optimizes thermal conductivity in as printed condition, making the powder easy to process. By annealing the printed parts, the conductivity can be increased to meet the application specific requirements.

Two heat treatments are suggested but these can be tailored further if needed, balancing mechanical properties and conductivity

Electrical Conductivity up to 93% IACS[1]

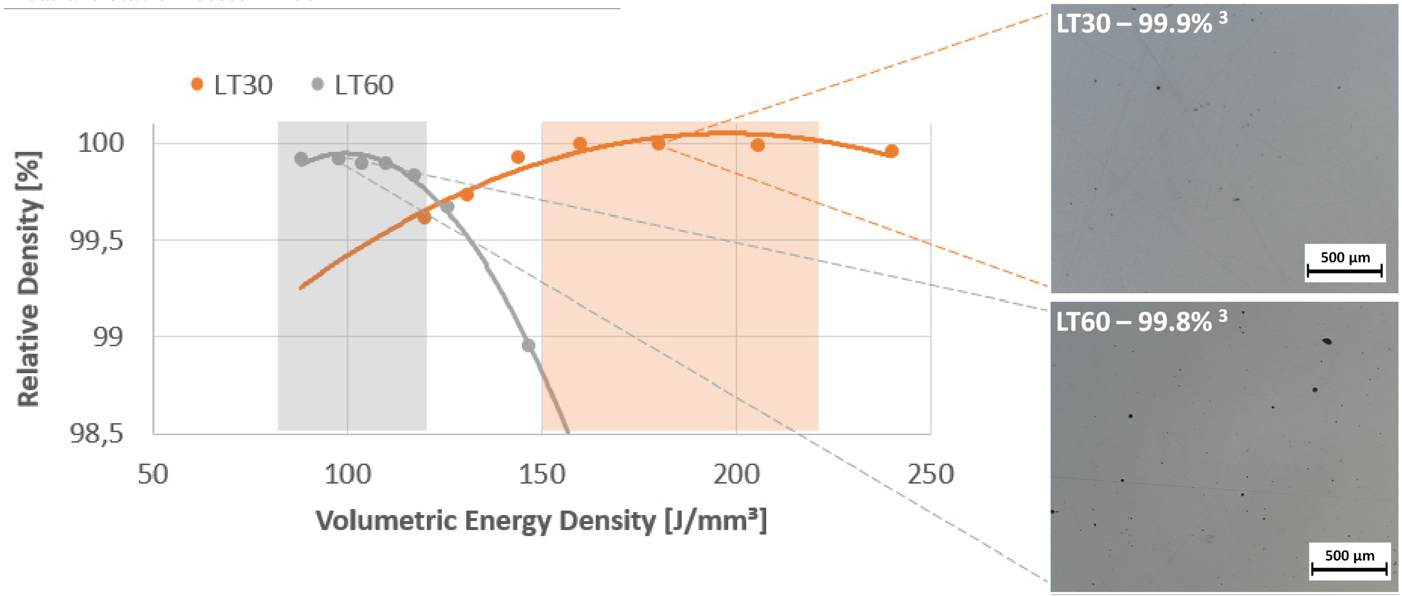




Part height	34.5 mm
Print time	4.5 h (Batch size: 1)
Layer thickness	60 µm

1 Electrical conductivity measured according to ASTM B193. IACS = International Annealed Copper Standard.
2 No surface treatment applied, measured in as printed condition according to ISO 25178.

Broad and Stable Process Window



Heat Exchangers with a Thermal Conducivity up to 390 W/mK[4]

3D printing is a versatile production process that enables the creation of complex shapes with high surface area-to-volume ratios. This flexibility, together with the high thermal conductivity of Certified CuCr2.4, maximizes the thermal efficiency for different types of heat exchanger applications.

Part height	101 mm
Print time	4 h (Batch size: 1)
Layer thickness	60 µm

DMP FLEX 350, DMP FACTORY 350[1,5]	HEAT TREATEMENT 500°C		HEAT TREATEMENT 700°C	
	23°C	427°C	23°C	427°C
Ultimate tensile strength (MPa | ksi)	790 | 114	312 | 45	330 | 48	142 | 20
Yield strength Rp0.2% (MPa | ksi)	725 | 105	278 | 40	222 | 32	138 | 20
Plastic elongation (%)	11	1.0	27	12
Electrical conductivity (% IACS)	~ 61	-	~ 93	-

3 Values based on a limited sample population (<15). Values shown are typical values from density test coupons, may deviate depending on specific part geometry.
4 Calculated with the Wiedemann-Franz law and based on 93% IACS which was measured on printed parts according to ASTM B193.
5 Values based on a limited sample population (<15). Mechanical properties tested using horizontally and vertically oriented ASTM E8 type 4 specimens printed in LT30 and LT60. Tests were conducted at 23°C and at 427°C according to ASTM E21 (soaking time = 20 minutes).

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

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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

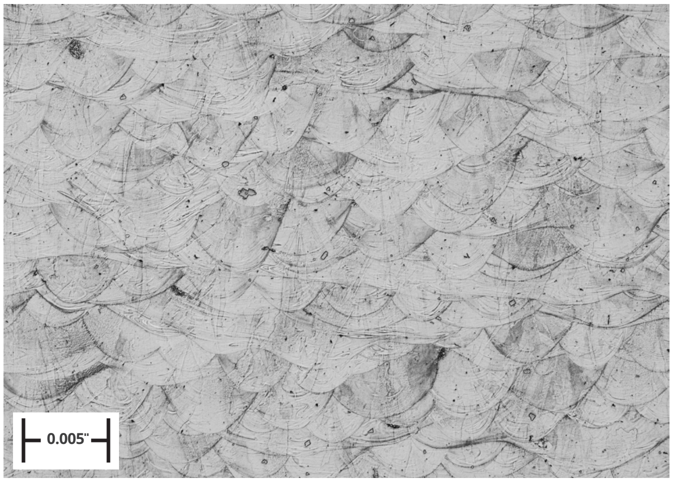
Typical Printed Part Properties

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	

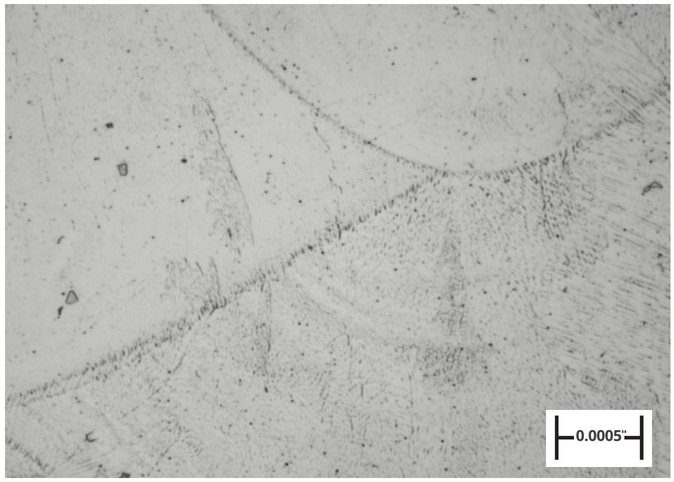
[1] No Heat Treatment.
[2] Machined and tested according to ASTM E8 using round tensile test specimen type 4. Typical values, averaged over 3 vertical and 3 horizontal tensile coupons.
[3] Parts manufactured with standard parameters and protocols on DMP ProX 320, Config B using layer thickness 30 μm. 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

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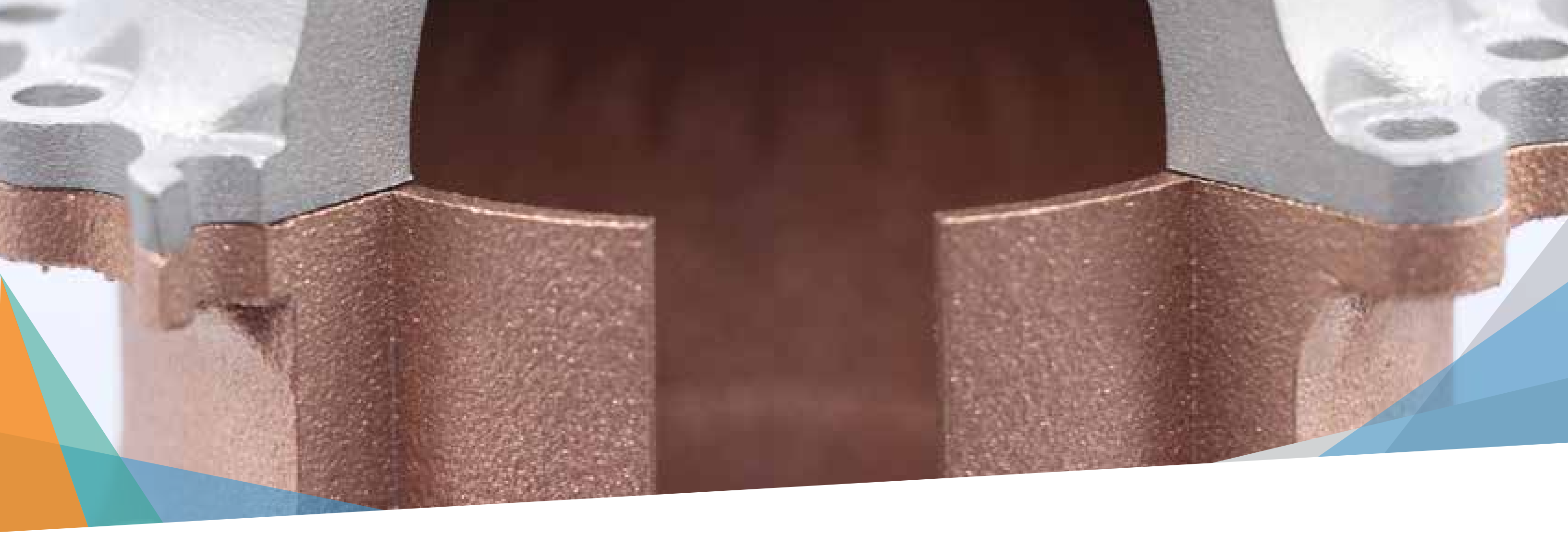


Certified GRCop-42 (A)

Certified GRCop-42 (A) is a copper alloy specifically designed for high-temperature, high-thermal transfer applications where high strength and creep properties are also a hard requirement. Parts in GRCop-42 can operate reliably up to a service temperature of approximately 750 °C.

3D Systems offers application development and part production using the integrated additive manufacturing (AM) workflow software, 3DXpert®, and the DMP Flex and DMP Factory 350 metal 3D printers. 3D Systems' Certified GRCop-42 parameters were developed, tested, and optimized on real heat management applications in cooperation with 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.

For companies looking to develop new applications and processes with Certified GRCop-42, our Application Innovation Group (AIG) can support and accelerate application development.

Typical Properties

DMP FLEX 350, DMP FACTORY 350 - LT 60[2]	TEST METHOD	HEAT TREATMENT HIP[3]
Ultimate tensile strength (MPa | ksi)	ASTM E8	360 | 52
Yield strength Rp0.2% (MPa | ksi)		195 | 28
Elongation (%)		33
Electrical conductivity (% IACS1)	ASTM B193	>85

Typical Applications

- Regeneratively cooled, liquid bi-propellant thrust chambers
- High-temperature aerospace components
- Advanced thermal management with high conductivity needs in temperatures up to 800°C
- High thermal transfer applications where pure Cu is too weak

Material Description

Certified GRCop-42 is a copper-chrome-niobium alloy developed by NASA. The addition of Cr and Nb to the Cu matrix enables dispersion strengthening after HIP via Cr2Nb precipitates. These precipitates improve mechanical strength, creep resistance and low cycle fatigue life at high temperatures. At room temperature, electrical conductivity of over 85% IACS1 can be obtained.

Certified GRCop-42 (A) powder chemistry

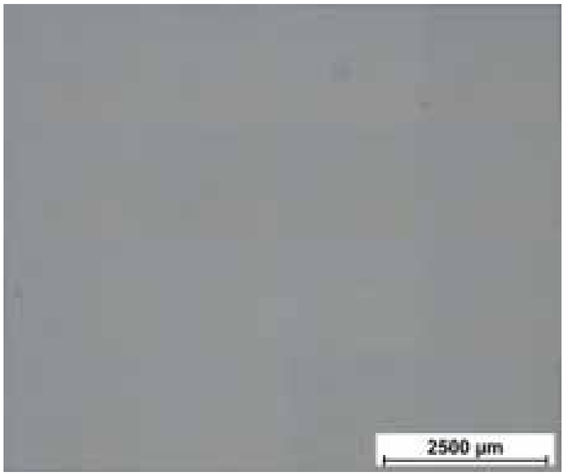
ELEMENT	WT%
Cr	3.1 - 3.4
Nb	2.7 - 3.0
Fe	< 250 ppm, target < 50 ppm
O	< 500 ppm, target < 250 ppm
Al	< 400 ppm
Si	< 350 ppm, target < 100 ppm
Cu	Balance

Source: NASA report AIAA-2019-4228

3D Systems offers this standard alloy now as a solution for additive manufacturing. The extremely low oxygen environment of the DMP Flex and Factory 350 vacuum chamber azrchitecture minimizes oxygen pickup, ensuring the best conductivity properties. And with the DMP Factory 350 system, the powder handling can be done completely in an inert environment.

1. IACS = International Annealed Copper Standard.
2. Samples printed with a layer thickness of 60 µm (LT60). Machined and tested according to ASTM E8 using round tensile test specimen type 4. Typical values, average of 10 vertical and 23 horizontal tensile coupons.
3. HIP = Hot Isostatic Pressing - 954°C for 3 hours at 103Mpa

Layer thickness 60 relative density typically 99.8 - 99.9%[4] after HIP



Typical Roughness Ra
8 - 10 µm

Typical Electrical Conductivity
> 85% IACS[1]

Application Focus:

SPACE - THRUST CHAMBERS

The high thermal conductivity of GRCop-42 greatly improves cooling of the chamber during operation. As a result, GRCop-42 allows combustion chambers to operate at higher temperatures which significantly increases efficiency. Moreover, GRCop-42 is an alloy specifically designed to meet the strength and creep requirements desired by the space industry. With a service temperature up to 750°C, GRCop-42 is therefore a go-to material for use in load-bearing high-temperature (typically 400-600°C) propulsion applications.

JUGGLE COMPLEXITY AND SIMPLIFY ASSEMBLY IN 3DXPERT

Benefit from the 3DXpert design features to generate cooling channels with unlimited complexity. Analyze your design inside the same software environment. Leverage the power of additive manufacturing to simplify assemblies by integrating additional functions such as structural elements and fixtures into a single part.

Part height	260 mm
Print time	45 h (Batch size: 1)
Layer thickness	60 µm

4. Values based on a limited sample population (<15). Values shown are typical values from density test coupons, may deviate depending on specific part geometry.
5. No surface treatment applied, measured in as printed condition according with a Keyence microscope. Values based on a limited sample population (<5).

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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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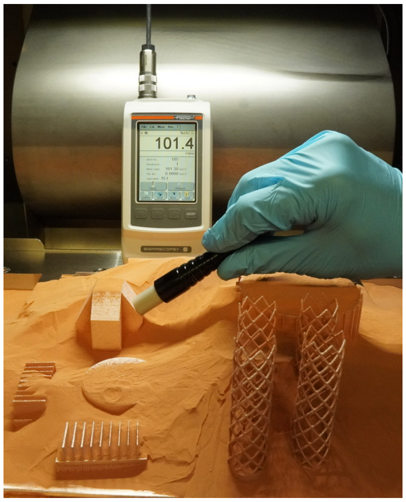
APPLICATION INSIGHT

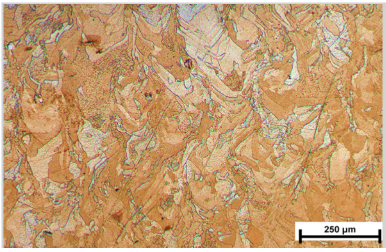
Oxygen-controlled copper printing on 3D Systems DMP platforms

For electrical applications and heat exchangers, the conductivity is the key property for choosing copper. Oxygen in the Cu matrix has a detrimental effect on the electrical and thermal conductivity of copper. Maintaining the purity of the copper powder during printing is therefore of critical importance. This is extremely challenging, given the high surface area-to-volume area for the fine powder used in L-PBF, as well as the higher temperatures in the powder bed to which the powder is exposed during the L-PBF process. Contrary to alternative LPBF systems that rely on purging with an inert gas, the 3D Systems DMP system architecture is better equipped to meet this challenge.

The robust platform architecture of the DMP Flex and Factory 350 allows for a vacuum pre-cycle prior to the printing job which actively removes air and moisture from the build chamber and the powder. After this cycle the chamber is filled with high-purity argon gas. This highly efficient and effective vacuum pre-cycle helps achieve an extremely low oxygen environment (around 5 ppm). Furthermore, the vacuum chamber's leak-tight design ensures that no oxygen can leak into the build chamber and results in exceptionally low argon consumption during printing. This vacuum chamber concept helps to eliminate the risks for oxygen pick up by the powder feedstock, resulting in stable powder chemistry and a significant enhancement of the Certified Oxygen-Free Copper powder batch reusability.

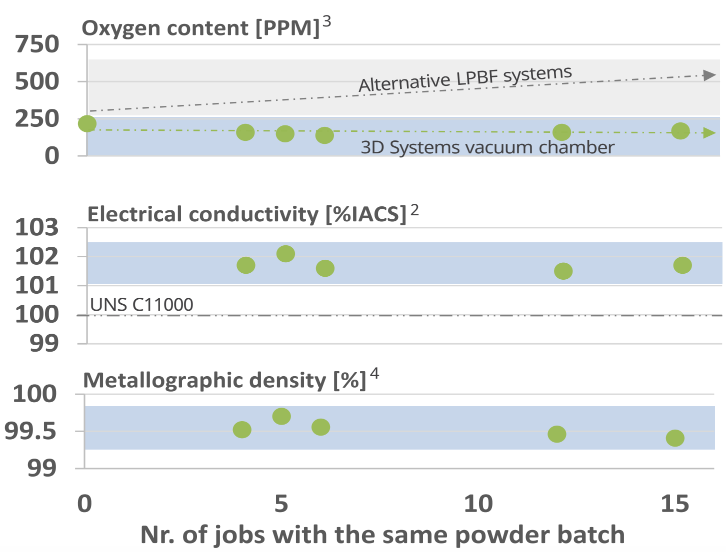


Electrical conductivity measurement after printing using the Electromagnetic (Eddy Current) method.



3D SYSTEMS CERTIFIED OXYGEN-FREE COPPER

3DSystems additively manufactured pure copper adheres to C11000. Monitoring studies on the DMP Flex 350, 1kW and the DMP Factory 350, 1kW show the Oxygen content in the solid material stays stable (typically below 250ppm) job after job[1] when reusing the same powder batch. The electrical conductivity typically exceeds 101% IACS[2] without heat treatment, directly after printing.



No oxygen pickup during reuse of the same powder batch.

Electrical conductivity above 101% IACS without heat treatment, directly after printing.

Stable part density without powder refresh.

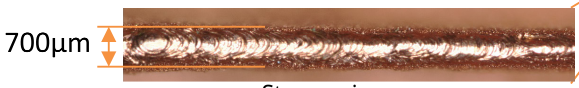
1. Tests conducted on tracking samples that were printed together with various customer application jobs, printed with the same powder batch.
2. Measured on a polished 90° surface using the electromagnetic method according to ASTM E1004-17.
3. Measured on powder (job 0) and printed parts using Fusion Analysis according to ASTM E1019.
4. Relative, based on pixel count.

Application Focus: Heat Exchanger Fins

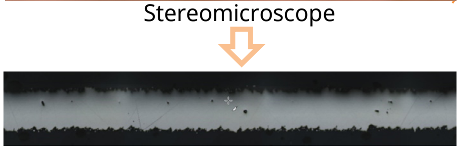
Replace Traditional Skiving by Additive and leverage the Design Freedom of Additive manufacturing to create fins for cooling applications with any bend.

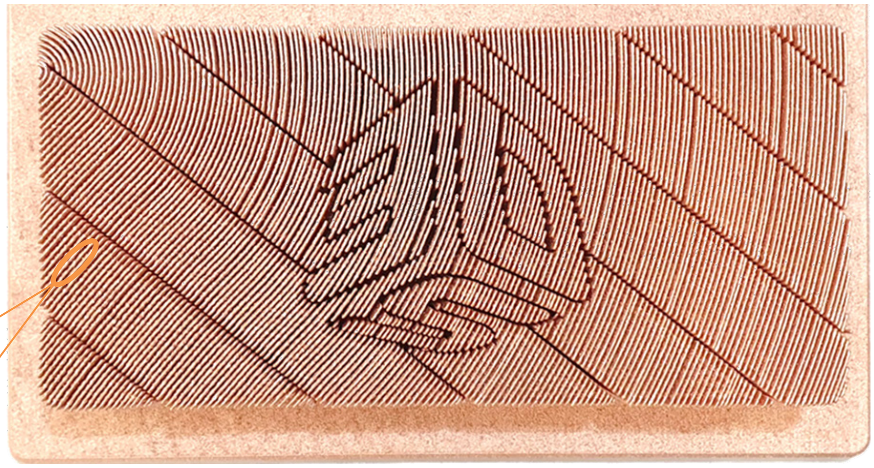
The thickness of the fins can go down to 700µm and the spacing to 400µm. Hybrid printing on a Solid Substrate is possible but the solid substrate can be printed directly as well.

Single fin: top view



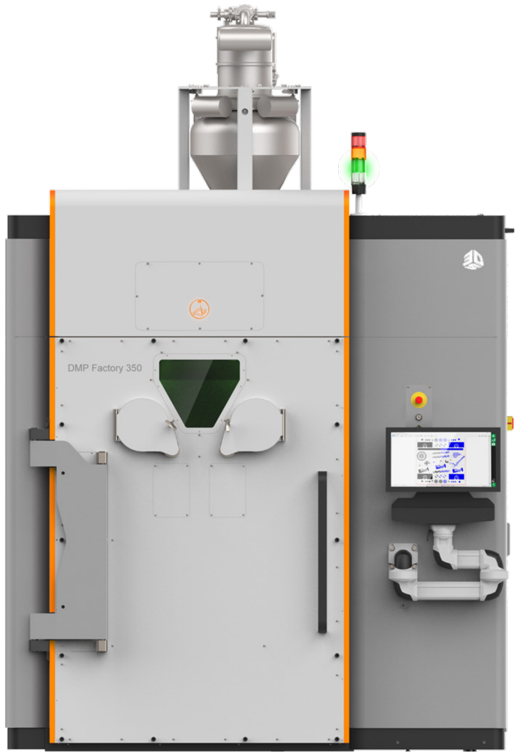
Polished





Part: Heat exchanger
Bounding box: 420x200x100 mm
Layer Thickness: 40 µm
Print time: 27h

DMP FLEX 350, 1KW DMP FACTORY 350, 1KW LT 40	TEST METHOD	AS BUILT TYPICAL VALUES[5]	
		METRIC	U.S.
Density - Relative, based on pixel count [%]	Optical	99.4	
Ultimate tensile strength [MPa | ksi] Horizontal direction - XY Vertical direction - Z	ASTM E8	155 150	22.4 21.7
Yield Strength Rp0.2% [MPa | ksi] Horizontal direction - XY Vertical direction - Z	ASTM E8	225 210	32.6 30.4
Plastic elongation [%] Horizontal direction - XY Vertical direction - Z	ASTM E8	44 60	
Electrical conductivity [%IACS][6]	ASTM E1004-17	101	
Surface roughness Ra [µm | µin][7,8] Top surface - 0° Up facing - 45° Vertical side surface - 90° Down facing - 45°	ISO 21920-2	17 11 14 43	665 430 550 1690



The robust platform architecture of the DMP Flex 350, 1kW and DMP Factory 350, 1kW allows for a vacuum pre-cycle that helps achieve an extremely low oxygen environment

5. Average value based on limited number of test samples (<15). Values might vary based on build location and part shape.
6. Measured on a polished 90° surface using the electromagnetic method according to ASTM E1004-17.
7. Measured before sandblasting using Fringe Projection with Keyence microscope . The extraction of line profile data and calculation of line roughness parameters is according to ISO 21920-2.
8. Values based on a limited sample population from test coupons, may deviate depending on specific part geometry.