9th INTERNATIONAL SECONDARY LEAD & BATTERY RECYCLING CONFERENCE

Kota Kinabalu, Malaysia• 1-2 September 2025

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ANTARES 30 YEARS

ISO 9001 ISO 14001

Davi Trindade

Director

ANTARES

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EcoSlag Project

Reusing the constituents of secondary lead slag

“Known as world's largest lead slag research and characterization project”

Other renowned Antares projects:

EcoAcid

“Recycling over 20 million liters/year of LAB electrolyte solution”

PbRemedy

“In-situ Treatment Product for Contaminated Soil”

ABOUT ANTARES

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EcoAcid

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- Antares has over **33 years** of market experience, recycling more than **54,000 metric tons of battery electrolyte acid solution per year.**
- This corresponds to approximately **6,000 tons of CO_2 emissions avoided**.
- **15 Acid Recycling Plants in South America**.

EcoSlag

PRESENTATION OUTLINE

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1. Introduction
2. Project Partners
3. Research Structure
4. Flowchart of the Research Process
5. Research Results
6. Project Operationalization Concept

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Primary Goal: Reutilization of the constituents of lead ferric slag and the development of an alternative to the massive disposal of this material in industrial landfills.

PROJECT PARTNERS

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- ✓ Number of Secondary Lead Smelters that Participated: 11
- ✓ Total of Chemical, Mineralogical & Physical Analysis: 448
- ✓ Number of Technicians Involved: 30+
- ✓ Number of Universities and Institutes Engaged: 5
- ✓ Years of research and development: 6

RESEARCH STRUCTURE

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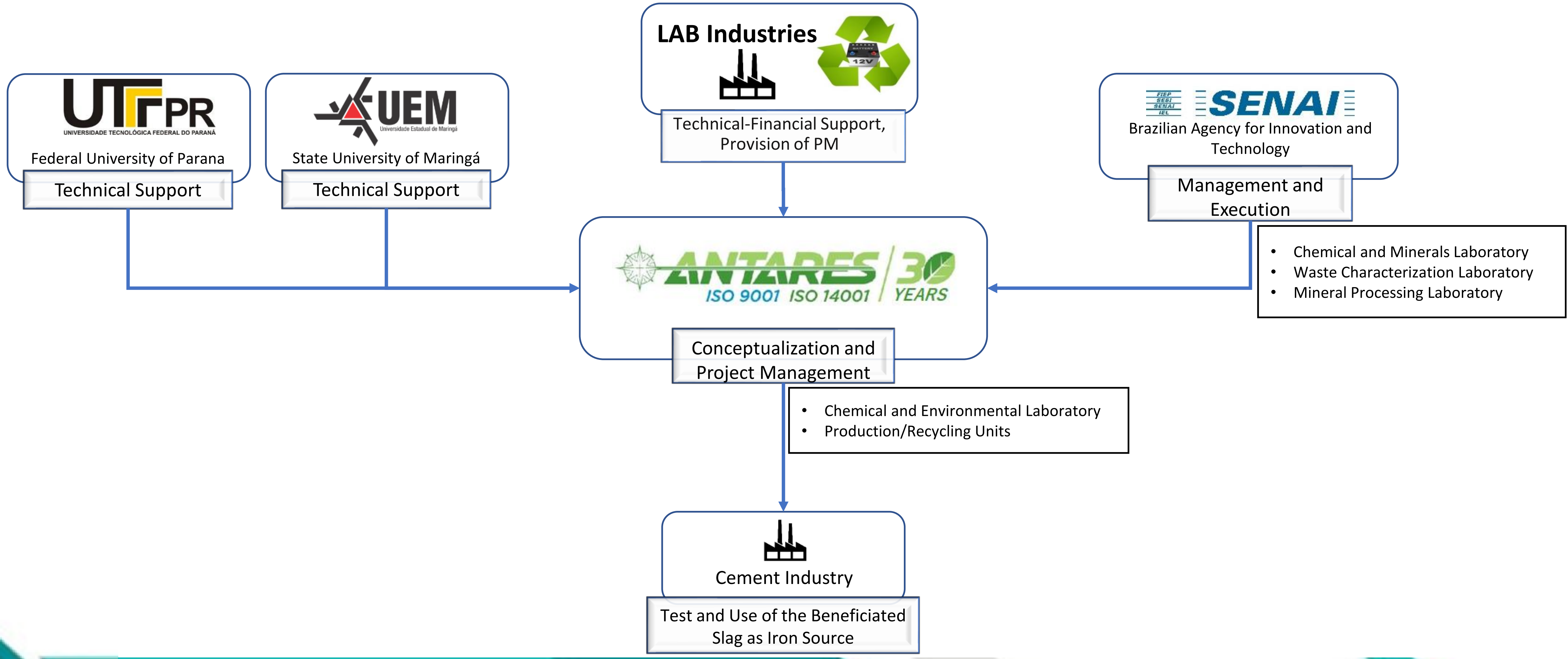

FLOWCHART OF THE RESEARCH PROCESS

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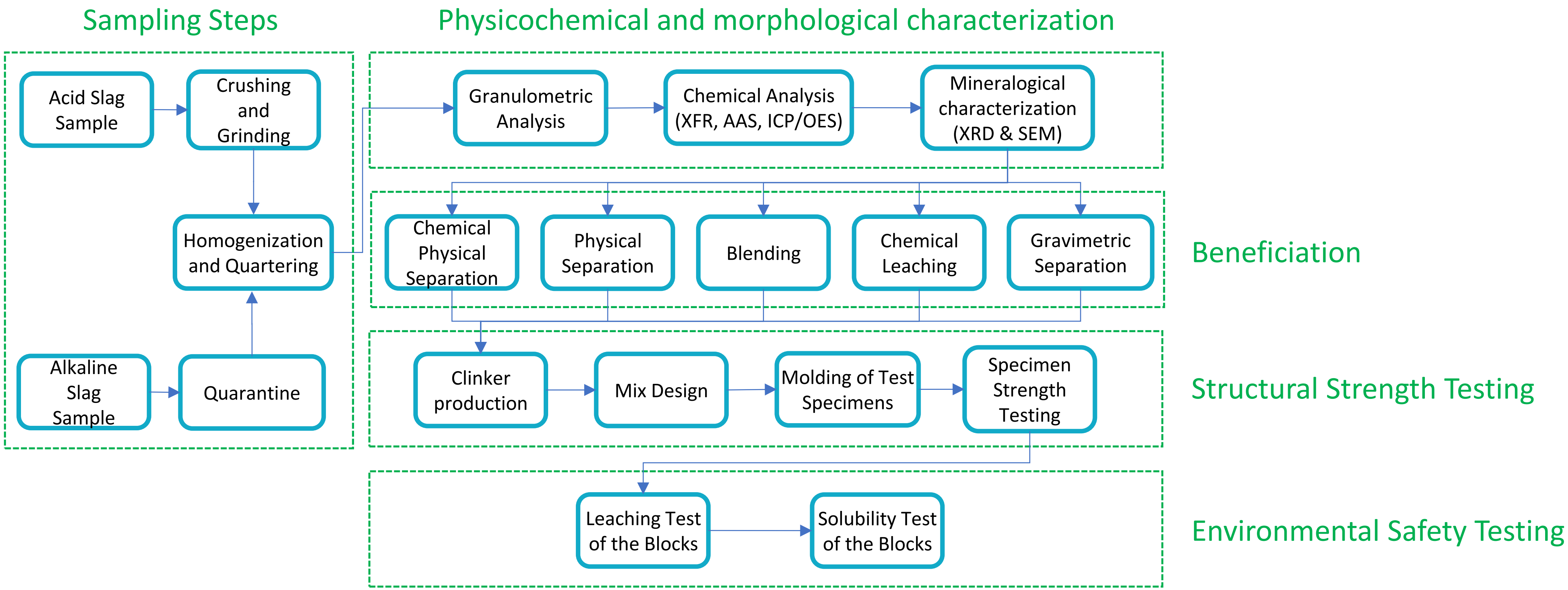

RESEARCH RESULTS

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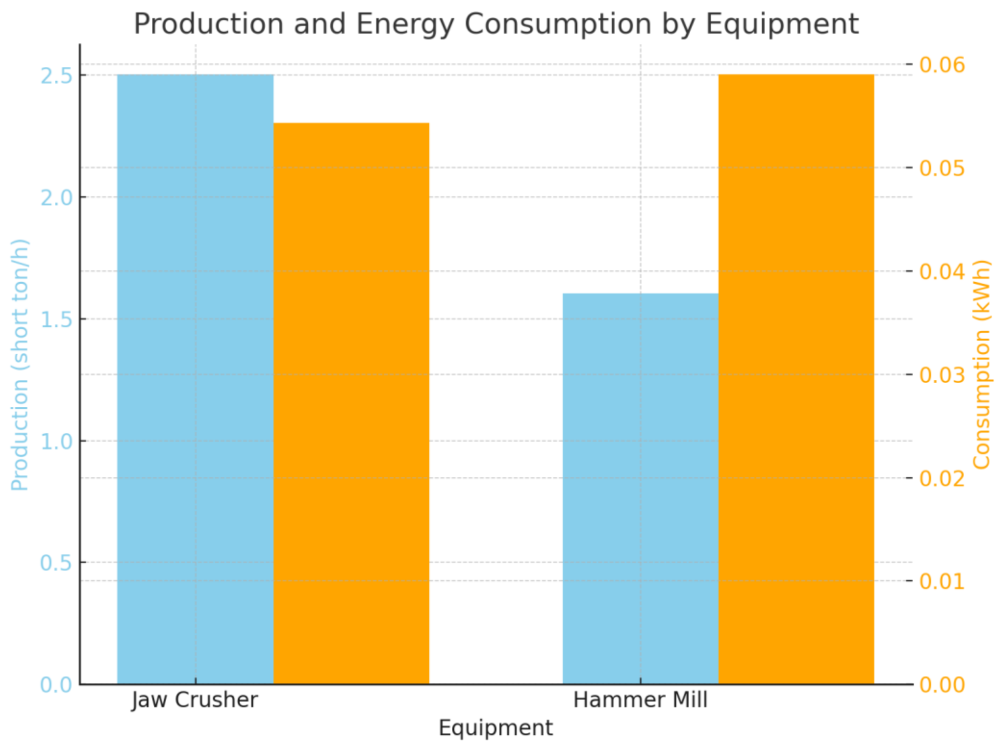
Physical Characterization of Secondary Lead Slag

- **<u>Alkaline slag does not require grinding</u>**, as natural pulverization of the material occurs during the quarantine process.

Efficiency of the "acid" slag grinding techniques tested.

Materials	Quantity (short ton)	Time (h)	Production (short ton/h)	Consumption (kWh)
Jaw crusher	0.0249	0.0099	2.5026	0.0543
Hammer mill	0.0466	0.0159	1.6056	0.0590



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Difference Between Acid and Alkaline Slag

Alkaline Slag

- Some smelters use Sodium Carbonate (soda ash) to accelerate the smelting process and increase production.

- This process produces a sodium sulfide–rich slag that, due to moisture absorption, naturally pulverizes into powder during quarantine without grinding.

Acid Slag

- Slag generated from processes without the use of soda ash, typically employed in smaller-scale foundries.

- This process produces a rigid and cohesive slag.

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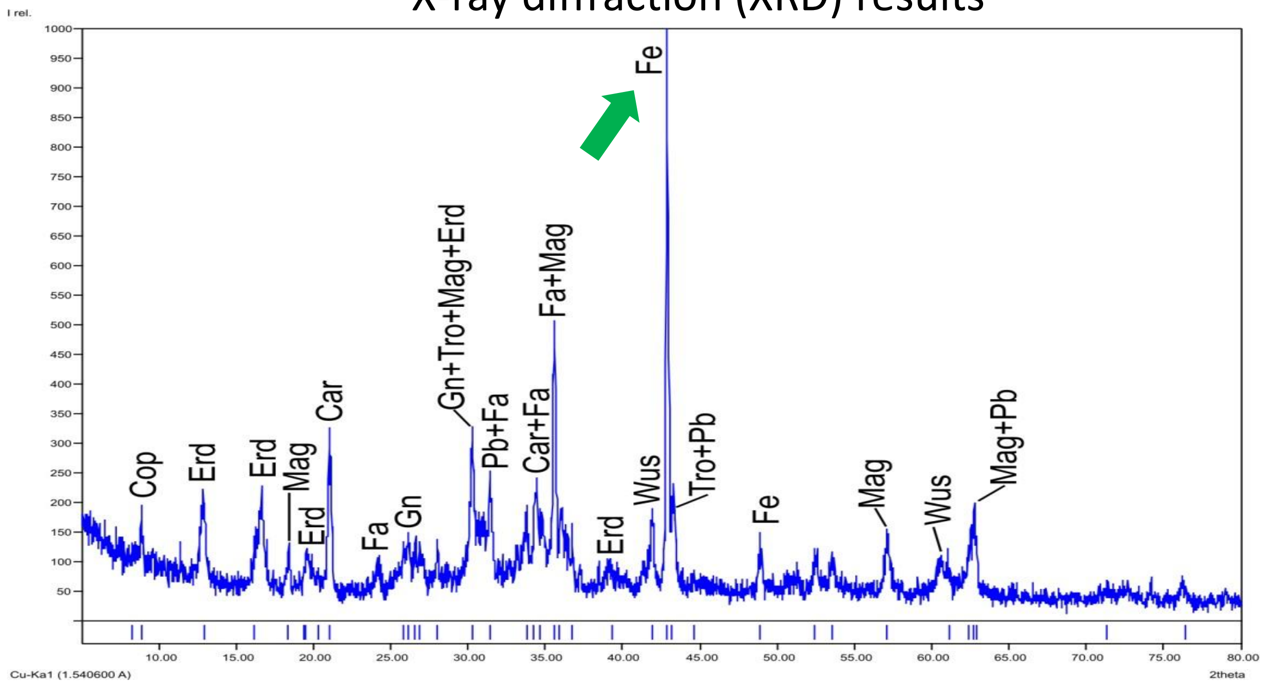
Morphological Characterization of the Secondary Lead Slag

Major Mineral Phases Identified by Rietveld Refinement

Phase	Abbreviation	Chemical Formula	Quantification (%)
Erdite	Erd	$NaFeS_2 \cdot 2H_2O$	25.1
Magnetite	Mag	Fe_3O_4	19.8
Wüstite	Wus	FeO	10.4

- Together, these phases account for more than 55% of the identified mineral composition, confirming the strongly ferric nature of the slag

X-ray diffraction (XRD) results



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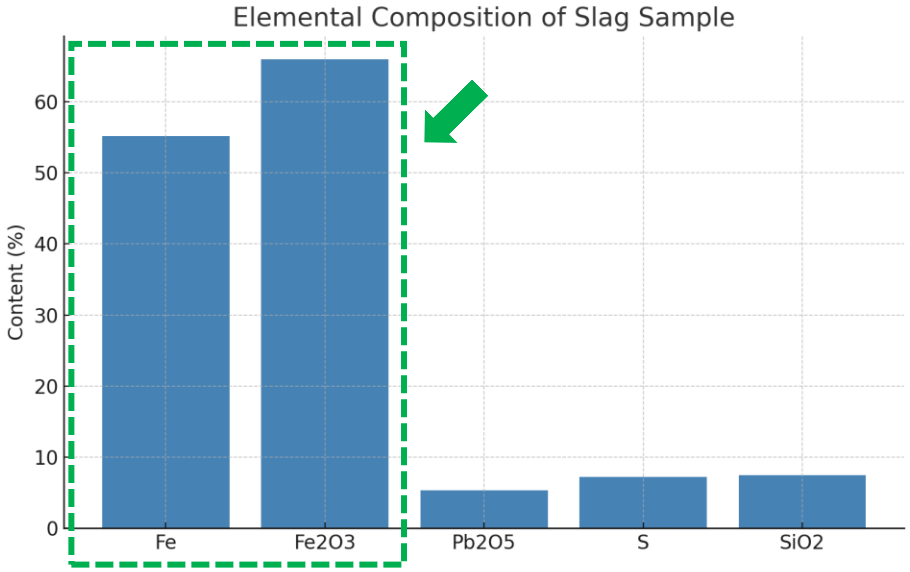
Chemical Characterization of the Secondary Lead Slag

Summary results of XRF, AAS, and ICP-OES analyses for the slag samples

Materials	Pb	Fe	Fe	Fe2O3	Pb2O5	S	SiO2
Method	ICP41C	ICP41C	AAS41B	XRF83B	XRF83B	XRF83B	XRF83B
Unit	ppm	ppm	%	%	%	%	%
Detection Limit	8	100	0.1	0.1	0.01	0.05	0.1
Results	>5000	>500000	55.17	65.97	5.35	7.24	7.45



- Ferric oxide (Fe_2O_3) was the major component, with an average content of 65.9%.

CHEMICAL COMPARISON OF THE SLAGS FROM THE PARTICIPATING SMELTERS

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Smelter	S (%)	S (ppm)	Ag ppm	Ag (%)	Ba (ppm)	Be (ppm)	Bi (ppm)	Ca (%)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Fe (ppm)	K (%)	La (ppm)	Li (ppm)	Mg (%)
A	4.52	45200	< 3	1.1	331	< 3	< 20	0.5	9.3	21	619	2022	53.6	536000	0.11	< 20	5	1.3
B	9.1	91000	< 3	1.5	947	< 3	30	0.66	22	42	1704	1061	54.8	452000	0.2	< 20	5.9	0.91
C	10.07	100700	< 3	1.9	188	< 3	< 20	7	< 3	8.9	451	339	58	340000	0.16	< 20	8.4	2.3
D	8.75	87500	< 3	1	331	< 3	26	1.3	21	26	1181	1398	56.2	473000	0.41	< 20	3.9	0.52
E	4.78	47800	< 3	1.3	132	< 3	< 20	2.1	11	8.7	558	609	59.2	376000	0.32	< 20	6.6	0.76
F	7.42	74200	< 3	1.7	238	< 3	< 20	0.5	6.2	12	2176	3552	57.4	512000	0.5	< 20	4.7	0.11
G	5.29	52900	< 3	1.4	213	< 3	< 20	3.3	< 3	25	530	431	55.4	418000	0.45	< 20	14	1.5
H	3.84	38400	< 3	2.9	244	< 3	70	1.2	14	12	251	195	51.8	491000	0.26	< 20	4.8	0.28
I	9.66	96600	< 3	0.43	172	< 3	< 20	0.8	24	27	560	1319	53.4	331000	0.1	< 20	< 3	0.4
J	7.32	73200	< 3	0.41	219	< 3	< 20	0.24	10	17	328	1003	54.4	344000	0.09	< 20	3.6	0.23
K	8.94	89400	< 3	0.8	212	< 3	< 20	0.72	8.6	143	2035	1763	52.6	326000	0.21	< 20	6	0.35
Average	7.24	72445.5		1.31	293		42	1.67	14.01	31.15	944.82	1244.73	55.17	418091	0.26		6.29	0.79

Smelter	Mn (%)	Mo (ppm)	Na (%)	Na (ppm)	Ni (ppm)	P (%)	Pb (%)	Pb (ppm)	Sb (ppm)	Sc (ppm)	Sn (ppm)	Sr (ppm)	Tî (%)	V (ppm)	W (ppm)	Y (ppm)	Zn (ppm)	Zr (ppm)
A	0.3	51	0.86	8600	242	0.26	4.9	49000	1437	«5	1943	47	0.09	50	36	5	433	47
B	0.43	161	0.37	3700	411	0.08	12.8	128000	1263	«5	880	66	0.15	92	52	8.6	935	68
C	0.81	9.3	0.43	4300	70	0.26	5.9	59000	2228	«5	351	241	0.2	366	«20	5.9	789	55
D	0.31	113	0.36	3600	362	0.11	7	70000	421	«5	529	83	0.11	58	56	4.8	547	59
E	0.36	17	1.5	15000	92	0.23	5.4	54000	1063	«5	991	120	0.18	78	30	6.2	316	53
F	0.37	60	1.7	17000	359	0.22	3.4	34000	1153	«5	1397	64	0.11	74	58	5.3	242	45
G	0.3	34	0.24	2400	284	0.19	4.5	45000	462	10	239	277	0.45	131	«20	6.7	369	67
H	0.28	7.7	0.34	3400	19	0.11	6.5	65000	379	«5	673	134	0.27	28	20	5.3	1112	92
I	0.21	76	7.7	77000	88	0.18	3.4	34000	431	«5	2982	84	0.18	129	41	«3	201	31
J	0.17	16	7.3	73000	146	0.08	2.2	22000	295	«5	1125	26	0.06	44	21	«3	852	29
K	0.2	346	7.6	76000	604	0.13	2.8	28000	1013	«5	2497	88	0.08	53	287	5.2	154	37
Average	0.34	81	2.58	25818.2	243.364	0.16818	5.35	53455	922.273		1237	111.818	0.17	100.273	66.78	5.89	540.909	53

(light blue)	"Acid" Slag
(light green)	"Alkaline" Slag

RESEARCH RESULTS

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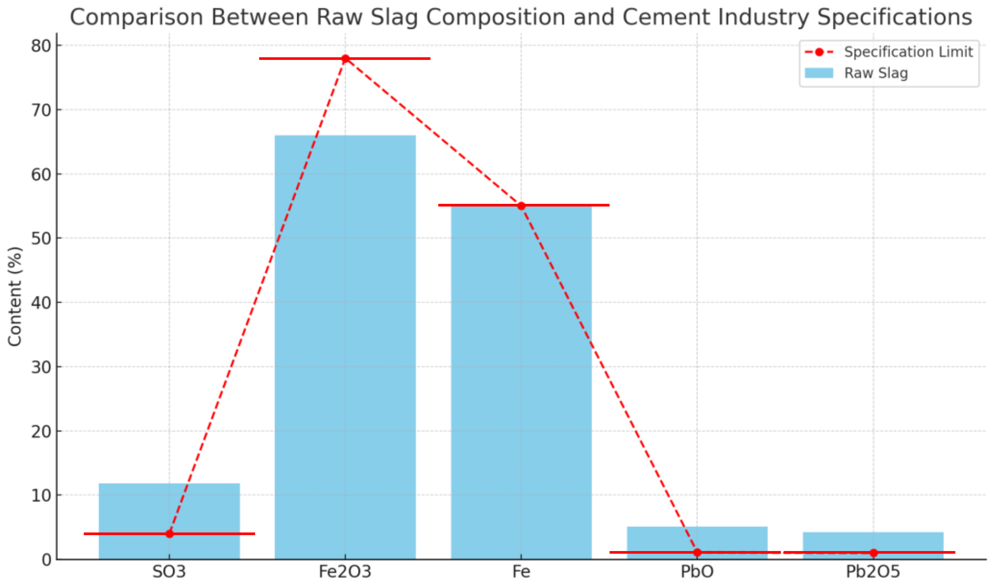
Comparison With the Parameters Required by regulation for the Cement Industries Partnering in the Project

The results show that the slag cannot be used without proper pretreatment.

Materials	SO3 (%)	Fe2O3 (%)	Fe (%)	PbO (%)	Pb2O5 (%)
Raw Slag (Average)	11.80	65.97	55.17	5.10	4.27
Specification (Cement Industry)	< 4	> 78	> 55	< 1.1	< 1

- The raw slag **exceeds** cement industry limits for SO_3, Fe_2O_3, PbO, and Pb_2O_5. Only Fe content meets the required specification. **Pretreatment is needed for potential use.**



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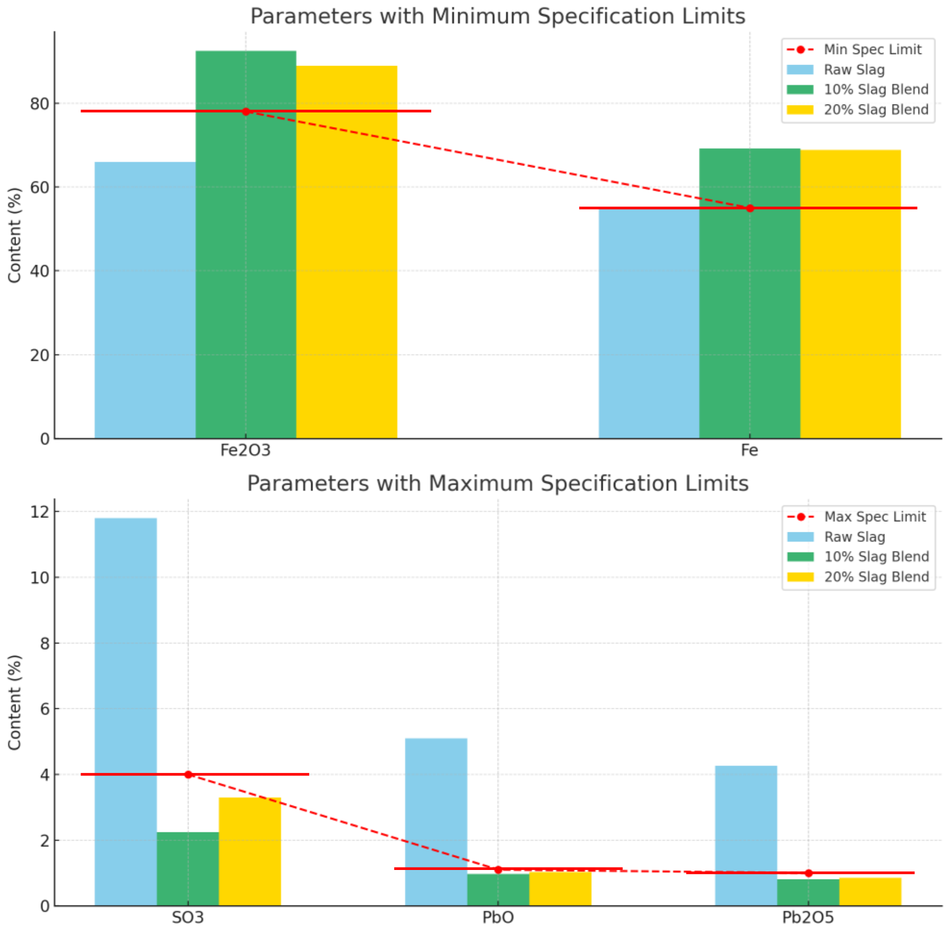
Results of the Beneficiation Methodology Compared With the Requirements of the Partner Cement Industries

Blending the beneficiated slag at 10% or 20% meets all cement industry specifications, making it suitable for use.

Materials	SO3 (%)	Fe2O3 (%)	Fe (%)	PbO (%)	Pb2O5 (%)
Raw Slag (Average)	11.80	65.97	55.17	5.10	4.27
Specification (Cement Industry)	< 4	> 78	> 55	< 1,1	< 1
10% Beneficiated Slag Blend	↓ 2.24	↑ 92.47	↑ 69.18	↓ 0.97	↓ 0.81
20% Beneficiated Slag Blend	↓ 3.30	↑ 88.91	↑ 68.83	↓ 1.03	↓ 0.86



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Clinker Production

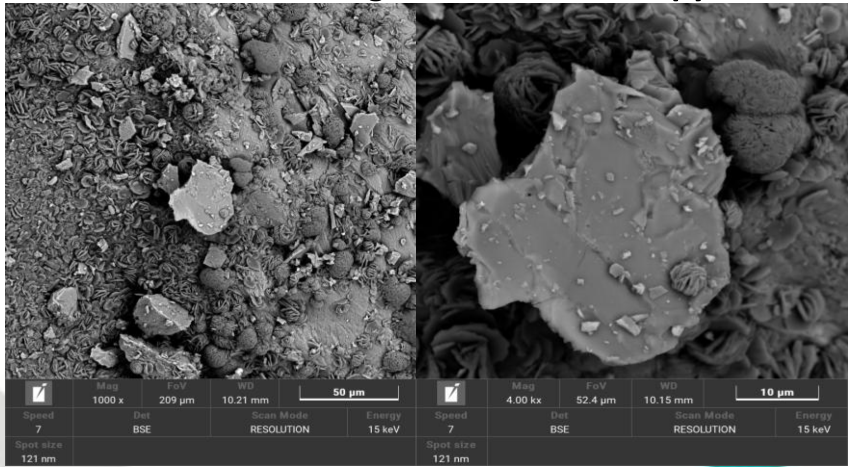
This was the formulation of each material used to produce the experimental clinker.

Material	Mass (g)	Oxide	Purity (%)	Oxide Mass (g)	Proportion (%)	Clinker Specification Range (%)
Limestone	1210	CaO	55	665.5	67.62	62-68%
Silica	224	SiO_2	98	219.52	22.31	19-25%
Beneficiated Lead Slag	75	Fe_2O_3	53.6	40.2	4.08	2-6%
Aluminum Hydroxide	90	Al_2O_3	65.5	58.95	5.99	4-8%

After that, the material was mixed with 5% gypsum ($CaSO_4$), then ground and sieved again using a 200-mesh sieve to produce the concrete specimens for strength and environmental safety testing.

Clinker Production with Beneficiated Slag

Clinker Scanning Electron Microscopy



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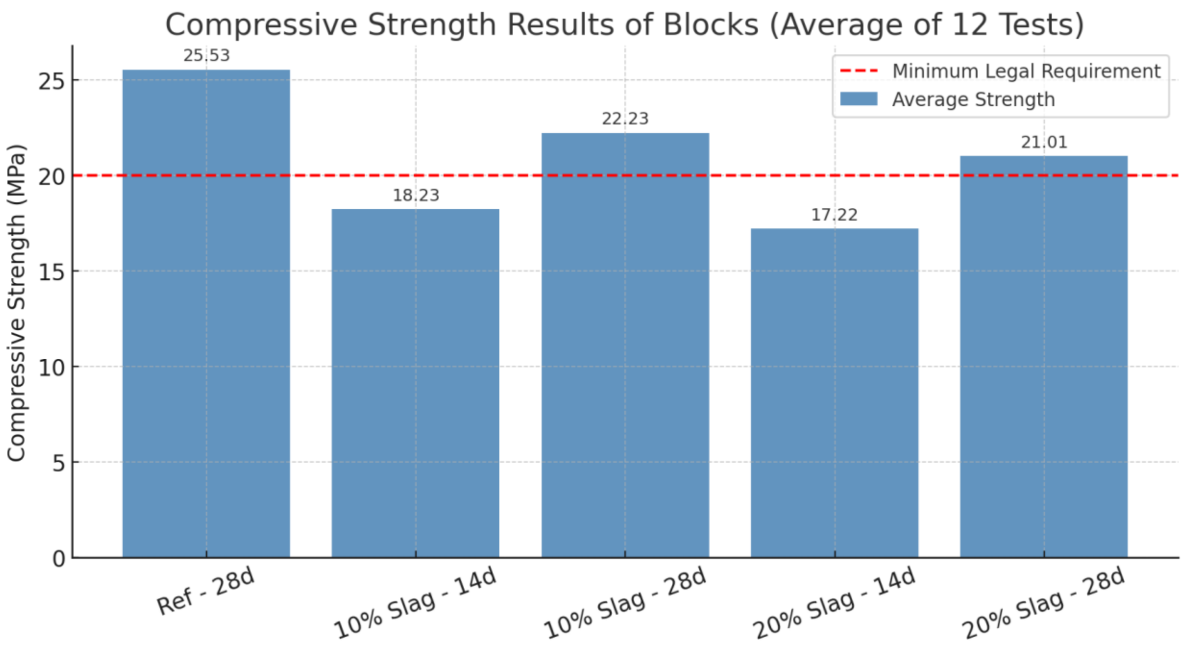
Structural Safety Test

Compressive strength test of the blocks were conducted.

Specimen	Ref. (MPa)	10% Slag (MPa)	20% Slag (MPa)
Curing Time	28 days	28 days	28 days
Average Results (12 tests per type)	25,53	22,23	21,01
Minimum Strength Required by Law	> 20	> 20	> 20

- Both the reference and slag blends **achieved the required strength.**



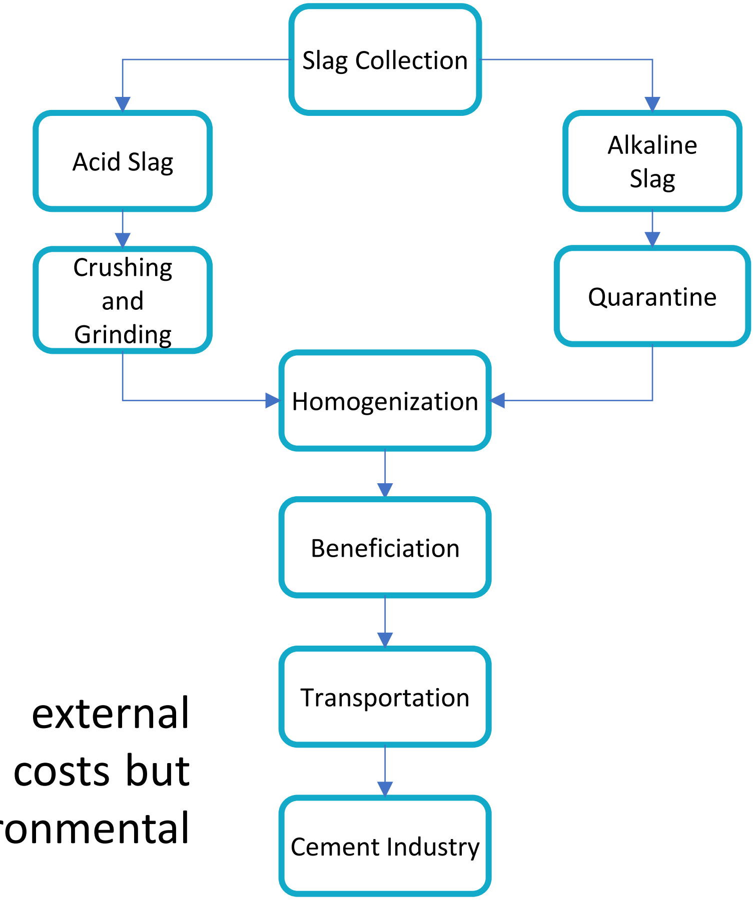
Environmental Safety Test

Leaching and Solubility Testing of Toxic Substances in Acidic and Alkaline Media Using the Residues from Compressive Strength Test Blocks

Parameter	Test	Unit	Reference Block Result	10% Slag Block	20% Slag Block	Limit (NBR 10.004)
Lead	Leaching	mg/L	< 1.00	< 1.00	< 1.00	300
Lead	Solubility	mg/L	< 0.005	< 0.005	< 0.005	300
Sulfate	Solubility	mg/L	44.0	42.0	44.0	N/A
Aluminum	Solubility	mg/L	3.9	0.35	1	N/A
Total Iron	Solubility	mg/L	< 0.20	< 0.20	< 0.20	N/A

- All values obtained in the leaching and solubility tests **were well below the limits established by Brazilian law**, confirming the environmental safety of the blocks produced with clinker using an alternative iron source.
- Traces of sulfate and aluminum also present on the reference block.

EcoSlag



Challenge:

- Competing on price with on-site and external industrial landfills, which usually have low costs but involve high co-responsibility for environmental liabilities.

Thank you!!

Davi Trindade

Director

ANTARES

davi@antares.eco.br
+55 (33) 99197-9777
www.antares.eco.br