



SLAG CEMENT

NSA Summary of a Presentation by Rene Galibert at March 1981 TC/MC and Executive Committee Meetings

This discussion will cover the following points:

1. Slag qualities for cement
2. Slag granulation processes
3. Comparisons of energy consumption required to produce types of cement
4. Slag cement processing
5. French cement specifications
6. Slag cement uses
7. French statistical data on cements
8. Gagneraud's pelletizing story from 1974 to 1981

1. SLAG QUALITIES

TABLE 1 STRENGTH COMPARISONS

Slag Tested	Compressive Strength (2) of ISO (1) Mortar Cubes					Blaine Fineness Cm ² /gm
	2 days	7 days	28 days	90 days	365 days	
D	5.4	20.6	34.4	43.8	50.6	3540
G	11.2	23.9	32.7	38.2	45.5	3495
H	8.8	21.3	33.9	42.2	50.3	3575
A	9.7	32.3	50.6	60.6	71.5	3470
B	8.2	26.8	42.2	54.3	69.5	3500
C	12.0	34.0	49.3	62.9	71.7	3485
E	12.9	30.3	43.1	54.7	65.3	3490
F	12.6	29.7	44.1	56.8	68.7	3625
Clinker						3520

(1) International Standard Organization (ISO) test procedures produce considerably higher strengths than do ASTM test methods because of different specimen shape.

(2) Strengths are shown in megapascals. One MPa= 145 psi.

Table 1 summarizes comparative strengths obtained from eight different sources of granulated slag, all of them obtained by the "Classical" (high water volume) granulating process. It depicts two different groups; the upper group of three is acid slags with a CaO/SiO₂ ratio between 1.0 and 1.2, the bottom group is basic slags with a CaO/SiO₂ ratio between 1.3 and 1.4. The top group was produced from hematite iron ore. When

the German, Belgian, French cement industries started to produce slag cement, they all utilized their national iron ore which gives a basic slag.

Examination of this data gives an idea of the different strength qualities that can be obtained from the two different types of slag, basic and acid, both produced by the "Classical" granulation process. It is clear that the hematite slags are not as hydraulic as the basic slags.

Some of these results may justify questions, as, for example, sample G strength at two days of age. Table 2 shows the chemical analysis of the eight slag sources. The high alumina content of slag G - nearly 22% - accounts for its high early strength. These tests were made by the French National Cement Research laboratory on samples of slag ground separately, to the fineness values shown in Table 1 and blended with a Portland cement of 3520 Blaine, to which 5% of gypsum was added.

TABLE 2 CHEMICAL ANALYSIS OF EIGHT SLAGS by STEEL RESEARCH LABORATORY, IRSID

	A	B	C	D	E	F	G	H
SiO ₂	35.77	33.49	31.64	36.06	31.25	31.52	33.64	33.43
Al ₂ O ₃	11.10	14.62	17.39	12.16	18.60	16.28	21.67	14.80
FeO	0.66	0.51	0.63	0.32	0.44	0.49	0.20	0.51
CaO	44.90	43.30	44.17	39.72	42.38	45.44	42.33	38.48
MgO	4.56	4.48	4.53	7.80	4.98	3.78	1.27	8.20
Na ₂ O	0.23	0.40	0.31	0.60	0.33	0.39	0.33	0.73
K ₂ O	0.25	0.70	0.76	1.13	1.00	0.77	0.71	1.08
S	0.76	0.56	0.71	0.95	0.85	0.80	1.01	0.93
TiO ₂	0.48	0.57	0.59	0.58	0.63	0.58	0.32	.074
P ₂ O ₅	0.24	0.32	0.16	0.10	0.24	0.26	0.07	0.08
MnO	0.81	0.73	0.37	0.68	0.53	0.72	0.07	1.18
	99.7	99.68	101.26	100.1	101.23	101.03	101.62	100.16

2. SLAG GRANULATION PROCESS

The Classical granulation process has been employed for a long time, and I do not believe it is necessary to describe it at this time.

The cement companies in Europe have preferred basic slag for a long time and when acid slag was blended with Portland cement, a much reduced percentage was used. Basic slag was utilized to prepare special cements for technical uses like dams, sea works, and resistance to chemical attack. For those purposes, the percentage of slag could reach 80 and even 90% with 10 to 20% of clinker.

By 1960 the German steel industry had developed the use of hematite iron ore to the extent they had to import French basic slag to meet the demand. This preference for basic slag was due to the particular quality characteristics of the basic slag and not all to the fact that it was produced by the "Classical" process.

The situation changed dramatically in 1974-75 with the first pelletizing machine operation at Fos sur Mer. The granulated slag obtained from it after screening had grading from 3mm (1/8") to O. Gagneraud Co. introduced this product into the cement market and proved that it was comparable to the one produced from hematite slag at Dunkerque by the "Classical" granulating process.

This fact was not quickly accepted, however, for many believed that the glass count of the pelletized slag was not as high as it should be in order to make good cement. After discussions with many buyers they were convinced of the truth of the pelletized slag tests, and this opinion no longer exists in France. French cement plant laboratories have concluded that it is feasible to use hematite pelletized slag with an adjustment of toe fineness of slag and clinker to attain specification requirements.

The three biggest cement corporations in France now use pelletized slag to reduce the energy consumption to produce cement.

3. COMPARISON OF ENERGY CONSUMPTION REQUIRED TO PRODUCE DIFFERENT TYPES OF CEMENT

Table 3 shows the quantity of fuel consumed for different types of cement containing between 0 to 85 % of slag and for 100% slag with 15 % and 0% moisture. It is significant to note that pelletized slag which does not have to be dried (which is feasible) only requires 15 % of the energy of Portland cement clinker.

4. SLAG CEMENT PROCESSING

Slag is used by cement companies in the following way to obtain a uniform product:

- a) Slag is blended or "homogenized" in the same way that steel industry does the regular blending of its Iron ore.
- b) Separate grinding of slag is becoming more popular as it permits the hydraulic power of slag to be utilized more efficiently.
- c) Blending of cement clinker and slag after grinding is precise and permits the cement company to produce the optimum type needed by customers for specific purposes.

TABLE 3 ENERGY REQUIRED TO PRODUCE DIFFERENT TYPES OF CEMENT

Cement Type	% Slag	Fuel consumption - kilos per metric ton of cement			Total kg/ton
		Clinker production	Drying slag with Grinding at 15% moisture	Grinding at 3000 Blaine	
Pure Portland cement - C.P.A.	0	106.1	0	10.5	116.6
Compound Portland cement - C.P.J.	35	68.9	5.6	13.1	87.6
Blast furnace slag cement - C.H.F.	40	63.7	6.4	13.5	83.6
	50	53.1	8.0	14.2	75.3
	60	42.4	9.6	15.0	67.0
	75	26.5	12.0	16.1	54.6
Slag cement and clinker - C.L.K.	85	15.9	13.6	16.9	46.4
Slag 15% moisture, dried and ground	100	0	16.0	18.0	34.0
Dry slag ground	100	0	0	18.0	18.0

5. FRENCH CEMENT SPECIFICATIONS

Specification compressive strengths vary between 35 and 55 MPa (5075 lb/in² - 7975 lb/in²). The pelletizer product can produce all types of cement except the high early strength 55 MPa type which requires a guarantee of 20 MPa (2900 lb/in²) at 2 days and 55 MPa at 28 days.

For all other purposes the following compressive strengths are required:

Compressive strengths resistance MPa

Class of Cements	<u>2 days</u>		<u>7 days</u>	<u>28 days</u>	
	inferior nominal limit	minimum value guarantee	minimum value guarantee	minimum value nominal guarantee	maximum value
35 MPa	--	--	10	25	45
45 MPa	--	--	17.5	35	55
45 R MPa	15	10	--	35	55
55 MPa	--	10	--	45	65
55 R MPa	--	15	--	45	65

To reach these requirements, basic slag is generally ground .between 3000 to 4000 Blaine and hematite slags need 1000 Blaine more; that is to say, 4000 to 5000 Blaine due to the type of cement required.

There is a big opportunity for a large development in the use of slag considering the fact that not more than 30% fly ash or pumice can be employed in concrete.

6. SLAG CEMENT USES

The market for slag cement includes the following principal uses:

- foundations and underground works
- civil engineering structures/roads/aerodromes
- dams and hydraulic works
- marine works
- power stations and factories
- buildings and prefabrication
- rural works and buildings

To demonstrate the capability of slag cement to be used on even difficult jobs, a power station cooling tower was recently built with a type of slag cement containing 70% of ground slag at a fineness of 5000 Blaine.

7. SLAG CONSUMPTION FOR CEMENT

Of the six million tons of granulated slag produced in France, four million are delivered to the cement industry, of which three million are for French cement plants and one million is shipped to German cement plants. Of the 31 million tons of cement produced in France, 20.48% of it consists of the following non-clinker materials:

9.75% granulated slag	2.89% fly ash	1.02% pumice
4.24% gypsum	2.58% fillers	

8. THE GAGNERAUD'S PELLETIZING STORY FROM 1974 UNTIL 1981

The story of our experience can be summarized as follows:

1. Amount of investment - Depending on the different designs required for specific locations, the amount to invest for pelletized granulated slag may be between 4 to 7 times less than that required for the Classical granulating process.
2. Cost of operation compared to classical process
 - water consumption: 5 to 10 times less
 - rate of depreciation: 4 to 7 times less
 - power consumption greatly reduced by easy handling; no crane bridge for handling; no pumping station; and, no dewatering bed
3. Commercial value

- a. selling price has increased due to cementitious value recognized by the three biggest French cement corporations;
 - b. low moisture between 0 and 5 % instead of 15 % or more with Classical granulating process;
 - c. increased use of slag through better knowledge of cement industry which thoroughly studied the different slags and the way to use them.
4. Improvement of initial Pelletizing Processing - (1), Conversion from ladle to runner feed and (2), obtained patents on several improvements and our "know how" allows us to find solutions for each particular case following blast furnace technique evolution.
 5. Concerning consequences of French EPA regulation - We are now increasing the rate of pelletization to 80% from 40% at present at the Fos sur Mer operation where the steel company must reduce the watering of their slag pit.
 6. Prospect of development - The many problems experienced by the steel industry do not facilitate the development of the pelletization process since the blast furnaces are already equipped with Classical granulating process. Our prospect is to gradually replace the old granulation installations by new pelletizers, which appears to be very soon In the case of the Dunkerque Steel Plant.

These evolutions and prospects will, I hope, contribute to the development of future international slag marketing.