A THREE PHASE ROTATING PLASMA FURNACE FOR PROCESSING OF HYDRAULIC MATERIALS

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ABSTRACT

A conventional Portland raw-mix has been processed, in the liquid state, in a three phase rotating plasma furnace, operating at 100 kW with air as plasma gas. The hydraulicity of the product is satisfactory and its mechanical properties during setting up are good. We have selected a.c copper sheathed graphite as electrode material and we experiment a continuously fed version, in order to counterbalance the electrode erosion.

1. INTRODUCTION

We have previously reported (1) experiments concerning the processing of a particulate feedstock into a three phase plasma reactor, namely the spheroidization of chamotte. This operation is carried out in a vertical water-cooled metallic reactor, as a co-current sedimentation process.
The system which is presently under investigation associates a three phase plasma generator and a rotating vessel which contains the material to be melted. It is supposed to combine the advantages of the gas-sheathed plasma generator (simplicity, low cost of investment, easiness for scaling up) with those inherent in a liquid rotating furnace (good thermal insulation , low radiation loss, large residence time, non contamination of the product by the wall).
The material to be processed is, for instance, a conventional Portland raw-mix. It is collected at the exit as a molten clinker.
In these experiments, we intend to study and (or) demonstrate the following items :

- hydraulicity of the plasma processed clinker
- feasibility of operation with cheap gases such as air
- energy consumption on the basis of a continuous operation.

2. EXPERIMENTAL

The plasma installation is schematically described in figure 1. It consists of the following main parts, i) a worm-type particles feeder (10 - 100 kg.h^{-1}), ii) an upper flange equipped with the three phase plasma generator (power 100 kW) and the particles injector, iii) a rotating water-cooled cylindrical vessel (0 - 200 r.p.m., 30 liters), iiii) a gas and product collection unit. The total duration of each run has been limited to less than 15 minutes.
The samples which are prepared (1-10 kg) are analysed by X Ray diffraction for the crystalline phases, calorimetry for the reactivity against water - hydraulicity -and, for some of them by chemical analysis. Hydraulic setting up is controlled by testing the compressive strength.

The electrode erosion data have been collected on separate plasma equipment which consists of only a three phase plasma generator installed inside a cylindrical water-cooled cavity.
Heat balances have been carried out through a micro-processor data logger unit, able to print out r.m.s. voltages, currents, power, and heat balance in each water-cooled circuit.

3. RESULTS

3.1. Electrode erosion data (air)

The following three materials have been tested, all of them being commercially available, i) d.c. graphite, ii) a.c. graphite, iii) a.c. copper-sheathed graphite.
The results are in figure 2, for a mean power of the air plasma equal to 90 ± 8 kW. The evolution of the erosion rate (g. h^{-1} per electrode) in terms of the initial velocity at the exit of the electrode cylindrical slit is reported. The best results are observed for a. c. copper sheathed graphite, 13 mm in diameter.

The accuracy of such measurements is not very good. Indeed the electrode wear is not constant versus time, since the electrode is fixed and the arc root moves upward with the electrode erosion. But these measurements are only intended for selecting the most suitable material, the optimum diameter (13 mm) and also to determine the order of magnitude of the linear erosion rate (about 0.2 $m.h^{-1}$ at Ø 13 mm and 50 $g.h^{-1}$ per electrode) for a given power.
These data have provided us with a satisfactory basis to design and build a new system which presently allows to feed continuously each electrode by means of a step by step manually - driven motor -. This version is currently being adapted for an automatic driving of the electrodes in order to keep them in a constant position.

3.2. Products data

The samples which have been collected exhibit an homogeneous composition and a satisfactory reactivity.
We have shown in (2) that, when the cooling rate of the liquid is very high (splitting and quenching by means of an air jet) free calcia can remain in the solid state and the alumino-ferrite phase, $(CaO)_4 Al_2O_3Fe_2O_3$, cannot be formed.
In table I, we report measurements concerning mechanical properties : compressive and flexuralstrength for concrete and pure paste made from a plasma prepared clinker (cooled in water, ground and gypsum added in a standard way). The chemical composition is indicated in table II. It should be noted that the alkali content (Na_2O, K_2O) is drastically reduced.

3.3. Energy data

The energy consumption corresponds to the following stages :
i) heating up of the raw material, ii) decarbonation of the calcareous content, iii) synthesis of the various compounds : $(CaO)_2 SiO_2$, $(CaO)_3 SiO_2$, $(CaO)_3 Al_2O_3$, $(CaO)_4 Al_2O_3 Fe_2O_3$ - exothermic stage -, iiii) melting of the mixture of these compounds.

Under industrial conditions the best values to consider for a dry process unit operating with pre-decarbonation at a significant scale (10^6 T/an) is 1 kWh.kg^{-1} for the manufacture of Portland clinker.
In our experiments, we were only able to achieve continuous operation during short periods (up to 10 minutes) with an energy consumption which lies in the range 2-4 kWh.kg^{-1}, without heat recovery neither from the clinker nor from the exhausting gases.

4. DISCUSSION

The manufacture of cementitous materials in plasmas has been reported by Tylko in (3). Further details are given by the same author in (4), where the manufacture of hydraulic cements and pozzolanic materials by a plasma method (expanded precessive plasma reactor or EPPR) is claimed with an energy consumption equal to or lower than a conventional rotary cement kiln. The particulate mixture is treated in flight in the plasma curtain which is formed, in order to collect a finely sintered product with minimal amount of fused product.
By the fact, melting of the feedstock is considered as a drawback, as pointed out in (5) by Glasser, which has prepared fused Portland cement in a vertical rotating furnace by a technique similar to that which is here described. The presence of large amounts of a glassy phase is noticed, which is detrimental for further hydraulic setting up of the mixture.
We were therefore able to demonstrate that hydraulic materials processed in the liquid state can retain a satisfactory hydraulicity. It is obvious that the energy consumption which is reported as well as the operating data are still far from the requirements which could lead to consider the utilization of plasma techniques for the manufacture of cement.

5. CONCLUSION

The plasma-prepared clinker, corresponding to the composition of the so-called Portland, exhibits a normal hydraulicity and good mechanical properties during its setting up.
The best electrode erosion for air plasma production is observed with a.c. copper sheathed graphite. An automatic version for constant positioning of the 3 electrode tips is under experimentation.
The energy consumption for total processing (including decarbonation) is in the range 2-4 kWh/kg. This value should be compared to 1 kWh. kg^{-1}, which is the most refined industrial requirement.

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Table I

Mechanical properties of plasma manufactured cements

Compressive strength : Concrete test (in 10^6. Pa)

	(Blaine) Fineness	water/cement	Days 1	Days 2	Days 7	Days 28
A	2980	0.57	7.0	14.5	27.0	38.0
B	3120	0.61	6.0	10.5	21.0	38.0
C	3140	0.58	6.0	9.0	18.5	34.5

Compressive strength : Pure past test

			Days 1	Days 7	Days 28
A	2980	0.40	10.0	51.0	66.0
C	3140	0.40	4.0	34.5	67.5

Flexural Strength : Concrete test

			Days 1	Days 2	Days 7	Days 28
A	2980	0.57	1.8	2.9	4.3	6.0
C	3140	0.58	1.4	2.1	4.0	5.3

A Blank sample : conventional clinker CPA 400 - Non representative, compare to B

B Mean annual value for CPA 400 in La Nouvelle plant

C Plasma prepared clinker corresponding to the same composition as CPA 400

Table II

Chemical analysis of the clinkers

x initial (CO_2 + H_2O) content of the raw-mix : 35,22 %.

x for the sake of simplicity we compare hereafter the plasma prepared clinker and the same decarbonated raw-mix.

	Decarbonated raw-mix (%)	Plasma prepared clinker, quenched into water
SiO_2	23.20	23.15
Al_2O_3	4.65	4.65
Fe_2O_3)	2.90	2.40
FeO)		0.10
CaO	66.50	66.85
MgO	1.40	1.50
SO_3)	0.48	0.05
CO_2)		0.25
water)		0.40
K_2O total	0.72	0.11
Na_2O total	0.15	0.05
Total	100	99.51

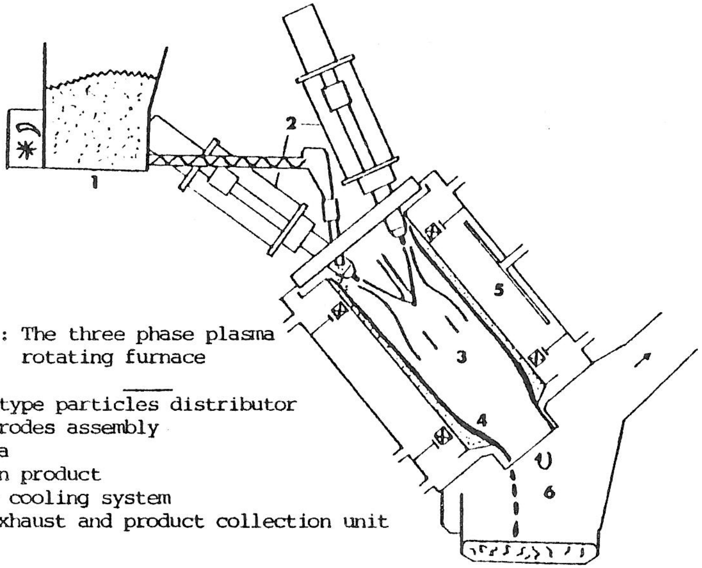

Figure 1 : The three phase plasma rotating furnace

1 - Worm-type particles distributor
2 - Electrodes assembly
3 - Plasma
4 - Molten product
5 - Water cooling system
6 - Gas exhaust and product collection unit

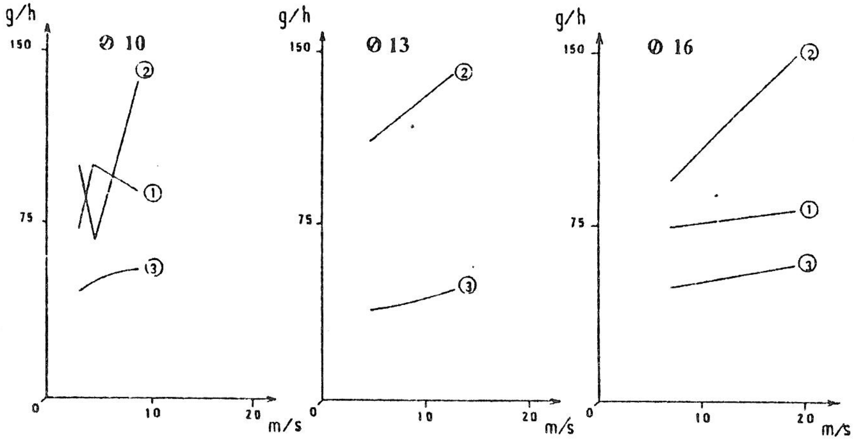
Air plasma : power 90 ± 8 kW, gas flowrate between 5.1. and 13.2 $M^3.h^{-1}$ (STP)

Figure 2 : Electrode erosion per electrode versus initial velocity of the air flow, for different graphite diameters (Ø 10, Ø 13, Ø 16 mm) and different materials ; ① : d.c. graphite ; ② : a.c. graphite ; ③ : a.c. copper-sheathed graphite.