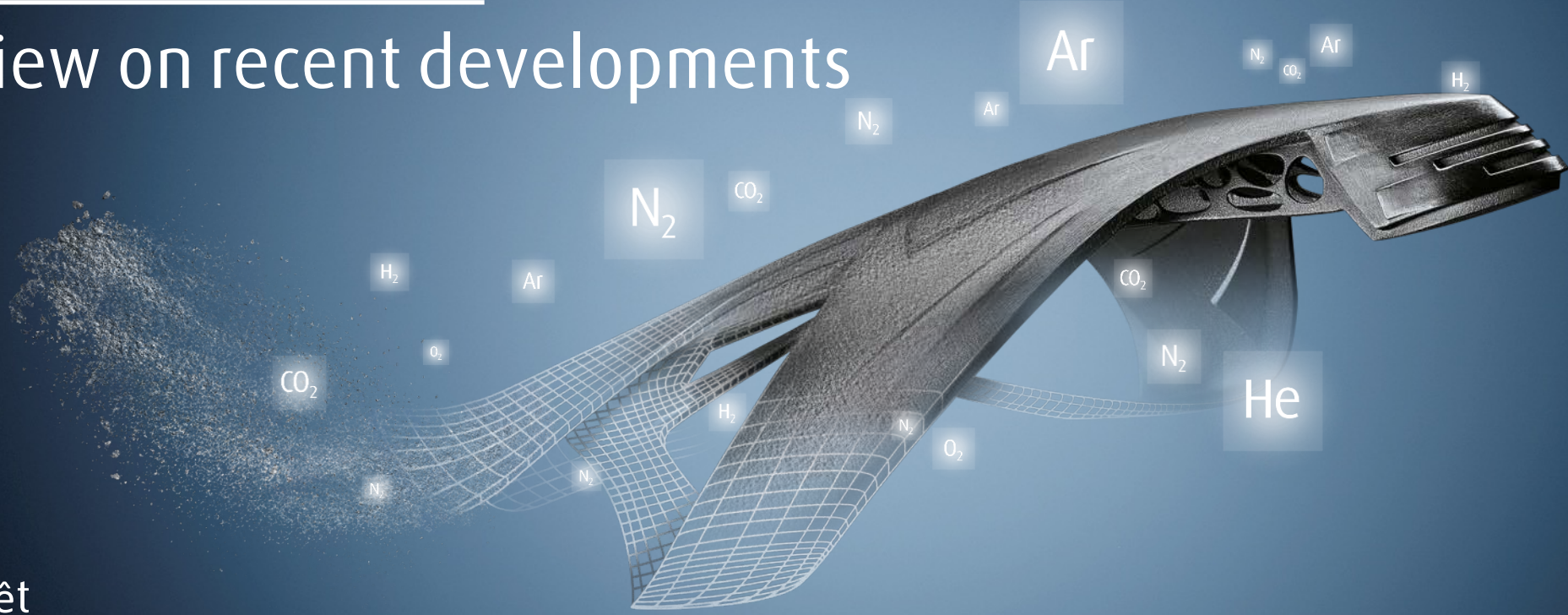


AMTC 2021

New Material Solution

Overview on recent developments



Pierre Forêt
October 2021

Making our world more productive

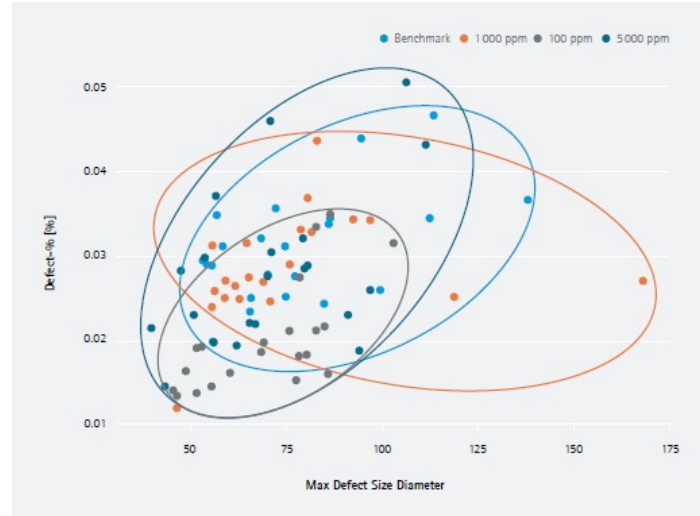
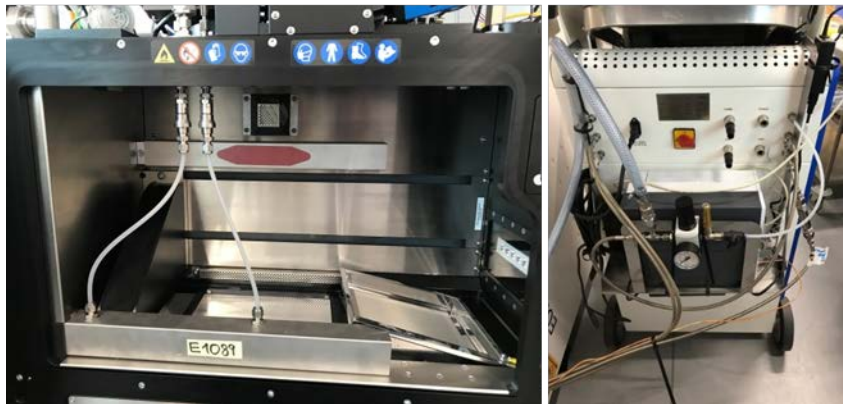




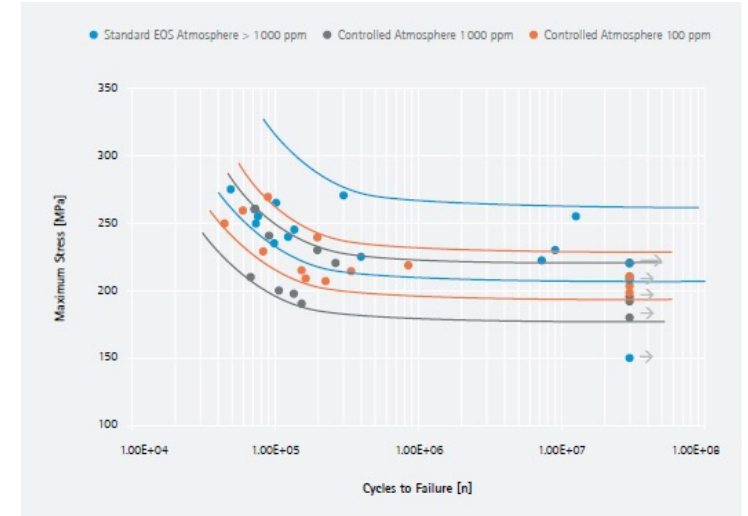
Periodic Table of Elements

1 IA 1 H Hydrogen 1.008																	18 VIIIA 2 He Helium 4.003
3 IIA 3 Li Lithium 6.941	4 IIA 4 Be Beryllium 9.012											5 IIIA 5 B Boron 10.811	6 IIIA 6 C Carbon 12.011	7 IVA 7 N Nitrogen 14.007	8 IVA 8 O Oxygen 15.999	9 VA 9 F Fluorine 18.998	10 VA 10 Ne Neon 20.180
11 IIA 11 Na Sodium 22.990	12 IIA 12 Mg Magnesium 24.305											13 IIIA 13 Al Aluminum 26.982	14 IIIA 14 Si Silicon 28.086	15 IVA 15 P Phosphorus 30.974	16 IVA 16 S Sulfur 32.066	17 VA 17 Cl Chlorine 35.453	18 VA 18 Ar Argon 39.948
19 IIB 19 K Potassium 39.098	20 IIB 20 Ca Calcium 40.078	21 IIB 21 Sc Scandium 44.956	22 IIB 22 Ti Titanium 47.88	23 IIB 23 V Vanadium 50.942	24 IIB 24 Cr Chromium 51.996	25 IIB 25 Mn Manganese 54.938	26 IIB 26 Fe Iron 55.933	27 IIB 27 Co Cobalt 58.933	28 IIB 28 Ni Nickel 58.693	29 IIB 29 Cu Copper 63.546	30 IIB 30 Zn Zinc 65.39	31 IIB 31 Ga Gallium 69.732	32 IIB 32 Ge Germanium 72.61	33 IIB 33 As Arsenic 74.922	34 IIB 34 Se Selenium 78.972	35 IIB 35 Br Bromine 79.904	36 IIB 36 Kr Krypton 84.80
37 IIB 37 Rb Rubidium 84.468	38 IIB 38 Sr Strontium 87.62	39 IIB 39 Y Yttrium 88.906	40 IIB 40 Zr Zirconium 91.224	41 IIB 41 Nb Niobium 92.906	42 IIB 42 Mo Molybdenum 95.95	43 IIB 43 Tc Technetium 98.907	44 IIB 44 Ru Ruthenium 101.07	45 IIB 45 Rh Rhodium 102.906	46 IIB 46 Pd Palladium 106.42	47 IIB 47 Ag Silver 107.868	48 IIB 48 Cd Cadmium 112.411	49 IIB 49 In Indium 114.818	50 IIB 50 Sn Tin 118.71	51 IIB 51 Sb Antimony 121.760	52 IIB 52 Te Tellurium 127.6	53 IIB 53 I Iodine 126.904	54 IIB 54 Xe Xenon 131.29
55 IIB 55 Cs Cesium 132.905	56 IIB 56 Ba Barium 137.327	57-71 IIB 57-71 La-Lu Lanthanum-Lutetium	72 IIB 72 Hf Hafnium 178.49	73 IIB 73 Ta Tantalum 180.948	74 IIB 74 W Tungsten 183.85	75 IIB 75 Re Rhenium 186.207	76 IIB 76 Os Osmium 190.23	77 IIB 77 Ir Iridium 192.22	78 IIB 78 Pt Platinum 195.08	79 IIB 79 Au Gold 196.967	80 IIB 80 Hg Mercury 200.59	81 IIB 81 Tl Thallium 204.383	82 IIB 82 Pb Lead 207.2	83 IIB 83 Bi Bismuth 208.980	84 IIB 84 Po Polonium [208.982]	85 IIB 85 At Astatine 209.987	86 IIB 86 Rn Radon 222.018
87 IIB 87 Fr Francium 223.020	88 IIB 88 Ra Radium 226.025	89-103 IIB 89-103 Ac-Lr Actinium-Lawrencium	104 IIB 104 Rf Rutherfordium [261]	105 IIB 105 Db Dubnium [262]	106 IIB 106 Sg Seaborgium [266]	107 IIB 107 Bh Bohrium [264]	108 IIB 108 Hs Hassium [269]	109 IIB 109 Mt Meitnerium [268]	110 IIB 110 Ds Darmstadtium [269]	111 IIB 111 Rg Roentgenium [272]	112 IIB 112 Cn Copernicium [277]	113 IIB 113 Uut Ununtrium	114 IIB 114 Fl Flerovium [289]	115 IIB 115 Uup Ununpentium	116 IIB 116 Lv Livermorium [292]	117 IIB 117 Uus Ununseptium	118 IIB 118 Uuo Ununoctium
57 IIB 57 La Lanthanum 138.906	58 IIB 58 Ce Cerium 140.115	59 IIB 59 Pr Praseodymium 140.908	60 IIB 60 Nd Neodymium 144.24	61 IIB 61 Pm Promethium 144.913	62 IIB 62 Sm Samarium 150.36	63 IIB 63 Eu Europium 151.966	64 IIB 64 Gd Gadolinium 157.25	65 IIB 65 Tb Terbium 158.925	66 IIB 66 Dy Dysprosium 162.50	67 IIB 67 Ho Holmium 164.930	68 IIB 68 Er Erbium 167.26	69 IIB 69 Tm Thulium 168.934	70 IIB 70 Yb Ytterbium 173.04	71 IIB 71 Lu Lutetium 174.967			
89 IIB 89 Ac Actinium 227.028	90 IIB 90 Th Thorium 232.038	91 IIB 91 Pa Protactinium 231.036	92 IIB 92 U Uranium 238.029	93 IIB 93 Np Neptunium 237.048	94 IIB 94 Pu Plutonium 244.064	95 IIB 95 Am Americium 243.061	96 IIB 96 Cm Curium 247.070	97 IIB 97 Bk Berkelium 247.070	98 IIB 98 Cf Californium 251.080	99 IIB 99 Es Einsteinium [254]	100 IIB 100 Fm Fermium 257.095	101 IIB 101 Md Mendelevium 258.1	102 IIB 102 No Nobelium 259.101	103 IIB 103 Lr Lawrencium [262]			

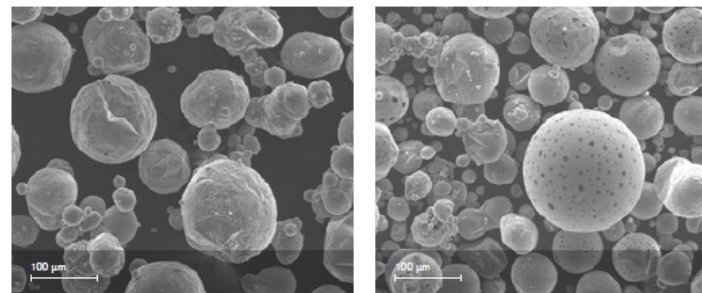
Linde and EOS leverage ADDvance O₂ precision technology for AlSi10Mg study



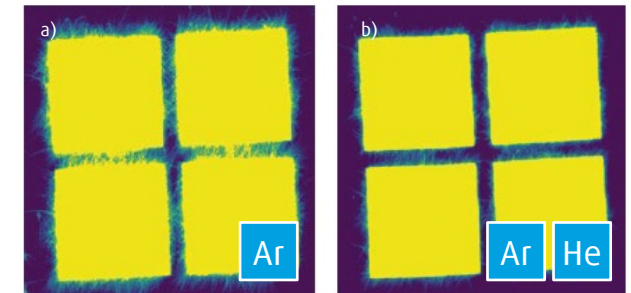
Defect percentage and maximum defect size depending of the oxygen level. Each dot represents one density cube.



Fatigue results for specimens



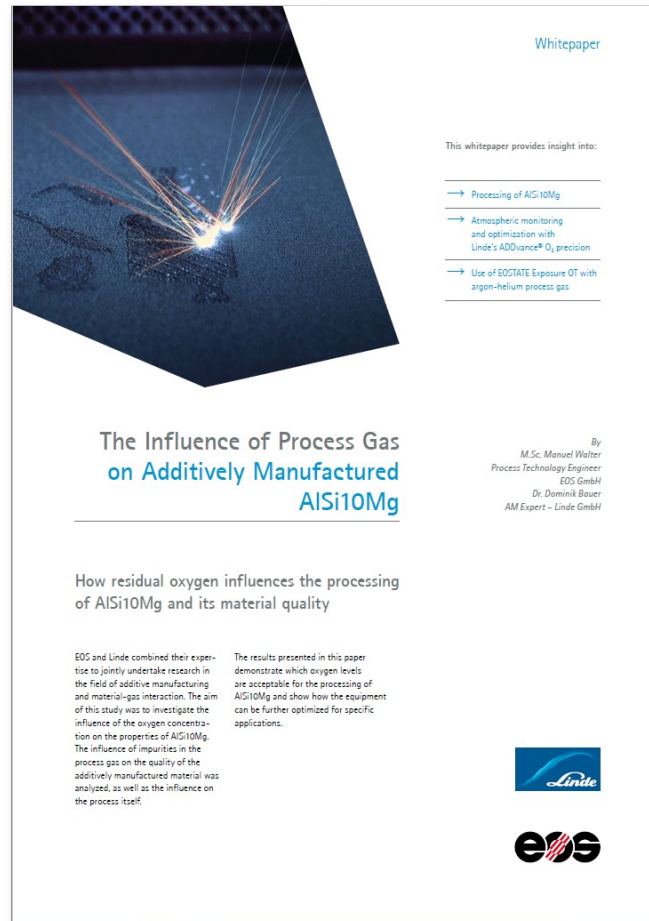
SEM images (500 X) of powder particles collected in the suction nozzles after the build for the EOS standard atmosphere condition (left) and for a process gas atmosphere with 5000 ppm of residual oxygen (right).



EOSTATE Exposure OT picture. 4 cubes with a) argon b) argon/helium process gas mixture



Linde and EOS leverage ADDvance O₂ precision technology for AlSi10Mg study



The results highlight that:

- The EOS M 290 with the EOS Aluminium AlSi10Mg powder and process parameters enable a high-quality, reproducible final part
- An oxygen content below 1000 ppm needs to be maintained during processing to prevent increasing the number and size of pores, ensure high part density and required mechanical properties
- Powder aging is reduced by keeping the O level below 1000 ppm which enables more frequent reuse of the powder
- The position of the oxygen sensor influences the measurement, with a sensor placed near to the powder bed giving optimal measurement

Ni

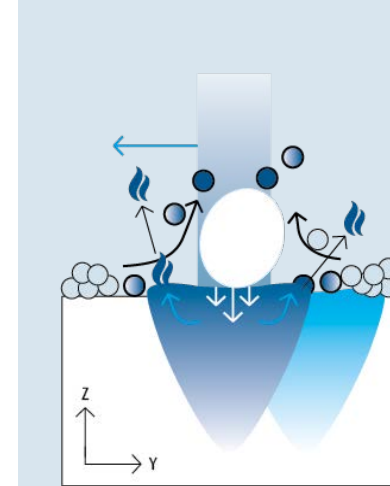
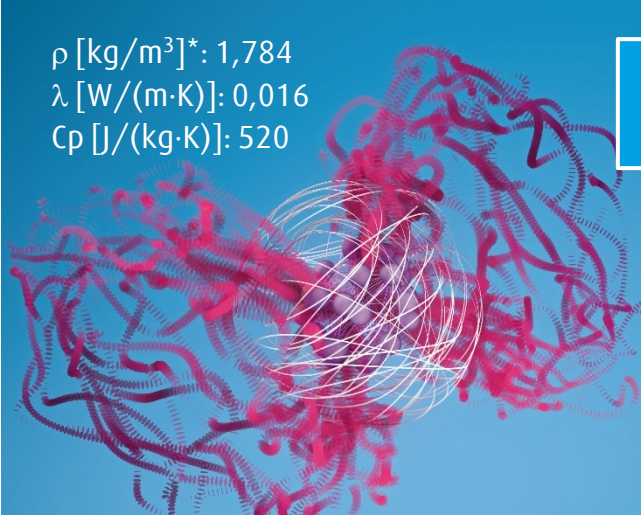
IN718 - Reduction of process by-products.

SIEMENS
ENERGY

Linde

ρ [kg/m³]*: 1,784
 λ [W/(m·K)]: 0,016
 C_p [J/(kg·K)]: 520

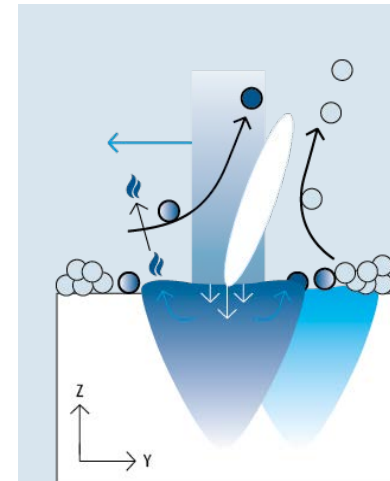
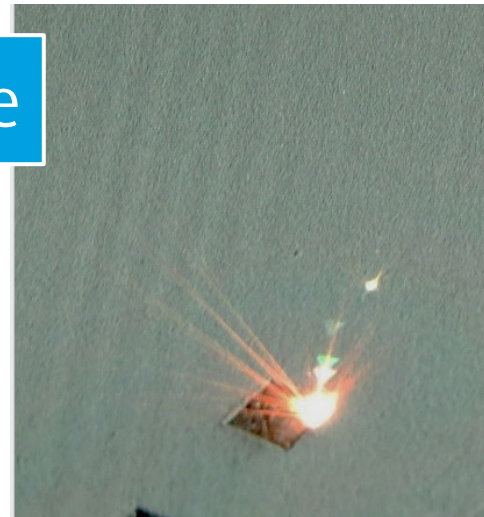
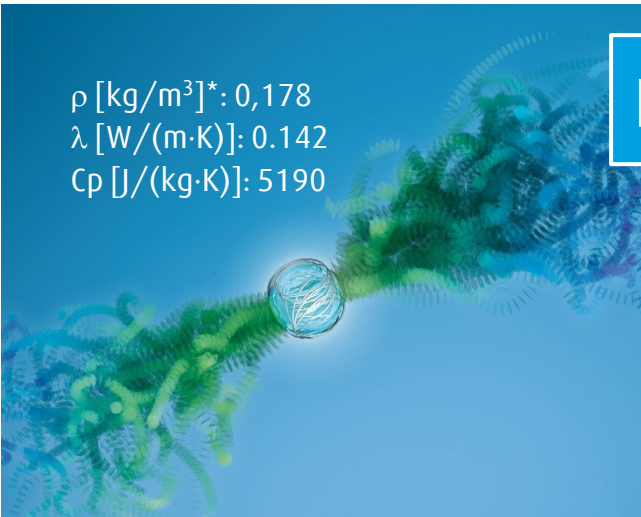
Ar



- Recoil pressure leads to process by-products
- Fumes are generated

ρ [kg/m³]*: 0,178
 λ [W/(m·K)]: 0,142
 C_p [J/(kg·K)]: 5190

He



- Recoil pressure is reduced leading to less process by-product ejections
- Less fumes are generated

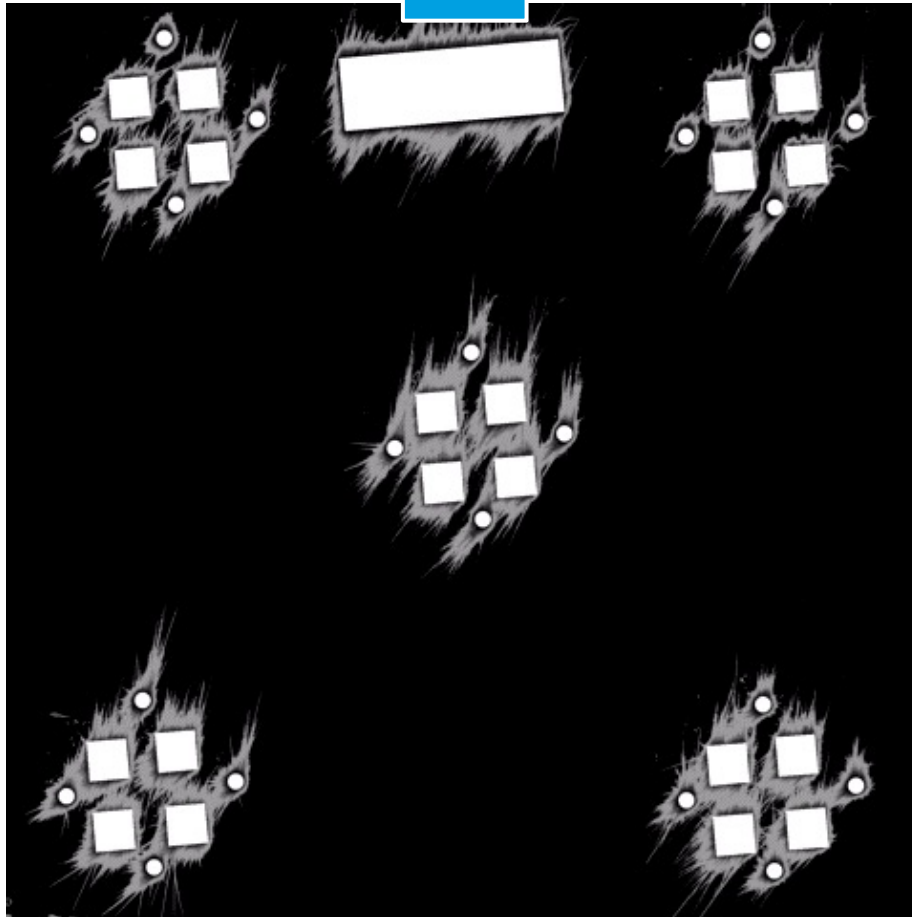
Ni

IN718 - Reduction of process by-products.

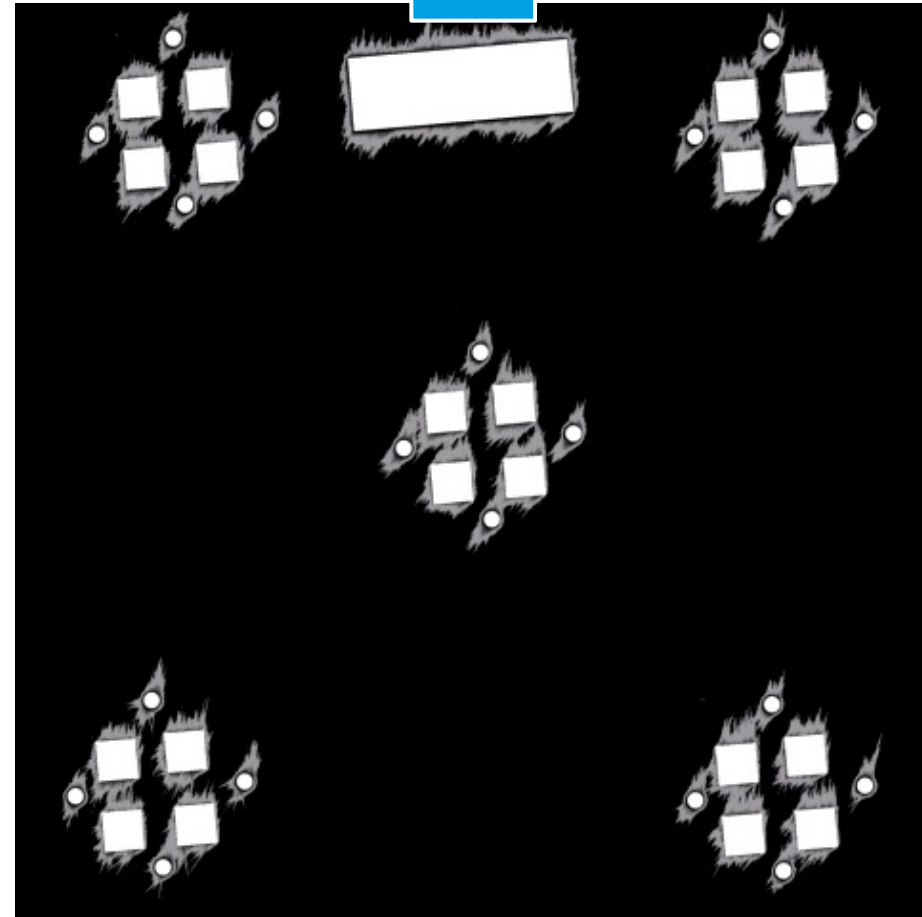
SIEMENS
ENERGY

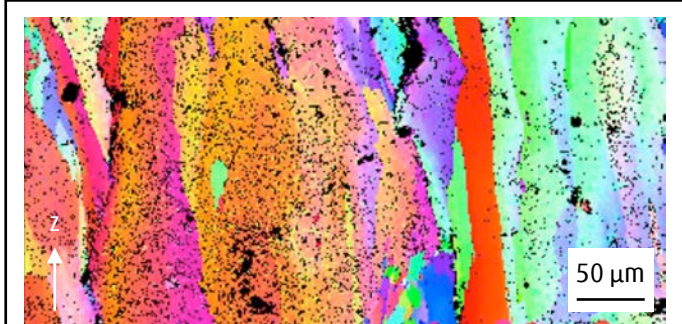
Linde

Ar



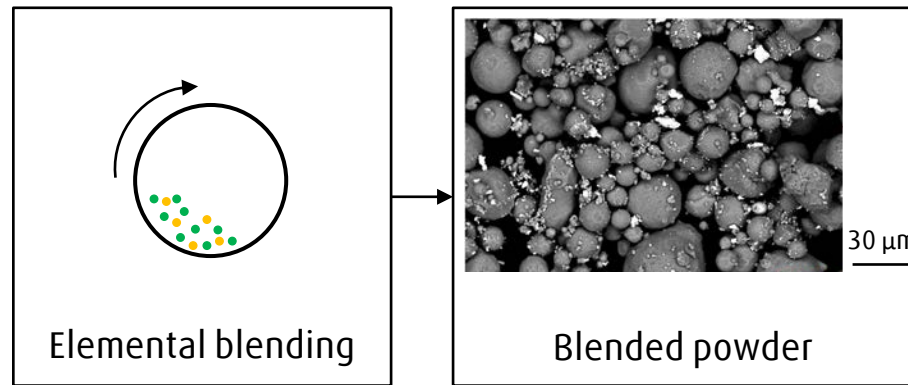
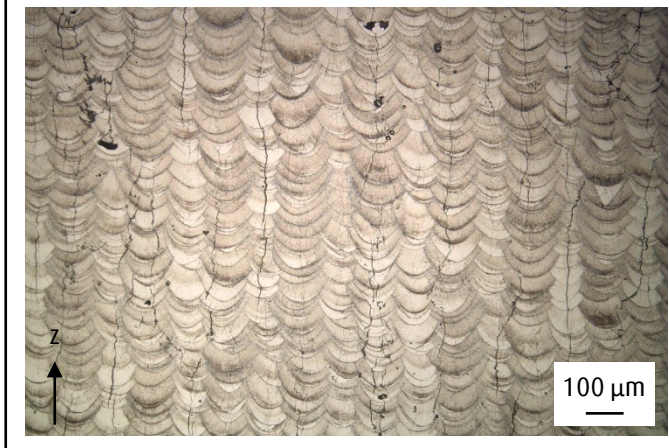
He





Pure 2000 series Al alloy in PBF-LB/M:

- Affected by hot cracking
- Elongated large grains



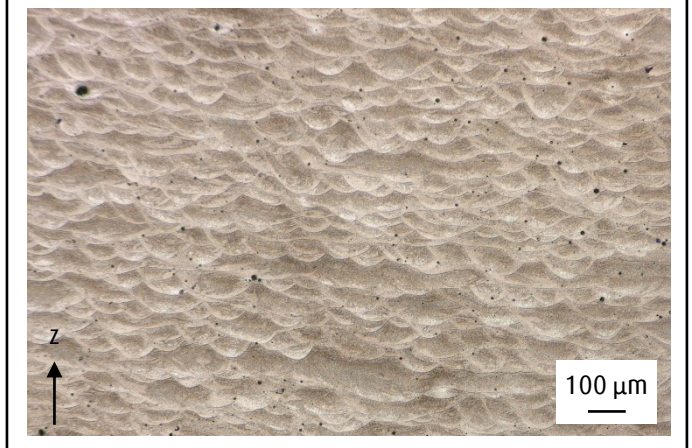
2000 series Al alloy

Selected transition metal element



Project 2000 series Al alloy in PBF-LB/M:

- No hot cracking
- Equiaxed sub-micron grains

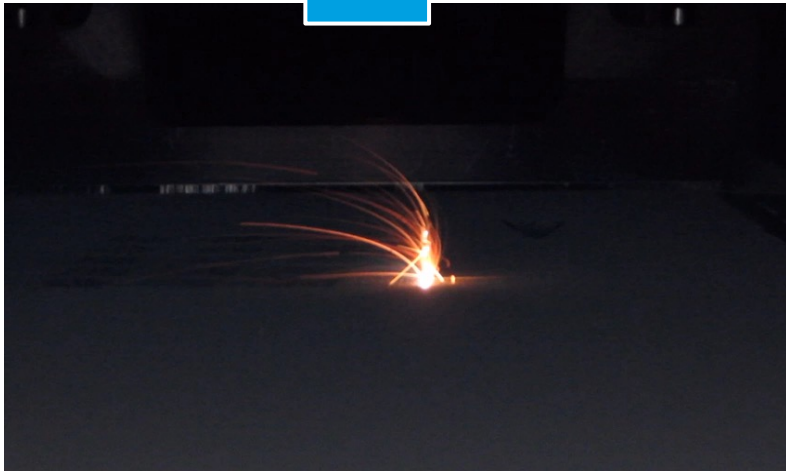




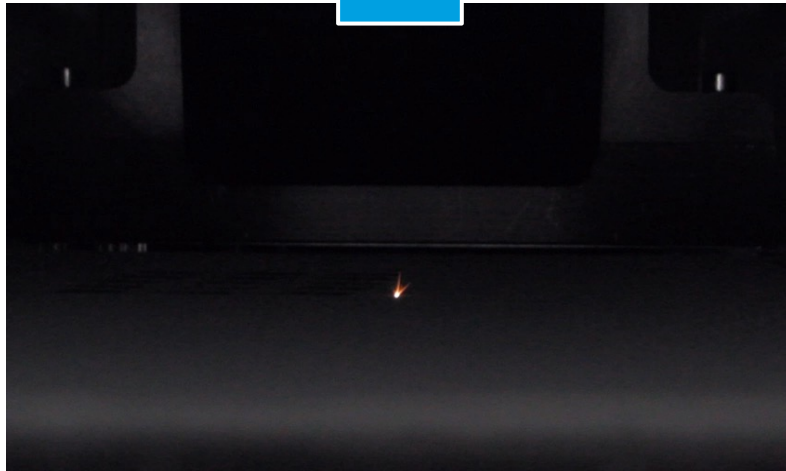
GasAlloy-X: Influence of Ar, He and CO₂ on process by-products



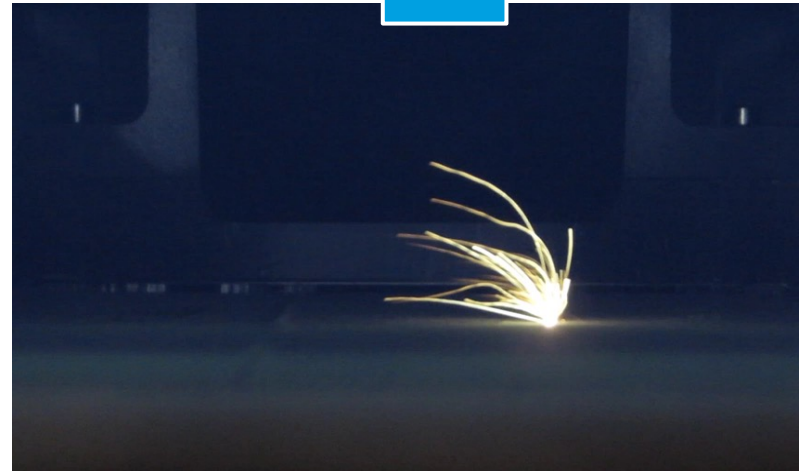
Ar



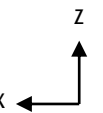
He

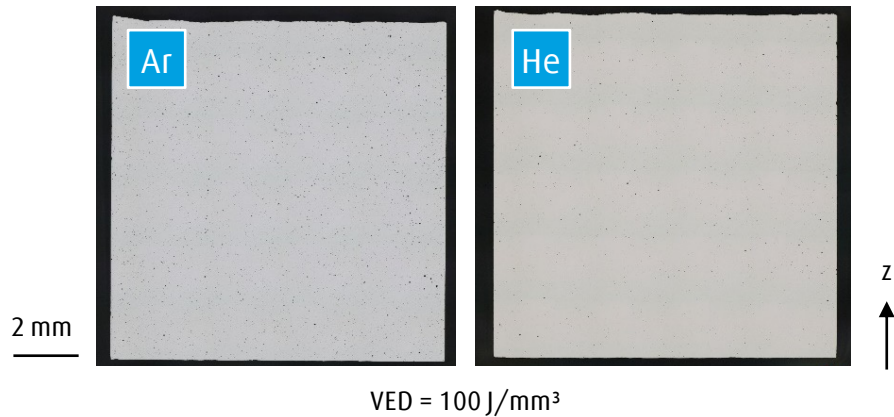
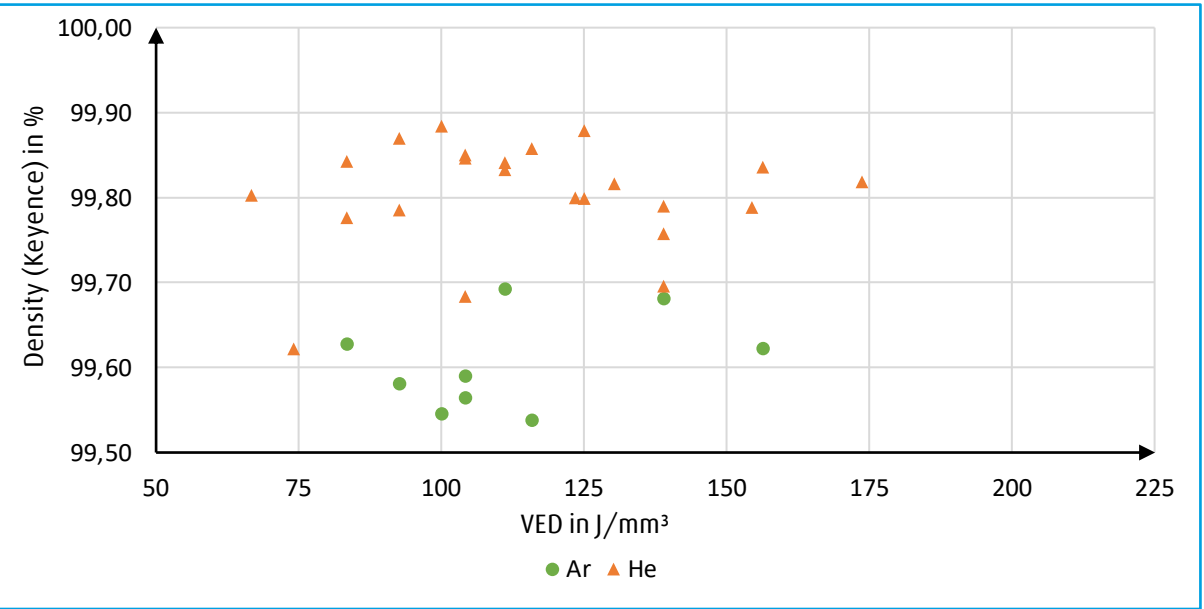
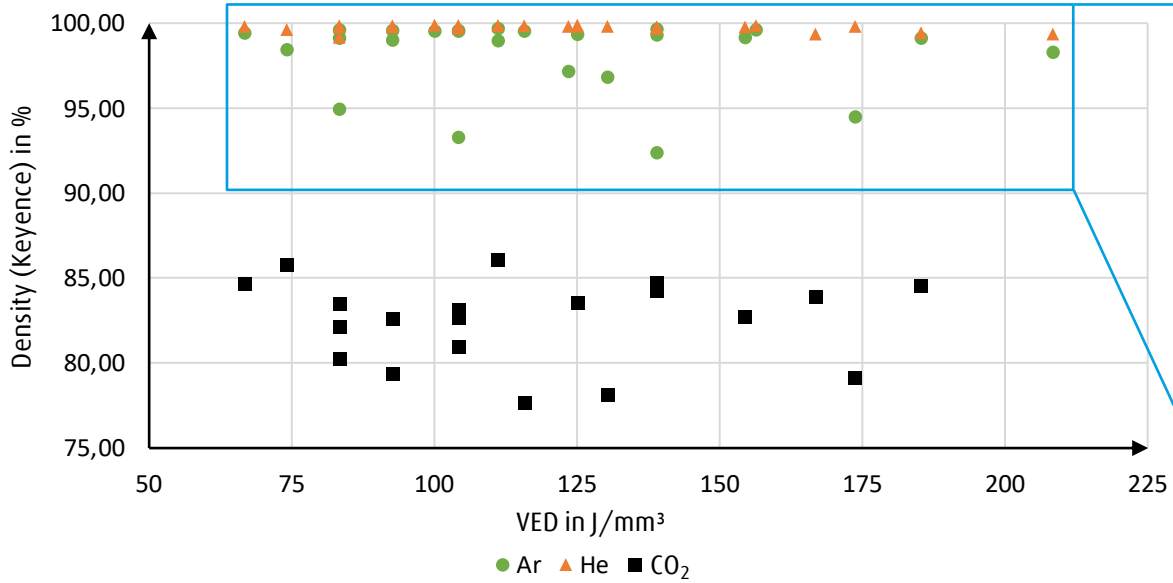


CO₂



x = gas flow direction, z = build direction



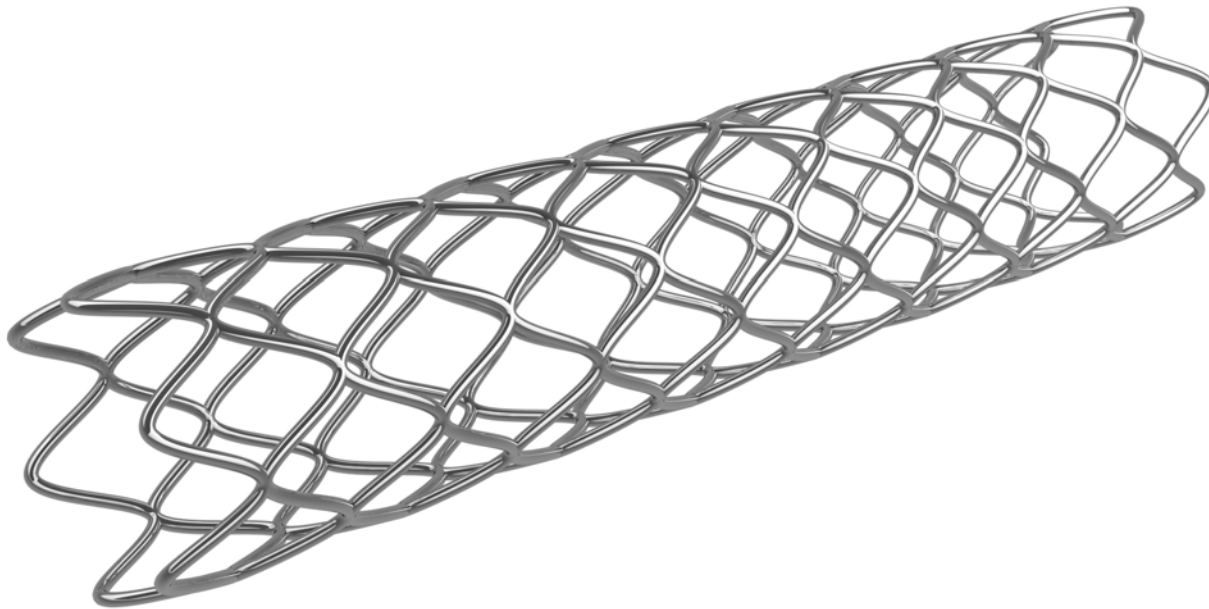


Compared to Ar and CO₂, He leads to...

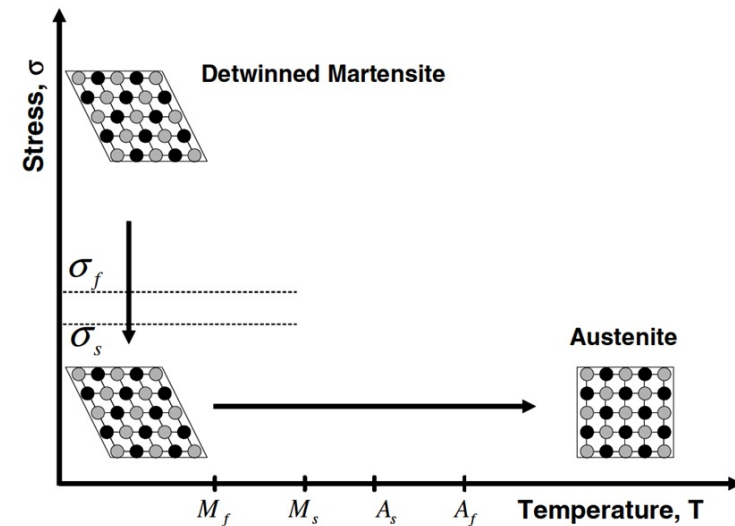
- ...consistently high bulk densities (Archimedes and optical)
- ...smooth surfaces of the printed parts
- ...less visible process by-products



Nitinol – Shape memory alloy for medical and aerospace applications – Process gas is key



Nitinol 3D printed spring.



Schematic of the shape memory effect of SMA showing the unloading and subsequent heating to austenite under no load condition

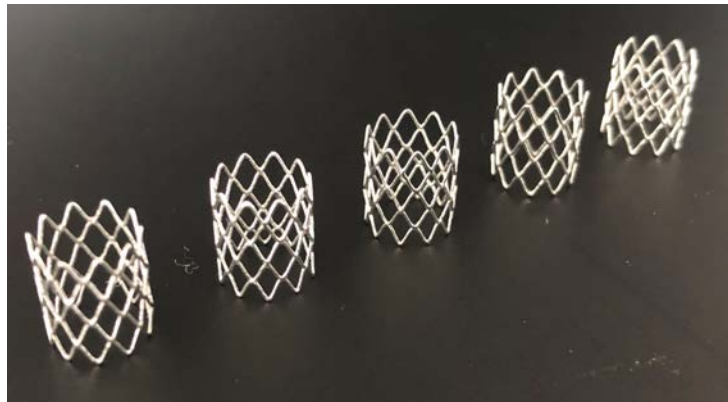


Nitinol – Shape memory alloy for medical and aerospace applications – Process gas is key



Problems

- Cold working and machining are difficult because the enormous elasticity of the alloy increases die or roll contact, leading to tremendous frictional resistance and tool wear
- Nitinol is prone to oxidation. The presence of oxygen influences the grain boundary character of the alloy.



Solution

- AM can solve manufacturing challenges for high value products for medical and aerospace applications
- O_2 level during printing $<10ppm$



<1000ppm O_2 in the printing chamber



<10ppm O_2 in the printing chamber



Nitinol – Shape memory alloy for medical and aerospace applications – Process gas is key

MARLE
3D MED LAB



<1000ppm O2 in the printing chamber



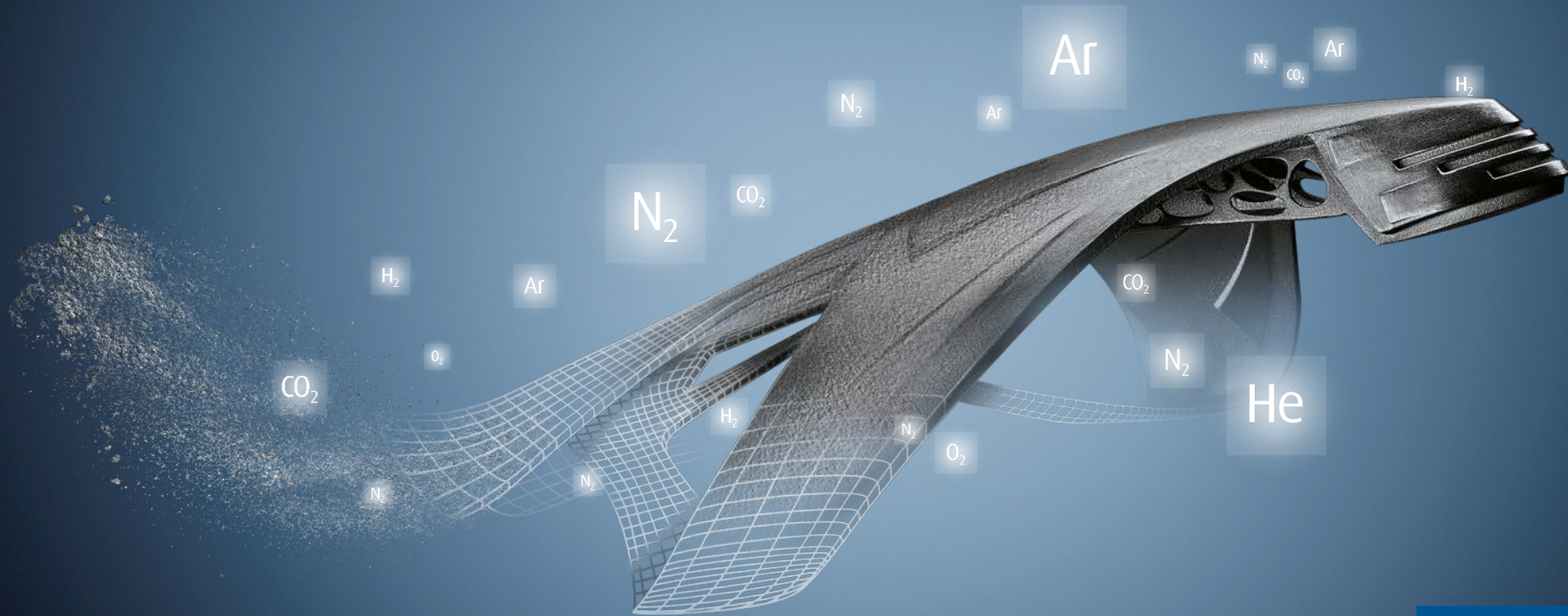
<10ppm O2 in the printing chamber



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Thank you for your attention



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Making our world more productive

