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)	ASTM E8M				
Horizontal direction — XY		1060 ± 15	990 ± 25	154 ± 2	144 ± 4
Vertical direction — Z		1060 ± 15	990 ± 30	154 ± 2	144 ± 4
Yield strength Rp 0.2% (MPa | ksi)	ASTM E8M				
Horizontal direction — XY		970 ± 15	890 ± 30	141 ± 2	129 ± 4
Vertical direction — Z		960 ± 20	900 ± 50	139 ± 3	130 ± 7
Plastic elongation (%)	ASTM E8M				
Horizontal direction — XY		15 ± 3	17 ± 3	15 ± 3	17 ± 3
Vertical direction — Z		15 ± 2	17 ± 4	15 ± 2	17 ± 4
Reduction of area (%)	ASTM E8M				
Horizontal direction — XY		40 ± 8	46 ± 9	40 ± 8	46 ± 9
Vertical direction — Z		44 ± 7	48 ± 6	44 ± 7	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)	ASTM E8				
Horizontal direction — XY		1045 ± 15	955 ± 20	152 ± 2	138± 3
Vertical direction — Z		1040 ± 10	960 ± 20	152 ± 2	139 ± 3
Yield strength Rp 0.2% (MPa | ksi)	ASTM E8				
Horizontal direction — XY		940 ± 20	845 ± 20	135 ± 3	123 ± 3
Vertical direction — Z		950 ± 40	835 ± 20	137 ± 4	121 ± 3
Plastic elongation (%)	ASTM E8				
Horizontal direction — XY		19 ± 4	17 ± 4	19 ± 4	17 ± 4
Vertical direction — Z		19 ± 3	19 ± 3	18 ± 3	19 ± 3
Reduction of area (%)	ASTM E8				
Horizontal direction — XY		50 ± 10	45 ± 5	50 ± 10	45 ± 5
Vertical direction — Z		50 ± 10	45 ± 5	50 ± 10	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

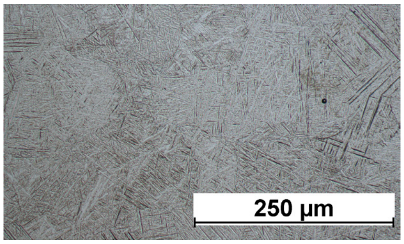
MEASUREMENT[13]	TEST METHOD	METRIC	U.S.
DMP Flex 100, DMP Flex 200[10, 15, 16, 17]			
Vertical side surface (µm | µin) Layer thickness 30 µm	NF EN ISO 4288	Typically 9	Typically 354
DMP Flex/Factory 350, DMP Flex/Factory 350 Dual, DMP Factory 500[17,18]			
Vertical side surface (µm | µin)[1, 8] Layer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

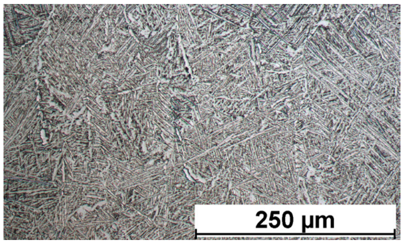
MEASUREMENT	CONDITION	METRIC	U.S.
Electrical conductivity[3] ((S/m) [x10^5])	Four point contact ASTM B193 at 20°C | 68°F	5.9 ± 0.1	5.9 ± 0.1
Thermal conductivity[12] (W/(m.K) | BTU inch/(hr.ft^2.°F))	at 20°C | 68 °F	6.70	46.5
Coefficient of thermal expansion[12] (µm/(m.°C) | µ inch/(inch.°F))	In the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

Chemical composition

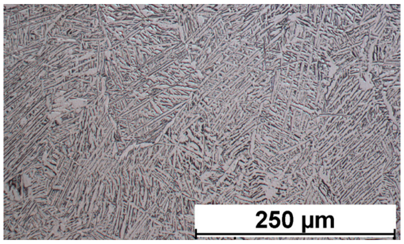
ELEMENT	% OF WEIGHT
Ti	Bal.
N	≤ 0.03
C	≤ 0.08
H	≤ 0.012
Fe	≤ 0.25
O	≤ 0.13
Al	5.50 - 6.50
V	3.50 - 4.50
Y	≤ 0.005
Other (each)	≤ 0.10
Other (total)	≤ 0.40



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.