

## **Supplementary information for:**

### **Comparative Life Cycle Assessment and Cost Analysis of the production of Ti6Al4V-TiC Metal-Matrix Composite powder by High-Energy Ball Milling and Ti6Al4V powder by Gas Atomization**

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Table S 1. Average values and database sets for Ti-6Al-4V alloy.

Saboori et. al 2018 doi.org/10.3791/56966	Baccar et. al 2013 doi.org/10.1007/978-1-4614-4226-4_23	Dong et. al 2021 doi.org/10.1016/j.addma.2020.101699	Ti-6Al-4V average		
			Element	Percentage	ecoinvent database v3.8
5,830	6	6	Al	5,9433	Aluminium, cast alloy {GLO}  market for   APOS, U
0,080	0,3	0,07	Fe	0,1500	Cast iron {GLO}  market for   APOS, U
0,017	0,08	0,053	C	0,0500	Carbon black {GLO}  market for   APOS, U
3,890	4	4	V	3,9633	Not found in ecoinvent databases
90,124	89,36	92	Ti	93,6512	Titanium, primary {GLO}  market for   APOS, U
0,001	0	0	S	0,0005	Sulfur {GLO}  market for   APOS, U
0,013	0,01	0	H	0,0077	Hydrogen, liquid {RER}  market for   APOS, U
0,022	0,05	0,009	N	0,0270	Nitrogen, liquid {GLO}  market for   APOS, U
0,023	0,2	0,288	O	0,1703	Oxygen, liquid {GLO}  market for   APOS, U

Table S 2. Database sets for the inputs involved in the HEBM (High Energy Ball Milling) and GA (Gas Atomization) processes.

Products	Alloy quantity (kg/kg material produced)	NPs quantity (kg/kg material produced)	Energy consumption (kWh/kg material produced)	Argon used (l/kg)
<b>Ti-6Al-4V – 3,8 wt% TiC</b>	1,13	0,038	4,5	0,4
<b>Reference (ecoinvent databases v3.8)</b>	Titanium alloy, Ti-6Al-4V {GLO}  market for   APOS, U	Titanium carbide, TiC {GLO}  market for (based on SiC and B4C production and SiC market for)   APOS, U *	Electricity, medium voltage {Europe without Switzerland}  market group for   APOS, U	Argon, liquid {RER}  market for argon, liquid   APOS, U
<b>Ti6Al4V powder</b>	1,3	0	55	10.000
<b>Reference (ecoinvent databases v3.8)</b>	Titanium alloy, Ti-6Al-4V {GLO}  market for   APOS, U	-	Electricity, medium voltage {Europe without Switzerland}  market group for   APOS, U	Argon, liquid {RER}  market for argon, liquid   APOS, U

\* TiO<sub>2</sub> (Titanium dioxide {RER}| market for | APOS, U) replaces SiO<sub>2</sub> (Silica sand {GLO}| market for | APOS, U), and Chemical factory, organics {GLO}| market for | APOS, U replaces Silicone factory {RER}| construction | APOS, U.

Table S 3. Characterization factors for the HEBM (High Energy Ball Milling) process.

Impact category	Unit	Total	Ti-6Al-4V	TiC	Argon	Electricity
Climate change	kg CO <sub>2</sub> eq	5,7E+01	5,4E+01	5,5E-01	7,7E-01	1,8E+00
Ozone depletion	kg CFC11 eq	7,0E-06	6,8E-06	7,4E-08	4,9E-08	1,1E-07
Ionising radiation	kBq U-235 eq	5,5E+00	3,9E+00	1,2E-01	4,5E-01	1,0E+00
Photochemical ozone formation	kg NMVOC eq	2,2E-01	2,1E-01	2,0E-03	1,8E-03	4,0E-03
Particulate matter	disease inc.	4,6E-06	4,5E-06	3,8E-08	1,4E-08	3,1E-08
Human toxicity, non-cancer	CTUh	8,8E-07	8,4E-07	1,2E-08	7,5E-09	1,7E-08
Human toxicity, cancer	CTUh	1,1E-07	1,1E-07	1,2E-09	2,4E-10	5,3E-10
Acidification	mol H <sup>+</sup> eq	3,5E-01	3,3E-01	9,0E-03	4,2E-03	9,7E-03
Eutrophication, freshwater	kg P eq	3,1E-02	2,8E-02	2,5E-04	7,8E-04	1,8E-03
Eutrophication, marine	kg N eq	5,9E-02	5,6E-02	5,9E-04	7,4E-04	1,7E-03
Eutrophication, terrestrial	mol N eq	6,0E-01	5,8E-01	5,3E-03	6,4E-03	1,5E-02
Ecotoxicity, freshwater	CTUe	1,5E+03	1,4E+03	1,3E+01	1,1E+01	2,5E+01
Land use	Pt	2,7E+02	2,5E+02	3,8E+00	2,9E+00	6,7E+00
Water use	m <sup>3</sup> depriv.	1,8E+01	1,5E+01	5,2E-01	1,5E+00	5,6E-01
Resource use, fossils	MJ	6,7E+02	6,1E+02	8,6E+00	1,7E+01	3,8E+01
Resource use, minerals and metals	kg Sb eq	2,5E-04	2,4E-04	2,9E-06	2,2E-06	4,6E-06

Table S 4. Characterization factors for the GA (Gas Atomization) process.

Impact category	Unit	Total	Ti-6Al-4V	Argon	Electricity
Climate change	kg CO <sub>2</sub> eq	4,7E+02	6,2E+01	3,8E+02	2,2E+01
Ozone depletion	kg CFC11 eq	3,4E-05	7,8E-06	2,5E-05	1,4E-06
Ionising radiation	kBq U-235 eq	2,4E+02	4,5E+00	2,2E+02	1,3E+01
Photochemical ozone formation	kg NMVOC eq	1,2E+00	2,4E-01	8,8E-01	4,9E-02
Particulate matter	disease inc.	1,2E-05	5,2E-06	6,8E-06	3,8E-07
Human toxicity, non-cancer	CTUh	4,9E-06	9,7E-07	3,8E-06	2,1E-07
Human toxicity, cancer	CTUh	2,5E-07	1,3E-07	1,2E-07	6,5E-09
Acidification	mol H <sup>+</sup> eq	2,6E+00	3,8E-01	2,1E+00	1,2E-01
Eutrophication, freshwater	kg P eq	4,4E-01	3,2E-02	3,9E-01	2,2E-02
Eutrophication, marine	kg N eq	4,6E-01	6,4E-02	3,7E-01	2,1E-02
Eutrophication, terrestrial	mol N eq	4,0E+00	6,6E-01	3,2E+00	1,8E-01
Ecotoxicity, freshwater	CTUe	7,4E+03	1,6E+03	5,4E+03	3,0E+02
Land use	Pt	1,8E+03	2,9E+02	1,5E+03	8,1E+01
Water use	m <sup>3</sup> depriv.	7,6E+02	1,7E+01	7,4E+02	6,9E+00
Resource use, fossils	MJ	9,5E+03	7,0E+02	8,3E+03	4,6E+02
Resource use, minerals and metals	kg Sb eq	1,4E-03	2,8E-04	1,1E-03	5,6E-05

Table S 5. Normalization factors for HEBM (High Energy Ball Milling) process.

Impact category	Unit	Total	Ti-6Al-4V	TiC	Argon	Electricity
Climate change	-	7,055E-03	6,674E-03	6,847E-05	9,494E-05	2,182E-04
Ozone depletion	-	1,303E-04	1,259E-04	1,388E-06	9,138E-07	2,060E-06
Ionising radiation	-	1,306E-03	9,276E-04	2,835E-05	1,065E-04	2,433E-04
Photochemical ozone formation	-	5,420E-03	5,230E-03	4,872E-05	4,317E-05	9,867E-05
Particulate matter	-	7,777E-03	7,638E-03	6,449E-05	2,299E-05	5,167E-05
Human toxicity, non-cancer	-	3,830E-03	3,670E-03	5,253E-05	3,270E-05	7,439E-05
Human toxicity, cancer	-	6,686E-03	6,567E-03	7,364E-05	1,410E-05	3,147E-05
Acidification	-	6,388E-03	5,977E-03	1,616E-04	7,554E-05	1,740E-04
Eutrophication, freshwater	-	1,921E-02	1,745E-02	1,563E-04	4,848E-04	1,123E-03
Eutrophication, marine	-	3,013E-03	2,857E-03	3,006E-05	3,810E-05	8,749E-05
Eutrophication, terrestrial	-	3,418E-03	3,269E-03	3,018E-05	3,624E-05	8,308E-05
Ecotoxicity, freshwater	-	3,470E-02	3,355E-02	3,102E-04	2,547E-04	5,804E-04
Land use	-	3,263E-04	3,100E-04	4,596E-06	3,563E-06	8,129E-06
Water use	-	1,533E-03	1,310E-03	4,517E-05	1,287E-04	4,898E-05
Resource use, fossils	-	1,036E-02	9,393E-03	1,322E-04	2,559E-04	5,838E-04
Resource use, minerals and metals	-	3,937E-03	3,785E-03	4,532E-05	3,413E-05	7,251E-05

Table S 6. Normalization factors for GA (Gas Atomization) process.

Impact category	Unit	Total	Ti-6Al-4V	Argon	Electricity
Climate change	-	5,78E-02	7,68E-03	4,75E-02	2,67E-03
Ozone depletion	-	6,27E-04	1,45E-04	4,57E-04	2,52E-05
Ionising radiation	-	5,73E-02	1,07E-03	5,32E-02	2,97E-03
Photochemical ozone formation	-	2,88E-02	6,02E-03	2,16E-02	1,21E-03
Particulate matter	-	2,09E-02	8,79E-03	1,15E-02	6,31E-04
Human toxicity, non-cancer	-	2,15E-02	4,22E-03	1,63E-02	9,09E-04
Human toxicity, cancer	-	1,50E-02	7,56E-03	7,05E-03	3,85E-04
Acidification	-	4,68E-02	6,88E-03	3,78E-02	2,13E-03
Eutrophication, freshwater	-	2,76E-01	2,01E-02	2,42E-01	1,37E-02
Eutrophication, marine	-	2,34E-02	3,29E-03	1,90E-02	1,07E-03
Eutrophication, terrestrial	-	2,29E-02	3,76E-03	1,81E-02	1,02E-03
Ecotoxicity, freshwater	-	1,73E-01	3,86E-02	1,27E-01	7,09E-03
Land use	-	2,24E-03	3,57E-04	1,78E-03	9,94E-05
Water use	-	6,65E-02	1,51E-03	6,44E-02	5,99E-04
Resource use, fossils	-	1,46E-01	1,08E-02	1,28E-01	7,13E-03
Resource use, minerals and metals	-	2,23E-02	4,35E-03	1,71E-02	8,86E-04

Table S 7. Weighting factors for HEBM (High Energy Ball Milling) process.

Impact category	Unit	Total	Ti-6Al-4V	TiC	Argon	Electricity
<b>Total</b>	<b>mPt</b>	<b>5,9E+00</b>	<b>5,5E+00</b>	<b>6,8E-02</b>	<b>9,1E-02</b>	<b>1,9E-01</b>
Climate change	mPt	1,5E+00	1,4E+00	1,4E-02	2,0E-02	4,6E-02
Ozone depletion	mPt	8,2E-03	7,9E-03	8,8E-05	5,8E-05	1,3E-04
Ionising radiation	mPt	6,5E-02	4,6E-02	1,4E-03	5,3E-03	1,2E-02
Photochemical ozone formation	mPt	2,6E-01	2,5E-01	2,3E-03	2,1E-03	4,7E-03
Particulate matter	mPt	7,0E-01	6,8E-01	5,8E-03	2,1E-03	4,6E-03
Human toxicity, non-cancer	mPt	7,0E-02	6,8E-02	9,7E-04	6,0E-04	1,4E-03
Human toxicity, cancer	mPt	1,4E-01	1,4E-01	1,6E-03	3,0E-04	6,7E-04
Acidification	mPt	4,0E-01	3,7E-01	1,0E-02	4,7E-03	1,1E-02
Eutrophication, freshwater	mPt	5,4E-01	4,9E-01	4,4E-03	1,4E-02	3,1E-02
Eutrophication, marine	mPt	8,9E-02	8,5E-02	8,9E-04	1,1E-03	2,6E-03
Eutrophication, terrestrial	mPt	1,3E-01	1,2E-01	1,1E-03	1,3E-03	3,1E-03
Ecotoxicity, freshwater	mPt	6,7E-01	6,4E-01	6,0E-03	4,9E-03	1,1E-02
Land use	mPt	2,6E-02	2,5E-02	3,6E-04	2,8E-04	6,5E-04
Water use	mPt	1,3E-01	1,1E-01	3,8E-03	1,1E-02	4,2E-03
Resource use, fossils	mPt	8,6E-01	7,8E-01	1,1E-02	2,1E-02	4,9E-02
Resource use, minerals and metals	mPt	3,0E-01	2,9E-01	3,4E-03	2,6E-03	5,5E-03
Impact category	Unit	Total	Ti-6Al-4V	TiC	Argon	Electricity
<b>Total</b>	<b>%</b>	<b>100</b>	<b>94,09</b>	<b>1,15</b>	<b>1,56</b>	<b>3,20</b>
Climate change	%	100	94,59	0,97	1,35	3,09
Ozone depletion	%	100	96,65	1,07	0,70	1,58
Ionising radiation	%	100	71,04	2,17	8,16	18,63
Photochemical ozone formation	%	100	96,48	0,90	0,80	1,82
Particulate matter	%	100	98,21	0,83	0,30	0,66
Human toxicity, non-cancer	%	100	95,83	1,37	0,85	1,94
Human toxicity, cancer	%	100	98,22	1,10	0,21	0,47
Acidification	%	100	93,56	2,53	1,18	2,72
Eutrophication, freshwater	%	100	90,82	0,81	2,52	5,85
Eutrophication, marine	%	100	94,83	1,00	1,26	2,90
Eutrophication, terrestrial	%	100	95,63	0,88	1,06	2,43
Ecotoxicity, freshwater	%	100	96,70	0,89	0,73	1,67
Land use	%	100	95,01	1,41	1,09	2,49
Water use	%	100	85,46	2,95	8,40	3,19
Resource use, fossils	%	100	90,62	1,28	2,47	5,63
Resource use, minerals and metals	%	100	96,14	1,15	0,87	1,84

Table S 8. Weighting factors for GA (Gas Atomization) process.

Impact category	Unit	Total	Ti-6Al-4V	Argon	Electricity
<b>Total</b>	<b>mPt</b>	<b>5,42E+01</b>	<b>6,34E+00</b>	<b>4,56E+01</b>	<b>2,29E+00</b>
Climate change	mPt	1,22E+01	1,62E+00	1,00E+01	5,62E-01
Ozone depletion	mPt	3,96E-02	9,14E-03	2,88E-02	1,59E-03
Ionising radiation	mPt	2,87E+00	5,35E-02	2,67E+00	1,49E-01
Photochemical ozone formation	mPt	1,38E+00	2,88E-01	1,03E+00	5,76E-02
Particulate matter	mPt	1,87E+00	7,87E-01	1,03E+00	5,66E-02
Human toxicity, non-cancer	mPt	3,95E-01	7,77E-02	3,01E-01	1,67E-02
Human toxicity, cancer	mPt	3,19E-01	1,61E-01	1,50E-01	8,19E-03
Acidification	mPt	2,90E+00	4,26E-01	2,34E+00	1,32E-01
Eutrophication, freshwater	mPt	7,73E+00	5,62E-01	6,79E+00	3,84E-01
Eutrophication, marine	mPt	6,93E-01	9,73E-02	5,64E-01	3,17E-02
Eutrophication, terrestrial	mPt	8,49E-01	1,40E-01	6,72E-01	3,77E-02
Ecotoxicity, freshwater	mPt	3,32E+00	7,41E-01	2,45E+00	1,36E-01
Land use	mPt	1,78E-01	2,83E-02	1,41E-01	7,89E-03
Water use	mPt	5,66E+00	1,28E-01	5,48E+00	5,09E-02
Resource use, fossils	mPt	1,21E+01	8,99E-01	1,06E+01	5,94E-01
Resource use, minerals and metals	mPt	1,68E+00	3,29E-01	1,29E+00	6,69E-02
Impact category	Unit	Total	Ti-6Al-4V	Argon	Electricity
<b>Total</b>	<b>%</b>	<b>100</b>	<b>11,70</b>	<b>84,07</b>	<b>4,23</b>
Climate change	%	100	13,28	82,11	4,61
Ozone depletion	%	100	23,10	72,88	4,02
Ionising radiation	%	100	1,86	92,95	5,19
Photochemical ozone formation	%	100	20,89	74,93	4,19
Particulate matter	%	100	42,02	54,97	3,02
Human toxicity, non-cancer	%	100	19,66	76,11	4,23
Human toxicity, cancer	%	100	50,40	47,04	2,57
Acidification	%	100	14,70	80,75	4,55
Eutrophication, freshwater	%	100	7,27	87,76	4,97
Eutrophication, marine	%	100	14,04	81,39	4,57
Eutrophication, terrestrial	%	100	16,42	79,14	4,43
Ecotoxicity, freshwater	%	100	22,31	73,59	4,10
Land use	%	100	15,94	79,62	4,44
Water use	%	100	2,27	96,83	0,90
Resource use, fossils	%	100	7,41	87,70	4,89
Resource use, minerals and metals	%	100	19,52	76,51	3,97



