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PRELIMINARY STUDY OF 19TH CENTURY MORTARS FROM RAILWAY ENGINEERING STRUCTURES ABANDONED SINCE 1950

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Introduction

Portland cement-based binders from the second half of the eighteenth century are known as “early age Portland cements” [1] or “meso-Portland cement” [2]. They cover a compositional range broader than modern Portland cement, especially concerning a richer Al content [3].

The present study investigates mortars from masonry structure on a 19th century railway line from the French Massif Central, built around 1880, which was subsequently totally abandoned in 1950 due to the flooding of the valley by a dam lake. The studied railway runs through the Chavanon valley located ca. a hundred kilometers to the west of Clermont-Ferrand (Figure 1), mainly constituted of various acidic metamorphic rocks (migmatites, gneisses and micaschists). The incision of the valley ranges from 180 to 250 meters in the area of interest, with locally cliffs and mainly steep slopes as well as a narrow river. The altitude of the present section ranges from 600 to 550 meters above sea level.

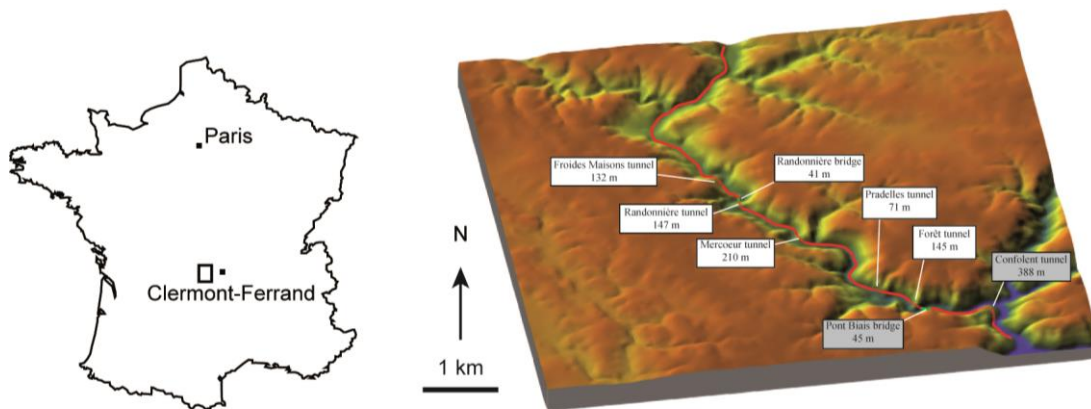


Fig. 1: location of the studied railway in France and detail of the itinerary along the Chavanon valley. The locations of the two structures on which sampling have been carried out have a light grey frame.

In the ca. 8,5 km long in the more incised part of the valley (figure 2), the railway crosses six tunnels for a total amount of 1100 meters and two bridges for a total of ca. 85 meters. All structures are in masonry and were built around 1880 since the railway line has opened in 1882. The present study documents two structures from the southern part of the line.



Fig. 2: a steam train on the Randonnière bridge, getting outside the Randonnière tunnel. Picture from [4]

The *Confolent* tunnel (figure 3) is a 388 m long, curved tunnel. Its northeastern entrance is partly collapsed, the southeastern one still stands. Moss and calcite deposits are abundant on exposed surfaces; from time to time the southern entrance is partly flooded, depending on the level of the dam lake.

The *Pont Biais* bridge (figure 3) cuts across the Chavanon river at an angle, hence its name (*biais*, in French, means “not orthogonal”). This masonry bridge is ca. 40 meters long. The intrados of the arch as well as the abutment are covered by calcite deposits forming locally some stalactites.



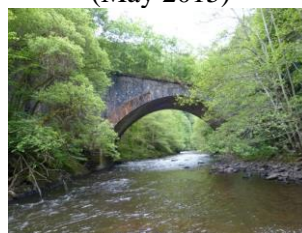
Southern entrance of the Confolent tunnel
(April 2007)



Northern entrance of the Confolent tunnel
(May 2015)



Interior of the Confolent tunnel (May 2015)



The Pont Biais bridge (May 2015)

Fig. 3: structures from which the mortars have been sampled

The goal of this study is to give a preliminary insight of the type of binders used since there is currently no data on those specific structures, as well as to give new descriptions to early Portland cement.

Materials and methods

Sampling for this preliminary study was done on two structures, one bridge (Pont Biais) and one tunnel (Confolent tunnel) at its two (northern and southern) entrances in May 2015. Since the study of historic mortars is greatly enhanced by the use of microscopy and microanalysis techniques [5], especially concerning early Portland cements [1], this preliminary study was based only on optical microscopy (OM) and scanning electron microscopy (SEM).

Thin sections were produced firstly at the conventional thickness (30 micrometers) to study the sand from the mortars, another sequence of thinner ones (15 micrometers) was done subsequently to study the binder.

Optical microscopy was carried out on a Zeiss Axiozoom macroscope (stereomicroscope observations under white and UV light), a Leica DMRXP microscope and a Nikon Eclipse polarizing/reflecting microscope. SEM-EDS, qualitative standardless analysis were done on a Hitachi S-4300SE/N SEM working in high vacuum mode, coupled to a ThermoScientificUltradryEDX detector. Semi-quantitative, standard-bases SEM-EDS analysis were obtained on a JEOL JSM-7001F operating at 15 kV, 0,3 nA with a working distance of 10 mm, coupled with an Oxford Penta FETx3 detector. Data acquisition was 60s with a dead time of 20%.

Results

The sand of the mortars is rounded and consists of quartz grains, feldspars and various metamorphic rocks as well as volcanic ones. It corresponds most probably to sand dredged from the Chavanon river close to the works during the construction of the structures.

Hand samples are characterized by a clear, light-grey color, with a local darker patina (figure 4).

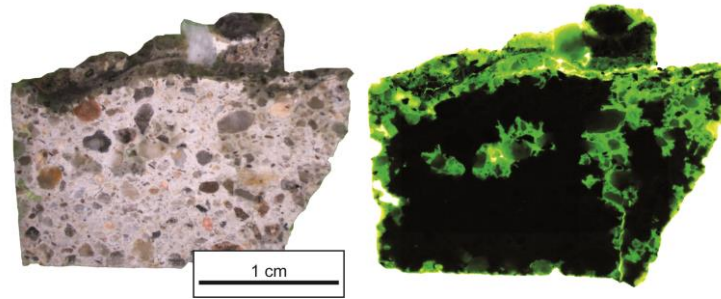


Fig. 4: ground slab of mortar from the southern entrance of the Confolent tunnel.
Left: white light, right: UV light.

The microscopical investigation of the binder has revealed that it consists of Portland cement. Hydraulic lime was not observed in the samples. The mineralogy is variable (figure 5). It is dominated by pseudowollastonite (CS), belite (C_2S) and alite (C_3S), as well as rankinite (C_3S_2) and local ye'elite ($C_4A_3\bar{S}$).

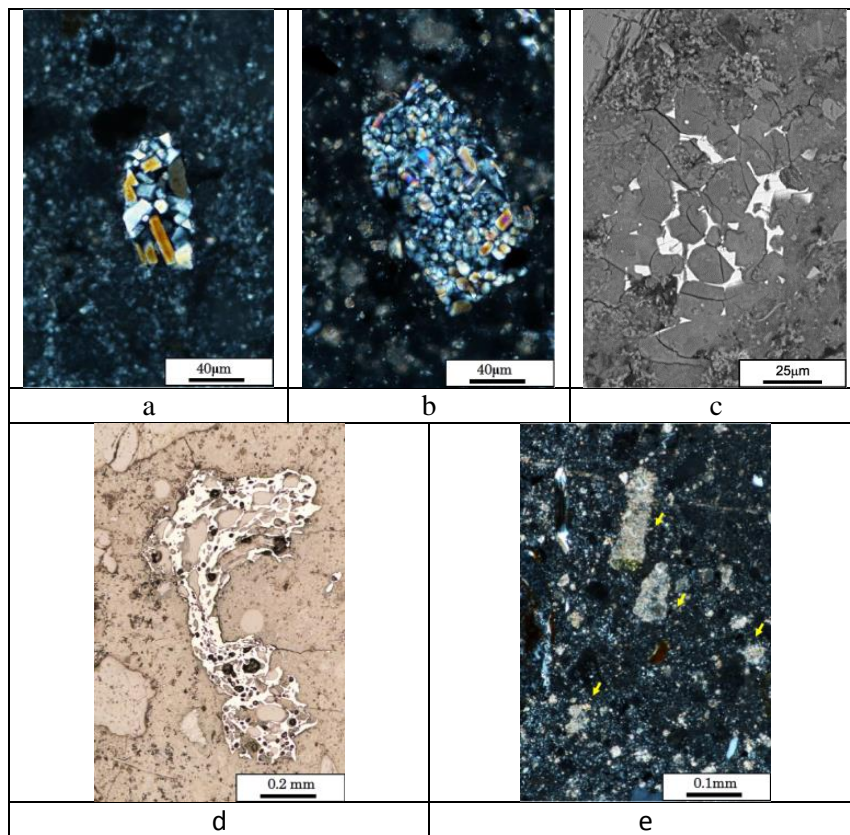


Fig.5: Features observed in binders as seen in optical microscopy, transmitted light and crossed polars except when indicated. a: cement particle composed of pseudowollastonite and potassium silicate (confirmed by EDS) from the Pont Biais Bridge, b: pseudowollastonite dominated assemblage, Confolent tunnel (southern entrance), c: SEM (BSE) image of a cement particle composed of hydrated alite (dark), hydrated belite (dark) and interstitial ferrite (bright), d: coal ash (reflected light), e: limestone filler, Confolent tunnel

Carbonation is conspicuous in cross sections of the surface of exposed mortars. Ettringite is quite abundant, both in voids and in cracks. The main features observed microscopically in the mortars and are summarized in table 1.

	Constituent		Biais Bridge		Confolent tunnel				
			P1	P2	Northern entrance		Southern entrance		
					N1	N2	S1	S2	
Binder	Portland cement	Isolated particle	x	x	x	x	x	x	
		Lump	x						
	Limestone powder		-	-	x	x	xx	xx	
	Coal ash		x	x	x	x	x	x	
Cement hydrates	Portlandite	Void	-	-	-	x	-	-	
		Cement paste matrix		-	-	x	x	-	-
	Ettringite	Void	-	-	-	-	x	x	
		Crack	Fresh	-	-	-	-	xx	xx
			Carbonated	-	-	-	-	xx	xx
Carbonation	Calcite	Void	-	-	x	x	-	x	
		Cement paste matrix		x	x	x	x	x	x
		Crack	-	-	x	-	xx	xx	

Table 1: summary of microscopical investigations in mortars from 2 structures built around 1880. -: not observed, x: minor, xx: abundant

Discussion and conclusions

This railway line has been opened the very year during which the famous French chemist Henry le Chatelier published the first description of Portland cement phases under the microscope [6]. At that time, cement was heterogeneous due to both the heterogeneity of the raw meal and the ill-defined calcination conditions [3]. The present study is in good agreement with such conclusions since several mineral assemblages, hydraulic or not, has been observed.

An excess of sulfur can be emphasized by the presence of $C_4A_3\bar{S}$ (ye'elimite) in unhydrated cement particles relics; its source is to find in the coal used for cement production, from which ash has been observed in all of the samples. Ettringite, present in both voids and cracks, is also a manifestation of the excess of sulfur.

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