

Supplementary Materials

Health risk assessment of personal exposure to fine particulate matter and elements among blacksmith workers in Indonesia

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Supplementary Figure 1. Metal CA spider charts per occupation group.

Supplementary Figure 2. Individual metal Hazard Quotients (HQ) by occupation, 8-panel grid.

Supplementary Figure 3. Scatter plots of PM/metal concentrations vs risk indices with Spearman rho.

Supplementary Table 1. Job-specific inhalation exposure parameters by occupation group

Supplementary Table 2. Reference concentrations (RfC) and inhalation unit risk (IUR) values used in health risk characterisation.

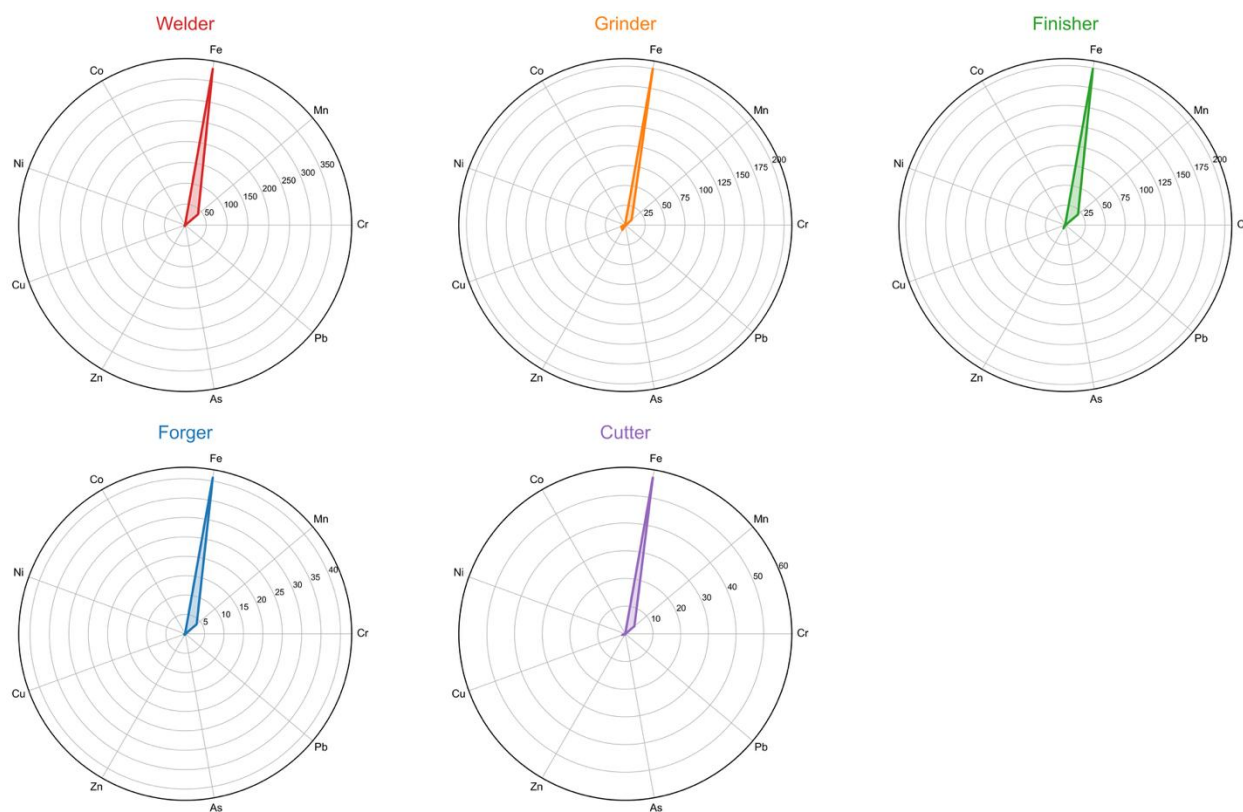
Supplementary Table 3. Descriptive statistics of particulate matter concentrations ($\mu\text{g}/\text{m}^3$) by occupation and size fraction. SD = standard deviation; P95 = 95th percentile. All values in $\mu\text{g}/\text{m}^3$.

Supplementary Table 4. Full PM and Elemental composition by occupation group.

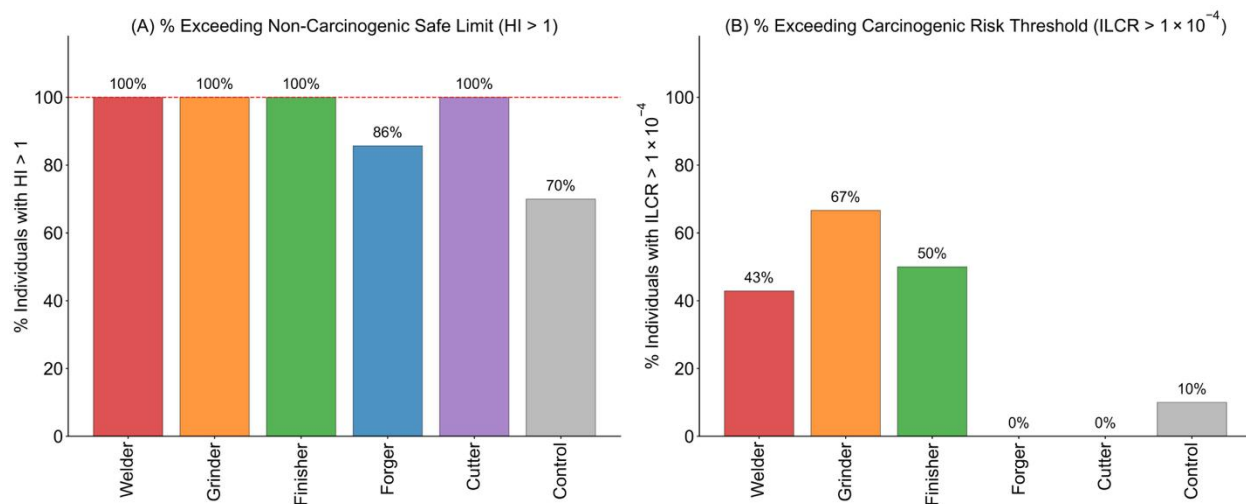
Supplementary Table 5. Full EC-NonCar and EC-Car by metal and occupation group.

Supplementary Table 6. Health risk summary: Hazard Index (HI) and total Incremental Lifetime Cancer Risk (ILCR_{total}) by occupation group. % > Limit: percentage of individuals exceeding HI=1 (non-carcinogenic) or ILCR= 1×10^{-4} (carcinogenic upper threshold).

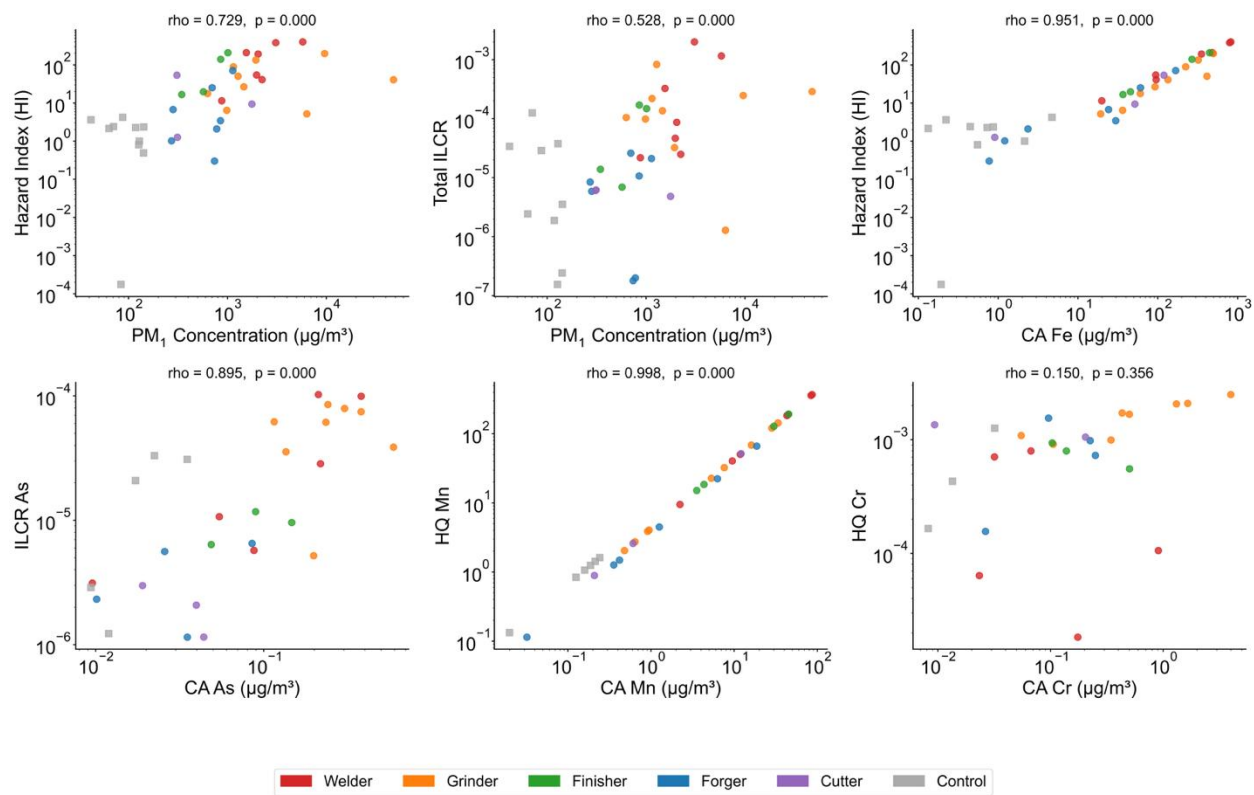
Supplementary Table 7. Health risk summary



Supplementary Figure 1. Metal CA spider charts per occupation group.



Supplementary Figure 2. Risk exceedance frequencies by occupation. (A) % individuals with HI>1. (B) % individuals with ILCR_{total}> 1×10^{-4} .



Supplementary Figure 3. Scatter plots of PM/metal concentrations vs risk indices with Spearman rho.

Supplementary Table 1. Job-specific inhalation exposure parameters by occupation group

Occupation	n	ET (h/day)	EF (days/yr)	ED (years) mean $\pm$ SD	AT-car (h)
Welder	7	6	311	19.0 $\pm$ 10.5	613,200
Grinder	9	6	311	17.8 $\pm$ 11.8	613,200
Finisher	4	6	311	7.3 $\pm$ 3.2	613,200
Forger	7	5	311	12.4 $\pm$ 7.8	613,200
Cutter	3	6	311	6.0 $\pm$ 5.3	613,200
Control	10	8	365	35.3 $\pm$ 26.5	613,200

ET = exposure time; EF = exposure frequency; ED = exposure duration; AT-car = averaging time for the carcinogenic pathway ($70 \text{ yr} \times 365 \text{ days} \times 24 \text{ h} = 613,200 \text{ h}$, applied uniformly to all participants). AT-noncar = $\text{ED} \times 365 \times 24 \text{ h}$, varies by individual (US EPA, 2009)

Supplementary Table 2. Reference concentrations (RfC) and inhalation unit risk (IUR) values used in health risk characterisation

Element	CAS No.	Target Species/ Compound	Toxicological Endpoint	RfC ($\mu\text{g}/\text{m}^3$)	IUR ($\mu\text{g}/\text{m}^3$) ⁻¹	Source
Al	7429-90-5	Metal fume/dust	Respiratory	—	—	—
Si	7440-21-3	Elemental	Respiratory	—	—	—
S	7704-34-9	SO ₂	Respiratory	—	—	—
Cl	7782-50-5	Cl ₂ gas	Respiratory	—	—	—
K	7440-09-7	Elemental	—	—	—	—
Ca	7440-70-2	Elemental	—	—	—	—
Ti	7440-32-6	Elemental	—	—	—	—
Cr	7440-47-3	Elemental	Respiratory	1,000	—	OSHA
Mn	7439-96-5	Elemental	Neurological	0.05	—	US EPA IRIS
Fe	7439-89-6	Elemental	—	—	—	—
Co	7440-48-4	Elemental	Respiratory/carcinogenic	0.02	9×10^{-3}	US EPA IRIS
Ni	7440-02-0	Elemental	Respiratory/carcinogenic	0.014	2.4×10^{-4}	US EPA IRIS
Cu	7440-50-8	Elemental	Respiratory	100	—	OEHHA
Zn	7440-66-6	Elemental	Respiratory	5,000	—	OSHA
As	7440-38-2	Elemental	Carcinogenic	0.015	4.3×10^{-3}	US EPA IRIS
Pb	7439-92-1	Elemental	Neurological/carcinogenic	0.15	8×10^{-5}	US EPA NAAQS/ RSL

RfC = inhalation reference concentration; IUR = inhalation unit risk; — = no established value applied in this study. RfC sources: US EPA IRIS (2023, 2024a), ATSDR (2021), US EPA NAAQS (2022), OSHA, OEHHA (2024). IUR sources: US EPA IRIS (2024b), US EPA Regional Screening Levels (RSL) (2024a). Access date: January 2026.

Supplementary Table 3. Descriptive statistics of particulate matter concentrations ($\mu\text{g}/\text{m}^3$) by occupation and size fraction

Variable / Occupation	n	Mean	SD	Median	P95	Max
PM_{0.5} Concentration ($\mu\text{g}/\text{m}^3$)						
Welder	7	774	631	768	1,550	1,600
Grinder	9	963	1,152	501	2,969	3,662
Finisher	4	446	285	375	783	851
Forger	7	300	250	180	638	698
Cutter	3	193	121	231	286	292
Control	10	39.3	15.6	38.6	62.5	64.1
PM_{0.5-1} Concentration ($\mu\text{g}/\text{m}^3$)						
Welder	7	1,733	1,268	1,485	3,659	4,341.6
Grinder	9	6,945	14,201	1,009	29,536	44,115.6
Finisher	4	250	138	193	418	452.7
Forger	7	380	225	390	635	638.2
Cutter	3	603	762	255	1,354	1,476.2
Control	10	61.3	24.7	58.9	95.7	107.1
PM₁ (total) ($\mu\text{g}/\text{m}^3$)						
Welder	7	2,507	1,590	2,044	4,969	5,777
Grinder	9	7,908	15,258	1,467	32,506	47,778
Finisher	4	696	296	713	988	1,011
Forger	7	680	309	741	1,049	1,134
Cutter	3	796	842	312	1,622	1,768
Control	10	101	35.7	103	142	143

SD = standard deviation; P95 = 95th percentile. All values in $\mu\text{g}/\text{m}^3$. *Kruskal-Wallis (all groups): PM total $H=30.78$, $p<0.001$. Mann-Whitney U (Workers vs Controls): $U=300$, $p=0.000003$*

Supplementary Table 4. Full PM and Elemental composition by occupation group

Group	Occupation	Variable	n	Mean	SD	Median	P25	P75	P95	Max
Worker	Welder	PM<0.5	7	774	631	768	176	1287	1550	1600
Worker	Welder	PM0.5–1	7	1733	1268	1485	845	1957	3659	4342
Worker	Welder	PM_total	7	2507	1590	2044	1764	2662	4969	5777
Worker	Welder	EC_PM<0.5	7	165	134	164	38	274	330	341
Worker	Welder	EC_PM0.5–1	7	369	270	316	180	417	779	925
Worker	Welder	EC_PM_total	7	534	339	435	376	567	1059	1231
Worker	Welder	CA_Al	7	1.1	1.6	0.3	0.0	1.9	3.6	3.7
Worker	Welder	CA_Si	7	92.7	80.8	101.9	17.8	149.2	195.7	207.7
Worker	Welder	CA_S	7	4.6	4.0	4.9	0.7	8.5	8.8	8.8
Worker	Welder	CA_Cl	7	2.5	1.7	1.7	1.1	4.0	4.6	4.8
Worker	Welder	CA_K	7	71.2	65.7	64.9	14.1	118.2	159.5	162.9
Worker	Welder	CA_Ca	7	0.6	0.6	0.5	0.2	0.8	1.4	1.7
Worker	Welder	CA_Ti	7	6.3	5.7	5.8	1.7	9.8	14.4	15.0
Worker	Welder	CA_Cr	7	0.4	0.4	0.2	0.0	0.7	1.0	1.1
Worker	Welder	CA_Mn	7	40.3	34.9	43.1	10.7	64.3	85.9	86.7
Worker	Welder	CA_Fe	7	380	334	353	95	638	813	821
Worker	Welder	CA_Co	7	0.8	0.8	0.6	0.1	1.5	1.9	1.9
Worker	Welder	CA_Ni	7	0.1	0.1	0.1	0.0	0.1	0.3	0.3
Worker	Welder	CA_Cu	7	1.7	2.4	0.5	0.2	2.3	5.6	6.7
Worker	Welder	CA_Zn	7	2.8	2.7	1.5	0.9	4.3	6.8	7.4

Group	Occupation	Variable	n	Mean	SD	Median	P25	P75	P95	Max
Worker	Welder	CA_As	7	0.1	0.1	0.1	0.0	0.2	0.3	0.4
Worker	Welder	CA_Pb	7	0.5	0.5	0.4	0.3	0.5	1.3	1.5
Worker	Grinder	PM<0.5	9	963	1152	504	268	931	2969	3662
Worker	Grinder	PM0.5–1	9	6945	14201	1009	646	6203	29536	44116
Worker	Grinder	PM_total	9	7908	15258	1467	1149	6343	32506	47778
Worker	Grinder	EC_PM<0.5	9	205	245	107	57	198	633	780
Worker	Grinder	EC_PM0.5–1	9	1479	3025	215	138	1321	6292	9397
Worker	Grinder	EC_PM_total	9	1685	3250	312	245	1351	6924	10177
Worker	Grinder	CA_Al	9	6.8	3.6	7.8	4.7	9.7	10.9	11.7
Worker	Grinder	CA_Si	9	28.4	33.4	17.2	1.1	51.2	80.3	95.1
Worker	Grinder	CA_S	9	8.5	6.3	9.7	1.3	11.5	16.6	16.6
Worker	Grinder	CA_Cl	9	3.3	2.6	2.7	1.6	3.7	7.5	9.0
Worker	Grinder	CA_K	9	25.9	28.7	17.2	4.3	31.8	74.6	78.8
Worker	Grinder	CA_Ca	9	3.3	3.5	1.2	0.8	4.3	9.2	10.0
Worker	Grinder	CA_Ti	9	4.3	5.2	2.1	0.1	7.0	12.6	15.1
Worker	Grinder	CA_Cr	9	1.0	1.2	0.5	0.3	1.3	3.1	4.0
Worker	Grinder	CA_Mn	9	10.5	12.8	5.3	0.9	16.1	31.6	33.7
Worker	Grinder	CA_Fe	9	200	175	134	60	321	463	497
Worker	Grinder	CA_Co	9	0.5	0.6	0.3	0.0	0.5	1.4	1.5
Worker	Grinder	CA_Ni	9	0.6	0.6	0.5	0.2	0.7	1.6	1.9
Worker	Grinder	CA_Cu	9	5.4	4.0	5.3	1.8	8.2	10.5	11.7

Group	Occupation	Variable	n	Mean	SD	Median	P25	P75	P95	Max
Worker	Grinder	CA_Zn	9	7.1	9.4	1.4	0.4	9.3	22.9	27.0
Worker	Grinder	CA_As	9	0.2	0.2	0.2	0.1	0.3	0.5	0.6
Worker	Grinder	CA_Pb	9	0.8	0.8	0.6	0.1	1.6	2.0	2.2
Worker	Finisher	PM<0.5	4	446	285	375	307	514	783	851
Worker	Finisher	PM0.5–1	4	250	138	193	162	280	418	453
Worker	Finisher	PM_total	4	696	296	713	515	894	988	1011
Worker	Finisher	EC_PM<0.5	4	95.0	60.8	80.0	65.4	109.6	166.9	181.2
Worker	Finisher	EC_PM0.5–1	4	53.2	29.5	41.1	34.5	59.7	89.1	96.4
Worker	Finisher	EC_PM_total	4	148	63	152	110	190	210	215
Worker	Finisher	CA_Al	4	3.6	0.7	3.7	3.4	3.9	4.3	4.4
Worker	Finisher	CA_Si	4	39.1	34.3	33.8	10.4	62.4	75.3	78.6
Worker	Finisher	CA_S	4	6.3	2.9	5.3	4.5	7.1	9.8	10.5
Worker	Finisher	CA_Cl	4	3.6	3.4	2.3	1.7	4.2	7.7	8.5
Worker	Finisher	CA_K	4	38.5	36.8	29.6	10.8	57.3	80.8	86.7
Worker	Finisher	CA_Ca	4	1.0	1.0	0.6	0.5	1.1	2.2	2.5
Worker	Finisher	CA_Ti	4	2.7	2.5	2.4	0.8	4.4	5.4	5.7
Worker	Finisher	CA_Cr	4	0.2	0.2	0.1	0.1	0.2	0.4	0.5
Worker	Finisher	CA_Mn	4	20.8	20.4	17.2	4.1	33.8	42.9	45.2
Worker	Finisher	CA_Fe	4	199	196	157	43	312	419	446
Worker	Finisher	CA_Co	4	0.4	0.5	0.3	0.1	0.7	0.9	1.0
Worker	Finisher	CA_Ni	4	0.1	0.1	0.1	0.0	0.2	0.3	0.3

Group	Occupation	Variable	n	Mean	SD	Median	P25	P75	P95	Max
Worker	Finisher	CA_Cu	4	1.0	1.0	0.9	0.2	1.7	2.0	2.1
Worker	Finisher	CA_Zn	4	4.8	5.2	3.8	0.9	7.7	10.7	11.4
Worker	Finisher	CA_As	4	0.1	0.1	0.1	0.0	0.1	0.1	0.1
Worker	Finisher	CA_Pb	4	0.4	0.3	0.4	0.2	0.7	0.7	0.7
Worker	Forger	PM<0.5	7	300	250	180	106	478	638	698
Worker	Forger	PM0.5–1	7	380	225	390	202	575	635	638
Worker	Forger	PM_total	7	680	309	741	492	815	1049	1134
Worker	Forger	EC_PM<0.5	7	53.2	44.3	31.9	18.8	84.9	113.2	124.0
Worker	Forger	EC_PM0.5–1	7	67.5	39.9	69.3	35.8	102.1	112.8	113.3
Worker	Forger	EC_PM_total	7	121	54.9	132	87	145	186	201
Worker	Forger	CA_Al	7	4.1	2.7	4.1	2.4	5.1	7.8	8.7
Worker	Forger	CA_Si	7	7.1	13.0	0.5	0.4	6.9	28.2	34.7
Worker	Forger	CA_S	7	13.9	19.4	9.2	1.2	15.2	43.3	55.3
Worker	Forger	CA_Cl	7	8.2	10.5	2.8	1.3	12.5	24.6	26.9
Worker	Forger	CA_K	7	63.3	89.4	19.8	8.7	76.0	200.0	252.8
Worker	Forger	CA_Ca	7	2.9	4.2	0.8	0.6	2.9	9.5	12.0
Worker	Forger	CA_Ti	7	1.1	1.5	0.2	0.0	1.7	3.3	3.6
Worker	Forger	CA_Cr	7	0.1	0.1	0.0	0.0	0.2	0.2	0.3
Worker	Forger	CA_Mn	7	3.9	6.9	0.4	0.2	3.8	15.0	18.7
Worker	Forger	CA_Fe	7	40.9	59.7	24.2	1.8	45.2	135.2	167.2
Worker	Forger	CA_Co	7	0.1	0.1	0.0	0.0	0.1	0.2	0.3

Group	Occupation	Variable	n	Mean	SD	Median	P25	P75	P95	Max
Worker	Forger	CA_Ni	7	0.1	0.0	0.1	0.1	0.1	0.1	0.1
Worker	Forger	CA_Cu	7	0.3	0.2	0.3	0.1	0.5	0.6	0.7
Worker	Forger	CA_Zn	7	0.3	0.3	0.1	0.1	0.5	0.8	0.9
Worker	Forger	CA_As	7	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Worker	Forger	CA_Pb	7	0.1	0.2	0.0	0.0	0.2	0.5	0.5
Worker	Cutter	PM<0.5	3	193	121	231	144	261	286	292
Worker	Cutter	PM0.5–1	3	603	762	255	166	865	1354	1476
Worker	Cutter	PM_total	3	796	842	312	310	1040	1622	1768
Worker	Cutter	EC_PM<0.5	3	41.2	25.8	49.2	30.7	55.6	60.8	62.1
Worker	Cutter	EC_PM0.5–1	3	128	162	54	35	184	288	315
Worker	Cutter	EC_PM_total	3	170	179	67	66	222	346	377
Worker	Cutter	CA_Al	3	3.8	3.3	4.9	2.5	5.6	6.2	6.3
Worker	Cutter	CA_Si	3	8.1	12.6	0.9	0.8	11.8	20.5	22.7
Worker	Cutter	CA_S	3	3.8	4.2	3.1	1.6	5.7	7.8	8.3
Worker	Cutter	CA_Cl	3	1.5	1.7	0.7	0.5	2.0	3.1	3.4
Worker	Cutter	CA_K	3	14.5	19.1	7.4	3.7	21.8	33.3	36.2
Worker	Cutter	CA_Ca	3	0.5	0.4	0.5	0.3	0.7	0.8	0.8
Worker	Cutter	CA_Ti	3	0.8	1.0	0.3	0.2	1.1	1.8	2.0
Worker	Cutter	CA_Cr	3	0.1	0.1	0.0	0.0	0.1	0.2	0.2
Worker	Cutter	CA_Mn	3	4.3	6.8	0.6	0.4	6.4	11.0	12.1
Worker	Cutter	CA_Fe	3	57.3	59.3	51.7	26.3	85.5	112.4	119.2

Group	Occupation	Variable	n	Mean	SD	Median	P25	P75	P95	Max
Worker	Cutter	CA_Co	3	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Worker	Cutter	CA_Ni	3	0.1	0.2	0.0	0.0	0.2	0.3	0.4
Worker	Cutter	CA_Cu	3	1.2	1.7	0.3	0.2	1.7	2.9	3.1
Worker	Cutter	CA_Zn	3	0.3	0.4	0.2	0.1	0.5	0.7	0.8
Worker	Cutter	CA_As	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Worker	Cutter	CA_Pb	3	0.2	0.2	0.1	0.0	0.2	0.4	0.4
Control	Control	PM<0.5	10	39.3	15.6	38.6	31.5	45.5	62.5	64.1
Control	Control	PM0.5–1	10	61.3	24.7	58.9	40.9	77.8	95.7	107.1
Control	Control	PM_total	10	101	35.7	103	74.0	128	142	143
Control	Control	EC_PM<0.5	10	13.1	5.2	12.9	10.5	15.2	20.8	21.4
Control	Control	EC_PM0.5–1	10	20.4	8.2	19.6	13.6	25.9	31.9	35.7
Control	Control	EC_PM_total	10	33.5	11.9	34.3	24.7	42.8	47.4	47.5
Control	Control	CA_Al	10	2.4	1.7	2.7	1.0	3.7	4.3	4.6
Control	Control	CA_Si	10	0.2	0.1	0.2	0.1	0.3	0.4	0.4
Control	Control	CA_S	10	0.7	1.0	0.0	0.0	1.2	2.5	2.7
Control	Control	CA_Cl	10	0.2	0.5	0.0	0.0	0.0	1.2	1.4
Control	Control	CA_K	10	0.4	0.7	0.0	0.0	0.7	1.6	2.3
Control	Control	CA_Ca	10	0.1	0.1	0.0	0.0	0.1	0.2	0.2
Control	Control	CA_Ti	10	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Control	Control	CA_Cr	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Control	Control	CA_Mn	10	0.1	0.1	0.1	0.0	0.2	0.2	0.2

Group	Occupation	Variable	n	Mean	SD	Median	P25	P75	P95	Max
Control	Control	CA_Fe	10	1.0	1.4	0.5	0.2	0.8	3.6	4.7
Control	Control	CA_Co	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Control	Control	CA_Ni	10	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Control	Control	CA_Cu	10	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Control	Control	CA_Zn	10	0.2	0.3	0.1	0.0	0.3	0.7	1.0
Control	Control	CA_As	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Control	Control	CA_Pb	10	0.0	0.1	0.0	0.0	0.1	0.1	0.1

Supplementary Table 5. Full EC-NonCar and EC-Car by metal and occupation group

Occupation	Metal	EC-NonCar	EC-NonCar	EC-NonCar	EC-Car	EC-Car	EC-Car
		Mean	SD	Median	Mean	SD	Median
Welder	Al	0.24	0.35	0.06	0.07	0.10	0.02
Welder	Si	19.8	17.2	21.7	5.9	8.4	2.0
Welder	S	0.99	0.86	1.05	0.26	0.35	0.13
Welder	Cl	0.53	0.36	0.37	0.15	0.17	0.06
Welder	K	15.16	13.99	13.83	4.61	6.43	1.29
Welder	Ca	0.13	0.12	0.10	0.04	0.07	0.02
Welder	Ti	1.35	1.22	1.23	0.43	0.61	0.16
Welder	Cr	0.09	0.10	0.04	0.02	0.03	0.00
Welder	Mn	8.58	7.43	9.17	2.59	3.49	0.72
Welder	Fe	80.9	71.2	75.1	24.6	33.1	7.2
Welder	Co	0.17	0.18	0.12	0.05	0.08	0.01
Welder	Ni	0.02	0.02	0.02	0.00	0.00	0.00
Welder	Cu	0.37	0.52	0.10	0.08	0.10	0.02
Welder	Zn	0.61	0.57	0.32	0.18	0.18	0.07
Welder	As	0.03	0.03	0.02	0.01	0.01	0.00
Welder	Pb	0.11	0.11	0.09	0.03	0.04	0.01
Grinder	Al	1.44	0.77	1.67	0.29	0.25	0.21
Grinder	Si	6.04	7.12	3.66	0.84	1.03	0.35
Grinder	S	1.80	1.34	2.08	0.32	0.26	0.25

Occupation	Metal	EC-NonCar	EC-NonCar	EC-NonCar	EC-Car	EC-Car	EC-Car
		Mean	SD	Median	Mean	SD	Median
Grinder	Cl	0.70	0.55	0.57	0.12	0.06	0.14
Grinder	K	5.53	6.11	3.66	0.72	0.50	0.57
Grinder	Ca	0.69	0.75	0.25	0.14	0.19	0.05
Grinder	Ti	0.91	1.11	0.44	0.17	0.30	0.04
Grinder	Cr	0.21	0.26	0.11	0.04	0.03	0.03
Grinder	Mn	2.23	2.72	1.13	0.27	0.25	0.17
Grinder	Fe	42.5	37.2	28.6	7.7	7.3	7.6
Grinder	Co	0.10	0.12	0.07	0.02	0.03	0.00
Grinder	Ni	0.13	0.13	0.10	0.03	0.03	0.03
Grinder	Cu	1.14	0.85	1.13	0.26	0.23	0.22
Grinder	Zn	1.52	2.01	0.30	0.21	0.28	0.06
Grinder	As	0.05	0.04	0.05	0.01	0.01	0.01
Grinder	Pb	0.17	0.18	0.12	0.03	0.05	0.02
Finisher	Al	0.77	0.16	0.79	0.08	0.05	0.08
Finisher	Si	8.33	7.30	7.19	0.84	0.76	0.76
Finisher	S	1.35	0.61	1.12	0.13	0.06	0.15
Finisher	Cl	0.76	0.72	0.50	0.07	0.05	0.07
Finisher	K	8.20	7.83	6.30	0.80	0.68	0.84
Finisher	Ca	0.22	0.21	0.12	0.03	0.03	0.01
Finisher	Ti	0.58	0.53	0.51	0.06	0.05	0.06

Occupation	Metal	EC-NonCar	EC-NonCar	EC-NonCar	EC-Car	EC-Car	EC-Car
		Mean	SD	Median	Mean	SD	Median
Finisher	Cr	0.04	0.05	0.03	0.00	0.00	0.00
Finisher	Mn	4.43	4.34	3.66	0.44	0.42	0.41
Finisher	Fe	42.3	41.8	33.3	4.19	3.84	4.08
Finisher	Co	0.09	0.10	0.07	0.01	0.01	0.01
Finisher	Ni	0.03	0.03	0.02	0.00	0.00	0.00
Finisher	Cu	0.21	0.21	0.19	0.02	0.02	0.02
Finisher	Zn	1.02	1.11	0.81	0.10	0.10	0.09
Finisher	As	0.02	0.01	0.01	0.00	0.00	0.00
Finisher	Pb	0.09	0.07	0.09	0.01	0.01	0.01
Forger	Al	0.72	0.49	0.73	0.10	0.07	0.08
Forger	Si	1.26	2.32	0.09	0.08	0.11	0.02
Forger	S	2.48	3.44	1.64	0.26	0.28	0.11
Forger	Cl	1.46	1.87	0.49	0.17	0.20	0.08
Forger	K	11.24	15.87	3.51	1.06	1.18	0.58
Forger	Ca	0.51	0.75	0.14	0.08	0.12	0.03
Forger	Ti	0.19	0.26	0.04	0.03	0.07	0.01
Forger	Cr	0.02	0.02	0.00	0.00	0.00	0.00
Forger	Mn	0.69	1.22	0.07	0.05	0.06	0.01
Forger	Fe	7.25	10.60	4.29	0.66	0.59	0.83
Forger	Co	0.01	0.02	0.00	0.00	0.00	0.00

Occupation	Metal	EC-NonCar	EC-NonCar	EC-NonCar	EC-Car	EC-Car	EC-Car
		Mean	SD	Median	Mean	SD	Median
Forger	Ni	0.01	0.01	0.01	0.00	0.00	0.00
Forger	Cu	0.05	0.04	0.05	0.01	0.01	0.00
Forger	Zn	0.06	0.06	0.02	0.01	0.01	0.00
Forger	As	0.00	0.01	0.00	0.00	0.00	0.00
Forger	Pb	0.02	0.04	0.00	0.00	0.01	0.00
Cutter	Al	0.80	0.71	1.05	0.04	0.04	0.03
Cutter	Si	1.73	2.68	0.19	0.06	0.07	0.03
Cutter	S	0.81	0.89	0.65	0.03	0.02	0.04
Cutter	Cl	0.31	0.36	0.14	0.01	0.01	0.01
Cutter	K	3.10	4.07	1.59	0.10	0.11	0.09
Cutter	Ca	0.10	0.08	0.11	0.01	0.00	0.00
Cutter	Ti	0.17	0.21	0.07	0.01	0.00	0.01
Cutter	Cr	0.02	0.02	0.00	0.00	0.00	0.00
Cutter	Mn	0.92	1.44	0.13	0.03	0.04	0.01
Cutter	Fe	12.20	12.64	11.02	0.46	0.38	0.63
Cutter	Co	0.01	0.01	0.00	0.00	0.00	0.00
Cutter	Ni	0.03	0.04	0.01	0.00	0.00	0.00
Cutter	Cu	0.25	0.37	0.07	0.01	0.02	0.00
Cutter	Zn	0.07	0.09	0.04	0.00	0.00	0.00
Cutter	As	0.01	0.00	0.01	0.00	0.00	0.00

Occupation	Metal	EC-NonCar	EC-NonCar	EC-NonCar	EC-Car	EC-Car	EC-Car
		Mean	SD	Median	Mean	SD	Median
Cutter	Pb	0.04	0.05	0.01	0.00	0.00	0.00
Control	Al	0.81	0.56	0.90	0.42	0.49	0.20
Control	Si	0.06	0.05	0.06	0.04	0.05	0.01
Control	S	0.23	0.35	0.00	0.07	0.12	0.00
Control	Cl	0.08	0.17	0.01	0.04	0.08	0.00
Control	K	0.15	0.25	0.00	0.05	0.09	0.00
Control	Ca	0.02	0.03	0.00	0.01	0.02	0.00
Control	Ti	0.00	0.01	0.00	0.00	0.01	0.00
Control	Cr	0.00	0.00	0.00	0.00	0.00	0.00
Control	Mn	0.03	0.03	0.02	0.02	0.03	0.01
Control	Fe	0.33	0.48	0.17	0.24	0.44	0.05
Control	Co	0.00	0.01	0.00	0.00	0.00	0.00
Control	Ni	0.01	0.01	0.01	0.01	0.01	0.00
Control	Cu	0.00	0.01	0.00	0.00	0.00	0.00
Control	Zn	0.07	0.10	0.03	0.05	0.09	0.01
Control	As	0.00	0.00	0.00	0.00	0.00	0.00
Control	Pb	0.01	0.02	0.00	0.01	0.02	0.00

Supplementary Table 6. Health risk summary

Occupation	n	Mean	SD	Median	P95	Max	% > Limit
Hazard Index (HI) — safe limit = 1							
Welder	7	184	160	193	395	400	100%
Grinder	9	63.2	65.8	40.7	173	199	100%
Finisher	4	96.4	94.6	80.0	199	209	100%
Forger	7	15.7	25.9	3.4	57.2	70.9	85.7%
Cutter	3	21.4	28.2	9.4	49.3	53.7	100%
Control	10	1.93	1.36	2.21	3.96	4.22	70%
ILCR total — upper threshold = 1×10^{-4}							
Welder (1×10^{-4})	7	5.2	7.7	0.87	17	20	42.9%
Grinder (1×10^{-4})	9	2.2	2.5	1.4	6.1	8.3	66.7%
Finisher (1×10^{-4})	4	0.85	0.86	0.81	1.7	1.7	50.0%
Forger (1×10^{-4})	7	0.1	0.10	0.08	0.25	0.26	0%
Cutter (1×10^{-4})	3	0.06	0.008	0.06	0.06	0.06	0%
Control (1×10^{-4})	10	0.23	0.39	0.03	0.86	1.3	10%

Hazard Index (HI) and total Incremental Lifetime Cancer Risk (ILCR_total) by occupation group. % > Limit: percentage of individuals exceeding HI=1 (non-carcinogenic) or ILCR= 1×10^{-4} (carcinogenic upper threshold). * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$ vs Control (Mann-Whitney U, two-sided). HI dominated by HQ_Mn. ILCR_total driven by ILCR_Co.

Supplementary Table 7. Health risk summary

Group	Occupation	Variable	n	Mean	SD	Median	P25	P75	P95	Max	Pct > Limit
Worker	Welder	HQ_Cr	7	0.0002	0.0004	0.0001	0	0.0004	0.0008	0.0008	0
Worker	Welder	HQ_Mn	7	171.6	148.5	183.5	45.4	274.0	365.7	369.2	100
Worker	Welder	HQ_Co	7	8.5	8.9	6.2	0.6	15.6	20.2	20.3	57.1
Worker	Welder	HQ_Ni	7	1.7	1.6	1.4	0.7	2.3	4.0	4.3	71.4
Worker	Welder	HQ_Cu	7	0.0037	0.0052	0.001	0.0005	0.0049	0.012	0.0142	0
Worker	Welder	HQ_Zn	7	0.0001	0.0001	0.0001	0	0.0002	0.0003	0.0003	0
Worker	Welder	HQ_As	7	1.9	2.0	1.2	0.5	3.0	4.7	5.4	57.1
Worker	Welder	HQ_Pb	7	0.7	0.7	0.6	0.4	0.8	1.8	2.2	14.3
Worker	Welder	HI	7	184.4	160.0	193.0	47.5	295.6	394.6	400.2	100.0
Worker	Welder	ILCR_Co	7	0.0005	0.0007	0.0001	0	0.0007	0.0016	0.0019	42.9
Worker	Welder	ILCR_Ni	7	0	0	0	0	0	0	0	0
Worker	Welder	ILCR_As	7	0	0	0	0	0.0001	0.0001	0.0001	14.3
Worker	Welder	ILCR_Pb	7	0	0	0	0	0	0	0	0
Worker	Welder	ILCR_total	7	0.0005	0.0008	0.0001	0	0.0007	0.0017	0.002	42.9
Worker	Grinder	HQ_Cr	9	0.0014	0.0008	0.0007	0.0001	0.0021	0.0023	0.0025	0
Worker	Grinder	HQ_Mn	9	44.6	54.5	22.7	3.9	68.6	134.6	143.6	100

Group	Occupation	Variable	n	Mean	SD	Median	P25	P75	P95	Max	Pct > Limit
Worker	Grinder	HQ_Co	9	4.9	6.0	3.5	0.4	5.1	15.0	15.5	55.6
Worker	Grinder	HQ_Ni	9	9.1	9.1	6.9	2.4	10.9	24.6	28.6	100
Worker	Grinder	HQ_Cu	9	0.0114	0.0085	0.0113	0.0038	0.0175	0.0224	0.0249	0
Worker	Grinder	HQ_Zn	9	0.0003	0.0004	0.0001	0	0.0004	0.001	0.0012	0
Worker	Grinder	HQ_As	9	3.5	2.4	3.3	1.9	4.3	7.2	8.4	88.9
Worker	Grinder	HQ_Pb	9	1.1	1.2	0.8	0.1	2.2	2.9	3.2	33.3
Worker	Grinder	HI	9	63.2	65.8	40.7	17.7	89.2	172.6	198.6	100
Worker	Grinder	ILCR_Co	9	0.0002	0.0002	0	0	0.0002	0.0005	0.0007	44.4
Worker	Grinder	ILCR_Ni	9	0	0	0	0	0	0	0	0
Worker	Grinder	ILCR_As	9	0	0	0.0001	0	0.0001	0.0001	0.0001	0
Worker	Grinder	ILCR_Pb	9	0	0	0	0	0	0	0	0
Worker	Grinder	ILCR_total	9	0.0002	0.0002	0.0001	0.0001	0.0002	0.0006	0.0008	66.7
Worker	Finisher	HQ_Cr	4	0.0008	0.0002	0.0008	0.0007	0.0008	0.0009	0.0009	0
Worker	Finisher	HQ_Mn	4	88.5	86.9	73.3	17.6	144.2	182.8	192.4	100
Worker	Finisher	HQ_Co	4	4.5	4.8	3.7	1.0	7.2	9.9	10.6	75
Worker	Finisher	HQ_Ni	4	1.8	1.9	1.6	0.3	3.1	3.8	4.0	50
Worker	Finisher	HQ_Cu	4	0.0021	0.0021	0.0019	0.0004	0.0036	0.0043	0.0045	0
Worker	Finisher	HQ_Zn	4	0.00	0.00	0.000	0	0.00	0.00	0.00	0

Group	Occupation	Variable	n	Mean	SD	Median	P25	P75	P95	Max	Pct > Limit
				02	02	2		03	05	05	
Worker	Finisher	HQ_As	4	1.0	0.9	1.0	0.5	1.5	2.0	2.1	50
Worker	Finisher	HQ_Pb	4	0.6	0.5	0.6	0.2	1.0	1.0	1.1	25
Worker	Finisher	HI	4	96.4	94.6	80.0	19.0	157.5	198.7	209.0	100
Worker	Finisher	ILCR_Co	4	0.0001	0.0001	0.0001	0	0.0001	0.0002	0.0002	50
Worker	Finisher	ILCR_Ni	4	0	0	0	0	0	0	0	0
Worker	Finisher	ILCR_As	4	0	0	0	0	0	0	0	0
Worker	Finisher	ILCR_Pb	4	0	0	0	0	0	0	0	0
Worker	Finisher	ILCR_total	4	0.0001	0.0001	0.0001	0	0.0002	0.0002	0.0002	50
Worker	Forger	HQ_Cr	7	0.0007	0.0005	0.0007	0.0004	0.0009	0.0014	0.0015	0
Worker	Forger	HQ_Mn	7	13.7	24.5	1.5	0.7	13.4	53.1	66.3	71.4
Worker	Forger	HQ_Co	7	0.6	0.9	0.0	0.0	0.7	2.1	2.5	28.6
Worker	Forger	HQ_Ni	7	1.0	0.5	0.8	0.7	1.4	1.6	1.6	42.9
Worker	Forger	HQ_Cu	7	0.0005	0.0004	0.0005	0.0002	0.0008	0.0011	0.0012	0
Worker	Forger	HQ_Zn	7	0	0	0	0	0	0	0	0
Worker	Forger	HQ_As	7	0.3	0.4	0.1	0.0	0.4	0.8	1.0	14.3
Worker	Forger	HQ_Pb	7	0.2	0.3	0.0	0.0	0.3	0.5	0.6	0
Worker	Forger	HI	7	15.7	25.9	3.4	1.6	16.0	57.2	71.0	85.7
Worker	Forger	ILCR_Co	7	0	0	0	0	0	0	0	0
Worker	Forger	ILCR_	7	0	0	0	0	0	0	0	0

Group	Occupation	Variable	n	Mean	SD	Median	P25	P75	P95	Max	Pct > Limit
Worker	Forger	Ni ILCR_ As	7	0	0	0	0	0	0	0	0
Worker	Forger	ILCR_P b	7	0	0	0	0	0	0	0	0
Worker	Forger	ILCR_t otal	7	0	0	0	0	0	0	0	0
Worker	Cutter	HQ_Cr	3	0.00 08	0.00 07	0.001 1	0.00 05	0.00 12	0.00 13	0.00 14	0
Worker	Cutter	HQ_Mn	3	18.4	28.8	2.6	1.7	27.1	46.7	51.6	66.7
Worker	Cutter	HQ_Co	3	0.4	0.5	0.1	0.1	0.5	0.9	0.9	0
Worker	Cutter	HQ_Ni	3	2.0	3.0	0.5	0.2	3.0	5.0	5.5	33.3
Worker	Cutter	HQ_Cu	3	0.00 25	0.00 37	0.000 7	0.00 04	0.00 37	0.00 61	0.00 67	0
Worker	Cutter	HQ_Zn	3	0	0	0	0	0	0	0	0
Worker	Cutter	HQ_As	3	0.5	0.2	0.6	0.4	0.6	0.6	0.6	0
Worker	Cutter	HQ_Pb	3	0.2	0.3	0.1	0.0	0.4	0.6	0.6	0
Worker	Cutter	HI	3	21.4	28.2	9.4	5.3	31.5	49.3	53.7	100
Worker	Cutter	ILCR_C o	3	0	0	0	0	0	0	0	0
Worker	Cutter	ILCR_ Ni	3	0	0	0	0	0	0	0	0
Worker	Cutter	ILCR_ As	3	0	0	0	0	0	0	0	0
Worker	Cutter	ILCR_P b	3	0	0	0	0	0	0	0	0
Worker	Cutter	ILCR_t otal	3	0	0	0	0	0	0	0	0
Control	Control	HQ_Cr	1	0.00	0.00	0.000	0.00	0.00	0.00	0.00	0

Group	Occupation	Variable	n	Mean	SD	Median	P25	P75	P95	Max	Pct > Limit
			0	08	06	9	03	12	14	15	
Control	Control	HQ_Mn	10	0.63	0.67	0.48	0.00	1.20	1.53	1.61	40
Control	Control	HQ_Co	10	0.08	0.25	0.00	0.00	0.00	0.44	0.80	0
Control	Control	HQ_Ni	10	0.92	0.86	0.85	0.25	1.34	2.23	2.78	40
Control	Control	HQ_Cu	10	0	0.0001	0	0	0	0.0002	0.0002	0
Control	Control	HQ_Zn	10	0	0	0	0	0	0	0.0001	0
Control	Control	HQ_As	10	0.21	0.27	0.10	0.00	0.35	0.65	0.78	0
Control	Control	HQ_Pb	10	0.09	0.14	0.00	0.00	0.18	0.32	0.33	0
Control	Control	HI	10	1.93	1.36	2.21	0.86	2.40	3.96	4.22	70
Control	Control	ILCR_Co	10	0	0	0	0	0	0.0001	0.0001	10
Control	Control	ILCR_Ni	10	0	0	0	0	0	0	0	0
Control	Control	ILCR_As	10	0	0	0	0	0	0	0	0
Control	Control	ILCR_Pb	10	0	0	0	0	0	0	0	0
Control	Control	ILCR_total	10	0	0	0	0	0	0.0001	0.0001	10