

Article

Chemical Stabilization Used to Reduce Geogenic Selenium, Molybdenum, Sulfates and Fluorides Mobility in Rocks and Soils from the Parisian Basin

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Supplementary Materials

Table S1. Results of standardized leaching tests (NF EN 12457-2) carried out on CS using various stabilizing agents. Dosing refers to the mass percentage of stabilizing agent per mass of dry excavated material. F, SO₄²⁻, Mo and Se concentrations were measured in the leachates as long as pH. The curing time refers to the time interval left between stabilization mix and leaching tests.

Stabilizing agent	Dosing	Trial Number	pH	Fluorides (mg/kg)	Sulfates (mg/kg)	Mo (mg/kg)	Se (mg/kg)	Curing time
Al(OH) ₃	1 %	Rep-1	9.1	<5	765	3.56	0.037	5 days
Al(OH) ₃	1 %	Rep-2	8.2	7.44	1120	4.52	0.022	5 days
Al(OH) ₃	2 %	Rep-1	8.2	<5	647	3.01	0.032	5 days
Al(OH) ₃	2 %	Rep-2	8.2	5.61	941	3.14	0.052	5 days
Al(OH) ₃	3 %	Rep-1	8.4	5.02	676	2.81	0.023	5 days
Al(OH) ₃	3 %	Rep-2	8.2	5.09	791	2.38	0.044	5 days
Al(OH) ₃	3 %	Rep-3	8.2	10.4	786	1.37	0.1	5 days
Al(OH) ₃	3 %	Rep-4	9.5	11.7	757	3.25	0.12	5 days
CSA	2 %	Rep-1	9.7	<5	3300	4.08	0.11	5 days
CSA	2 %	Rep-2	9.2	<5	2920	4.05	0.2	5 days
CSA	2 %	Rep-3	9.2	<5	4520	4.49	0.16	5 days
CSA	2 %	Rep-4	9.5	<5	3020	4.54	0.19	5 days
CSA	4 %	Rep-1	9.6	<5	3480	4	0.079	5 days
CSA	4 %	Rep-2	10.6	<5	2340	3.92	0.16	5 days
CSA	4 %	Rep-3	10.2	<5	2830	4.11	0.14	5 days
Fe ₃ O ₄	1 %	Rep-1	8.2	11.6	847	3.596	0.14	5 days
Fe ₃ O ₄	1 %	Rep-2	8.4	12.2	811	4.89	0.11	5 days
Fe ₃ O ₄	2 %	Rep-1	8.2	12.1	1190	3.87	0.12	5 days
Fe ₃ O ₄	2 %	Rep-2	8.1	12	986	3.57	0.12	5 days
Fe ₃ O ₄	3 %	Rep-1	8.6	11.3	831	3.15	0.11	5 days
Fe ₃ O ₄	3 %	Rep-2	8.8	12.7	1010	3.82	0.13	5 days
Fe ₂ O ₃	1 %	Rep-1	8.1	12.6	956	3.82	0.14	5 days
Fe ₂ O ₃	1 %	Rep-2	8.3	12.3	973	3.94	0.14	5 days
Fe ₂ O ₃	2 %	Rep-2	8	11.7	944	2.97	0.11	5 days

Fe ₂ O ₃	2 %	Rep-1	8.3	12.1	1120	3.18	0.11	5 days
Fe ₂ O ₃	3 %	Rep-1	8.6	11.9	925	2.81	0.12	5 days
Fe ₂ O ₃	3 %	Rep-2	8.2	11.5	868	2.71	0.13	5 days
FeSO ₄	1 %	Rep-1	7.7	9.64	4390	1.26	0.038	5 days
FeSO ₄	1 %	Rep-2	7.8	11.3	3240	1.57	0.059	5 days
FeSO ₄	1 %	Rep-3	7.9	11.2	2810	1.51	0.11	5 days
FeSO ₄	2 %	Rep-1	7.9	11.6	7050	0.806	0.04	5 days
FeSO ₄	2 %	Rep-2	7.6	11.6	6730	0.857	0.043	5 days
FeSO ₄	3 %	Rep-1	7.9	11.6	10900	0.339	0.027	5 days
FeSO ₄	3 %	Rep-2	7.8	12.9	10500	0.428	0.037	5 days
PC/CaO	1 %	Rep-1	10.3	12.9	1310	4.73	0.17	5 days
PC/CaO	4 %	Rep-1	12.3	8.58	222	3.61	0.045	5 days
PC/CaO	4 %	Rep-2	12.2	6.49	68.5	3.59	0.04	5 days
PC/CaO	4 %	Rep-3	12	9.12	438	3.72	0.06	5 days
PC/CaO	4 %	Rep-4	12.2	10	260	3.96	0.061	5 days
PC/CaO	4 %	Rep-5	11.6	9.27	637	3.68	0.095	5 days
PC/CaO	4 %	Rep-6	11.3	10.7	1010	4.104	0.1	5 days
PC/CaO	4 %	Rep-7	11.1	12.6	1310	3.91	0.11	5 days
PC/CaO	4 %	Rep-8	11.7	11.7	731	4.02	0.087	5 days
Lime	1 %	Rep-1	11.3	12.2	576	5.79	0.19	5 days
Lime	1 %	Rep-2	10.2	16.2	1240	5.87	0.26	5 days
Lime	4 %	Rep-1	12.6	6.88	50.2	3.42	0.067	5 days
Lime	4 %	Rep-2	12.6	7.08	144	3.82	0.07	5 days
MnO(OH)	1 %	Rep-1	8.4	11.1	1070	3.03	0.12	5 days
MnO(OH)	1 %	Rep-2	8.3	10.8	982	2.73	0.059	5 days
MnO(OH)	2 %	Rep-1	8.4	11.9	1010	2.53	0.1	5 days
MnO(OH)	2 %	Rep-2	7.9	12.1	805	2.47	0.036	5 days
MnO(OH)	3 %	Rep-1	8.4	13	958	2.08	0.041	5 days
MnO(OH)	3 %	Rep-2	8.3	11.8	1080	2.11	0.033	5 days
MnO(OH)	4 %	Rep-1	7.9	10.9	926	2.25	0.039	5 days
ZVI	1 %	Rep-1	8.8	9.72	878	0.506	0.026	5 days
ZVI	1 %	Rep-2	8.5	8.99	869	0.276	0.028	5 days
ZVI	1 %	Rep-3	8.4	9.96	1040	0.409	0.046	5 days
ZVI	1 %	Rep-4	8.6	10.3	1120	0.488	0.052	5 days
ZVI	1 %	Rep-5	8.2	10.6	902	0.396	0.048	5 days
ZVI	1 %	Rep-6	7.9	10.6	926	0.432	0.039	5 days
ZVI	1 %	Rep-7	8.1	11.6	943	0.537	0.016	5 days
ZVI	2 %	Rep-1	8	8.39	1120	0.308	0.017	5 days
ZVI	2 %	Rep-2	9.5	9.78	753	0.6	0.033	5 days
ZVI	2 %	Rep-3	7.7	10	995	0.446	0.023	5 days
ZVI	2 %	Rep-4	8	10.3	732	0.586	0.014	5 days
ZVI	3 %	Rep-1	8.4	7.87	860	0.287	< 0.01	5 days
ZVI	3 %	Rep-2	7.8	9.24	856	0.319	0.017	5 days
ZVI	3 %	Rep-3	8.8	12.7	992	0.671	< 0.01	5 days
ZVI	3 %	Rep-4	8.6	9.06	995	0.28	0.014	5 days

Table S2. Results of standardized leaching tests (NF EN 12457-2) carried out on LS using various stabilizing agents. Dosing refers to the mass percentage of stabilizing agent per mass of dry excavated material. F-, SO_4^{2-} , Mo and Se concentrations were measured in the leachates as long as pH. The curing time refers to the time interval left between stabilization mix and leaching tests.

Stabilizing agent	Dose	Trial Number	pH	Fluorides (mg/kg)	Sulfates (mg/kg)	Mo (mg/kg)	Se (mg/kg)	Curing time
$\text{Al}(\text{OH})_3$	1 %	Rep-1	8.3	38.4	458	0.068	1.2	5 days
$\text{Al}(\text{OH})_3$	1 %	Rep-2	8.3	35.9	431	0.065	1.2	5 days
$\text{Al}(\text{OH})_3$	3 %	Rep-1	8.3	36.5	339	0.074	1.2	5 days
$\text{Al}(\text{OH})_3$	3 %	Rep-2	8.4	37.5	406	0.069	1.4	5 days
Fe_3O_4	1 %	Rep-1	9.2	37.8	609	0.068	1.4	5 days
Fe_3O_4	1 %	Rep-2	8.3	38.1	414	0.05	1.2	5 days
Fe_3O_4	3 %	Rep-1	8.9	44.9	382	0.067	1.1	5 days
Fe_3O_4	3 %	Rep-2	8.4	38.1	373	0.057	1.3	5 days
Fe_2O_3	1 %	Rep-1	8.5	40.8	338	0.071	1.1	5 days
Fe_2O_3	1 %	Rep-2	8.4	39	384	0.062	1.4	5 days
Fe_2O_3	3 %	Rep-1	8.3	41.4	410	0.066	1.8	5 days
Fe_2O_3	3 %	Rep-2	8.6	37.3	323	0.045	1.4	5 days
$\text{MnO}(\text{OH})$	1 %	Rep-1	8.2	39.9	406	0.064	1.5	5 days
$\text{MnO}(\text{OH})$	1 %	Rep-2	8.2	36.7	399	0.051	1.7	5 days
$\text{MnO}(\text{OH})$	3 %	Rep-1	8.4	32.9	404	0.072	1.7	5 days
$\text{MnO}(\text{OH})$	3 %	Rep-2	8	36.3	387	0.055	1.6	5 days
ZVI	1 %	Rep-1	8.7	43.5	417	< 0.01	0.43	5 days
ZVI	1 %	Rep-2	8.2	38.8	507	0.011	0.41	5 days
ZVI	3 %	Rep-1	8.1	33.6	248	< 0.01	0.035	5 days
ZVI	3 %	Rep-2	8.6	32.7	391	< 0.01	0.077	5 days
FeSO_4	1 %	Rep-1	7.9	22.1	3490	0.03	0.51	5 days
FeSO_4	1 %	Rep-2	8	23.6	3500	0.035	0.52	5 days
FeSO_4	3 %	Rep-1	7.8	15	16000	< 0.01	1	5 days
FeSO_4	3 %	Rep-2	8.4	18.4	8200	< 0.01	0.75	5 days
Lime	2 %	Rep-1	11.1	50.3	310	0.084	1.9	5 days
Lime	2 %	Rep-2	11.4	43.5	382	0.107	2.4	5 days
Lime	4 %	Rep-1	12.2	20.1	98	0.055	0.99	5 days
Lime	4 %	Rep-2	12.2	16.9	72	0.059	1	5 days
PC/CaO	2 %	Rep-1	10.2	48.9	494	0.063	2.2	5 days
PC/CaO	2 %	Rep-2	9.9	47.5	737	0.107	1.9	5 days
PC/CaO	2 %	Rep-3	10.8	46.6	667	0.062	2.4	5 days
PC/CaO	2 %	Rep-4	11.1	42.7	899	0.106	1.5	5 days
PC/CaO	2 %	Rep-5	10.7	53.3	716	0.085	2.3	5 days
PC/CaO	4 %	Rep-1	11.4	34.4	875	0.152	1.7	5 days
PC/CaO	4 %	Rep-2	11.2	41.9	572	0.086	1.1	5 days
PC/CaO	4 %	Rep-3	11.6	23.2	655	0.203	1.7	5 days
PC/CaO	4 %	Rep-4	11.3	30	480	0.112	1.2	5 days
PC/CaO	4 %	Rep-5	11.5	42.6	755	0.117	1.9	5 days
CSA	2 %	Rep-1	9.6	43	5800	0.12	2.2	5 days
CSA	2 %	Rep-2	10.2	49.5	2310	0.177	1.7	5 days
CSA	2 %	Rep-3	8.7	48	2660	0.084	1	5 days
CSA	2 %	Rep-4	9.1	37.9	1700	0.144	1.3	5 days
CSA	4 %	Rep-1	10.1	37.2	5560	0.145	1.2	5 days
CSA	4 %	Rep-2	9.9	40.6	3260	0.365	1	5 days

CSA	4 %	Rep-3	7.6	12.8	7570	0.253	0.14	5 days
CSA	4 %	Rep-4	9.9	45.6	2670	0.219	1.2	5 days

Table S3. Results of standardized leaching tests (NF EN 12457-2) carried out on MLS-A using various stabilizing agents. Dosing refers to the mass percentage of stabilizing agent per mass of dry excavated material. F⁻, SO₄²⁻, Mo and Se concentrations were measured in the leachates as long as pH. The curing time refers to the time interval left between stabilization mix and leaching tests.

Stabilizing agent	Dose	Trial Number	pH	Fluorides (mg/kg)	Sulfates (mg/kg)	Mo (mg/kg)	Se (mg/kg)	Curing time
Al(OH) ₃	1%	Rep-1	7.8	12.5	3550	0.997	0.091	5 days
Fe ₃ O ₄	1%	Rep-1	7.9	13.7	3390	0.657	0.11	5 days
Fe ₃ O ₄	1%	Rep-2	7.9	14.2	4250	0.785	0.12	5 days
Fe ₃ O ₄	2%	Rep-1	7.8	14.8	3840	0.716	0.13	5 days
Fe ₃ O ₄	2%	Rep-2	7.7	14	4490	0.77	0.13	5 days
Fe ₂ O ₃	1%	Rep-1	7.7	13.8	4050	0.617	0.11	5 days
Fe ₂ O ₃	1%	Rep-2	7.6	13.7	4000	0.533	0.12	5 days
Fe ₂ O ₃	2%	Rep-1	8.4	13.7	3530	0.567	0.1	5 days
Fe ₂ O ₃	2%	Rep-2	7.9	12.7	4200	0.46	0.1	5 days
MnO(OH)	1%	Rep-1	7.9	13	4350	0.519	0.12	5 days
MnO(OH)	1%	Rep-2	7.8	12.5	4250	0.488	0.12	5 days
MnO(OH)	2%	Rep-1	7.8	12.8	4120	0.538	0.11	5 days
MnO(OH)	2%	Rep-2	7.8	13.1	4170	0.372	0.12	5 days
ZVI	1%	Rep-1	8.3	14.8	3730	0.256	0.017	5 days
ZVI	1%	Rep-2	7.9	10.2	3680	0.07	0.052	5 days
ZVI	2%	Rep-1	8	8.82	3960	0.052	0.034	5 days
ZVI	3%	Rep-1	8.3	8.24	3750	0.063	0.018	5 days
Lime	2%	Rep-1	12	12.6	2600	2	0.07	5 days
Lime	4%	Rep-1	12.7	9.4	2970	2.01	0.075	5 days
PC/CaO	1%	Rep-1	9.6	16.3	4020	1.45	0.15	5 days
PC/CaO	1%	Rep-2	9.7	16.8	3890	2.68	0.16	5 days

Table S4 : Results of standardized leaching tests (NF EN 12457-2) carried out on TM using various stabilizing agents. Dosing refers to the mass percentage of stabilizing agent per mass of dry excavated material. F, SO_4^{2-} , Mo and Se concentrations were measured in the leachates as long as pH. The curing time refers to the time interval left between stabilization mix and leaching tests.

Stabilizing agent	Dose	Trial Number	pH	Fluorides (mg/kg)	Sulfates (mg/kg)	Mo (mg/kg)	Se (mg/kg)	Curing time
$\text{Al}(\text{OH})_3$	1%	Rep-1	12	9.14	2310	1.34	< 0.01	5 days
$\text{Al}(\text{OH})_3$	2%	Rep-2	11.9	9.12	1810	1.21	< 0.01	5 days
$\text{Al}(\text{OH})_3$	3%	Rep-3	12.1	9.54	1440	1.24	< 0.01	5 days
ZVI	1%	Rep-1	11.8	8.54	3250	1.4	< 0.01	5 days
ZVI	2%	Rep-2	11.8	8.01	2920	1.11	< 0.01	5 days
ZVI	3%	Rep-3	11.9	8.75	2580	1.27	< 0.01	5 days
Lime	1%	Rep-1	12.3	9.31	2240	1.37	< 0.01	5 days
Lime	2%	Rep-2	12.4	9.42	2100	1.32	< 0.01	5 days
Lime	3%	Rep-3	12.4	8.98	2280	1.15	< 0.01	5 days
PC/CaO	1%	Rep-1	12.2	9.08	2080	1.34	< 0.01	5 days
PC/CaO	2%	Rep-2	12.3	9.12	2180	1.304	< 0.01	5 days
PC/CaO	3%	Rep-3	12.3	9.29	2040	1.37	< 0.01	5 days
CSA	3%	Rep-1	11.8	7.43	1390	1.23	0.012	5 days
CSA	3%	Rep-2	11.9	7.38	1570	1.14	< 0.01	5 days