

Supplementary Information document associated with preprint

AlloyBot: On-Demand Synthesis of Bulk Alloys by Automatic Arc-Melting

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Supplementary Video Files

Supplementary video files are enclosed to illustrate the operation of the automatic synthesis system presented here:

- **Video01_Weighing_Clip01_PlaceCupOnScale.mp4:** The robot drives up to the weighing module and places a clean copper crucible into the stacking position. The robot picks up a weighing cup and places it on the scale.
- **Video02_Weighing_Clip02_DispersePelletsIntoCup.mp4:** Pellets dropping from the funnel into the weighing cup on the scale and increasing the mass on the scale display. Inside view of a pellet dispenser, showing how the rotating disk mechanism singulates the copper pellet feedstock. (Wire dispensing not included here because difficult to show in video.) Once target mass is reached, the robot moves in to pick the cup from the scale.
- **Video03_Weighing_Clip03_WeighingAndStacking.mp4:** Accelerated view illustrating how the robot sequentially weighs out four different elements. Next, a demonstration how the robot stacks the copper pellets into the crucible by carefully tilting and pouring from the weighing cup. Finally, the robot picks up the copper crucible and drives over to the arc melter, where the load-lock chamber door opens.
- **Video04_Melting_Clip01_CrucibleLoadingSequence.mp4:** Robot places the crucible inside the load-lock, the robot retracts, the load-lock closes. Inside the load-lock chamber, the transfer mechanism picks up the crucible, drives it through the open gate valve into the melting chamber, and inserts it vertically into the hearth cavity. The transfer mechanisms retracts, and the arc electrodes drive into the melting position.
- **Video05_Melting_Clip02_MeltingSequence.mp4:** Top-view of the melting electrodes positioned over the crucible and feedstock. The arcs are activated, and the heat generated begins to melt the feedstock. The melt draws in the solid feedstock, which naturally mixes and merges until a single liquid droplet has formed. (The droplet is initially slightly off-center here, and then becomes more centered due to the concave crucible floor.) The arcs are deactivated, the alloy cools and solidifies into a room temperature button.
- **Video06_Melting_Clip03_ButtonFlipping.mp4:** After each (re)melting step, the electrodes retract, the transfer mechanism drives in, lowers the scoop, and progressively tilts the button up against the crucible sidewall, until it flips upside-down for the next remelting step.

Table S1: Cost of pure elemental feedstock, as used for the calculations presented in Fig.3.

Element	<u>Pellets:</u>		<u>Wire:</u>	
	Price / USD/5ccm	Vendor	Price / USD/5ccm	Vendor
Al	\$19	Kurt J. Lesker	Confidential Quote	Kurt J. Lesker
Ag	\$299	Kurt J. Lesker	\$2,010	Goodfellow
Au	\$22,195	Kurt J. Lesker	\$17,971	Kurt J. Lesker
Ce	\$355	Kurt J. Lesker	\$355	No availability found.
Co	\$266	Kurt J. Lesker	Confidential Quote	ESPI METALS
Cr	\$13	Kurt J. Lesker	\$13	No availability found.
Cu	\$49	Kurt J. Lesker	Confidential Quote	ESPI METALS
Fe	\$56	Kurt J. Lesker	\$4,229	Goodfellow
Ge	\$451	Kurt J. Lesker	\$451	No availability found.
Hf	Confidential Quote	Kurt J. Lesker	\$7,796	Goodfellow
La	\$151	Smart Elements	\$151	No availability found.
Mg	\$16	Kurt J. Lesker	\$9,444	Goodfellow
Mn	\$17	Kurt J. Lesker	\$17	No availability found.
Mo	\$133	Kurt J. Lesker	\$720	Goodfellow
Nb	\$75	Kurt J. Lesker	Confidential Quote	Kurt J. Lesker
Ni	\$79	Kurt J. Lesker	\$251	Kurt J. Lesker
Pb	\$89	Kurt J. Lesker	\$1,563	Goodfellow
Pd	\$5,069	Kurt J. Lesker	\$18,497	Goodfellow
Pt	\$12,255	Kurt J. Lesker	\$13,207	Kurt J. Lesker
Ru	Confidential Quote	Kurt J. Lesker	Confidential Quote	No availability found.
Si	\$13	Kurt J. Lesker	\$13	No availability found.
Sn	\$75	Kurt J. Lesker	\$3,822	Goodfellow
Ta	\$263	Kurt J. Lesker	\$1,771	Goodfellow
Ti	\$57	Kurt J. Lesker	\$669	Kurt J. Lesker
V	\$173	Kurt J. Lesker	\$6,013	Goodfellow
W	\$249	Kurt J. Lesker	\$784	Goodfellow
Y	\$55	Rare World Metals Mint	\$55	No availability found.
Zn	\$29	Kurt J. Lesker	\$2,803	Goodfellow
Zr	\$67	Kurt J. Lesker	\$2,425	Goodfellow

Table S2.1: Lower bound impurity estimation based on certified feedstock values.

a)

Ti-6Al-4V	Ti	Al	V		
Pellet Impurities					
C / ppmw	10		35		
O / ppmw	240		150		
N / ppmw	11		47		
Wire Impurities					
C / ppmw	13				
O / ppmw	214				
N / ppmw	10				
Weighed in Pellet Mass / g	10.089	0.739	0.437		
Weighed in Wire Mass / g	0.074	0.000	0.021		
				Total / ug	Total / ppmw
Weighed in C / ug	102	0	15	117	10
Weighed in O / ug	2437	0	66	2503	220
Weighed in N / ug	112	0	21	132	12

b)

Ti₂₀Zr₂₀Hf₂₀Nb₂₀Ta₂₀	Ta	Nb	Hf	Zr	Ti		
Pellet Impurities							
C / ppmw	5	26	20	100	10		
O / ppmw	23	86	230	1400	240		
N / ppmw	12	42	30	46	11		
Wire Impurities							
C / ppmw			83	100	13		
O / ppmw			320	1200	214		
N / ppmw			72	30	10		
Weighed in Pellet Mass / g	7.142	3.806	7.278	3.604	1.930		
Weighed in Wire Mass / g	0.260		0.033	0.132	0.031		
						Total / ug	Total / ppmw
Weighed in C / ug	36	99	148	374	20	676	28
Weighed in O / ug	164	327	1685	5204	470	7850	324
Weighed in N / ug	86	160	221	170	22	658	27

c)

Zr₅₅Cu₃₀Ni₅Al₁₀	Zr	Cu	Al	Ni		
Pellet Impurities						
C / ppmw	100			10		
O / ppmw	1400	2		20		
N / ppmw	46			1		
Wire Impurities						
C / ppmw	100					
O / ppmw	1200					
N / ppmw	30					
Weighed in Pellet Mass / g	15.160	5.631	0.800	0.887		
Weighed in Wire Mass / g	0.006	0.133	0.060			
					Total / ug	Total / ppmw
Weighed in C / ug	1517	0	0	8	1525	67
Weighed in O / ug	21231	11	0	18	21260	938
Weighed in N / ug	698	0	0	1	699	31

Table S2.2: Lower bound impurity estimation based on certified feedstock values, modified by revised Ti feedstock impurity concentrations as measured.

a)

Ti-6Al-4V	Ti	Al	V		
Pellet Impurities					
C / ppmw	70		35		
O / ppmw	750		150		
N / ppmw	50		47		
Wire Impurities					
C / ppmw	13				
O / ppmw	214				
N / ppmw	10				
Weighed in Pellet Mass / g	10.089	0.739	0.437		
Weighed in Wire Mass / g	0.074	0.000	0.021		
				Total / ug	Total / ppmw
Weighed in C / ug	707	0	15	722	64
Weighed in O / ug	7583	0	66	7648	673
Weighed in N / ug	505	0	21	526	46

b)

Ti ₂₀ Zr ₂₀ Hf ₂₀ Nb ₂₀ Ta ₂₀	Ta	Nb	Hf	Zr	Ti		
Pellet Impurities							
C / ppmw	5	26	20	100	70		
O / ppmw	23	86	230	1400	750		
N / ppmw	12	42	30	46	50		
Wire Impurities							
C / ppmw			83	100	13		
O / ppmw			320	1200	214		
N / ppmw			72	30	10		
Weighed in Pellet Mass / g	7.142	3.806	7.278	3.604	1.930		
Weighed in Wire Mass / g	0.260		0.033	0.132	0.031		
						Total / ug	Total / ppmw
Weighed in C / ug	36	99	148	374	136	792	33
Weighed in O / ug	164	327	1685	5204	1454	8834	365
Weighed in N / ug	86	160	221	170	97	733	30

Table S3: Vendor and purities information for the feedstock used for the synthesis of the demo alloys presented in Fig.8.

Element	<u>Pellets</u>		<u>Wire</u>	
	Purity	Vendor	Purity	Vendor
Al	99.99%	Kurt J. Lesker	99.999%	Kurt J. Lesker
Cu	99.99%	Kurt J. Lesker	99.999%	ESPI Metals
Hf	99.9% excl. Zr	Kurt J. Lesker	97%	Goodfellow
Nb	99.95% excl. Ta	Kurt J. Lesker	99.95% excl. Ta	Kurt J. Lesker
Ni	99.995%	Kurt J. Lesker	99.98%	Kurt J. Lesker
Ta	99.95%	Kurt J. Lesker	99.9%	Goodfellow
Ti	99.995%	Kurt J. Lesker	99.98%	Kurt J. Lesker
V	99.7%	Kurt J. Lesker	99.8%	Goodfellow
Zr	Grade 702	Kurt J. Lesker	99.2%	Goodfellow