

## Concrete block sites in Brazil for assessing ASR, ISA and coupled attack over time

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### Abstract

*This paper presents a Furnas R&D program that is being carried out in Brazil related to concrete blocks that are being monitored, and are supposed to last for a long time. They were cast with different concrete material combinations, different situations of local exposure and also microclimate in order to evaluate ASR, ISA and their coupled attack. All blocks were properly instrumented. The general purposes are to study their behaviour in respect to expansions, deformations, and changes in their characteristics over time. They are being subjected to non-destructive and also destructive tests in order to detect their changes over time due to DEF, AAR or both. Testing on their elasto-mechanical properties, as well as microstructural analyses are being performed. Similar situations were developed in the laboratory with the purpose to correlate them subsequently with real field performance of the concrete blocks. The program is at the beginning, and some results already obtained are presented in this paper.*

**Keywords:** ASR/DEF; concrete blocks; expansion; coupled attack

## 1. INTRODUCTION

Several researches have been performed trying to study and improve test methods in laboratory [1-6]. Other researches are attempting to devise proper mitigation procedures mainly to avoid DEF and coupled DEF and AAR attack. The procedures to mitigate ASR are already well known. Information on some concrete structures that are distressed due to expansive reactions as well as the correct diagnosis, assessment and laboratory tests are available [7-12]. It is well accepted that there is a big difference when comparing laboratory tests and the field behavior of concrete mixtures subjected to AAR and/or DEF.

For this reason, exposure blocks are of utmost importance. In the early sixties when the construction of Jupia hydroelectric powerplant and later when Ilha Solteira hydroelectric powerplant, in Brazil, had started to use crushed basalt and also river gravel as coarse aggregates. However, the gravel contained chalcedony and agate being therefore highly reactive with the cement alkalis. A plant that produced artificial pozzolan from calcined clay was installed nearby the Jupia site and supplied material to mitigate the potential ASR. Considering that it was a new achievement, in those days, CESP the hydropower plants owner decided to build in the early seventies its first exposure site to check the performance of the new pozzolan. Several blocks were cast containing a variety of concrete mixtures, with and without pozzolan in order to compare their behavior throughout the years. Figure 1.1(a) shows the blocks and some specimens to be tested still during construction of the powerplant. Figure 1.1(b) shows the blocks at the laboratory, still being studied after almost 50 years by others. Figure 1.2(a) compares the situation of concrete block number 10, cast with the reactive aggregate and with the mentioned pozzolan in 1974 and in 1997 showing that there are no cracks. Figure 1.2(b) shows block 9 that was cast without pozzolan and presenting cracks already in 1974 and some more in 1997.

There are a number of exposure sites around the world dealing with different materials and goals. However, one common objective is to study the behavior of concrete mixtures produced with different materials and how is it possible to enhance concrete durability subjected to different natural environments. Among these sites, it can be mentioned CANMET and Treat Island (Canada), University of Texas (Figure 1.3) (USA), exposure sites in Reykjavik (Iceland) (Figure 1.4), Trondheim and Brevik, (Norway), Boras (Sweden), Düsseldorf (Germany), Valencia-Paterna (Spain), Milano (Italy), Watford (England), Cadarache (France), Fukuoka (Japan), and others.



Figure 1.1: CESP's exposure blocks in Ilha Solteira laboratory: A) early 70's (Source: Flavio Salles); B) February 2019 (Source: Selmo Kuperman).

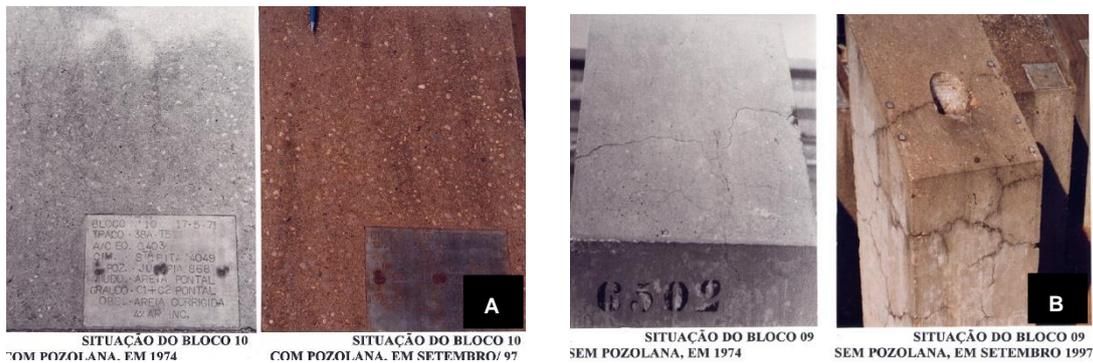


Figure 1.2: A) Block 10 - concrete containing reactive aggregates and pozzolan, in 1974; B) Block 9 – concrete with reactive aggregate and no pozzolan, in 1997 (Source: Flavio Salles).



Figure 1.3: Some exposure sites (Source: presentation by Kevin Folliard).



Figure 1.4: Exposure site in Reykjavik, Iceland (Source: Börge Wigum).

Furnas, one of the Brazilian energy companies, that has a long-time experience in mitigating AAR in its powerplants, either hydro, wind or thermal, decided to conduct research on the effect of nanomaterials and different types of cement on DEF, on ASR and also on the combined attack by DEF and ASR [13].

Besides casting laboratory specimens of paste, mortar and concrete, a decision was made to cast several concrete blocks in two different Brazilian environments: one in the South of the country where the weather is cold and another in the central region that presents hot weather almost all year.

Each block was instrumented with one embedded rod extensometer, one embedded Carlson type strain meter and embedded thermocouples. This long time Project has several goals and among them is to study later, when cracks start to appear, methods to contain the expansions and deformations.

The production of ASR was relatively easy, since there are several sources of reactive aggregates available and also cements without mitigating potential. For some blocks, in order to cast a concrete that would present DEF it was necessary to be sure that a high temperature would be reached. Besides using high cement content in the mix those blocks were isolated with 0,15 m of expanded polystyrene in all sides and on the bottom and top. Three dimensional calculations using the B4cast software showed that temperatures would reach values above 85°C, therefore enabling the formation of delayed ettringite.

Reference blocks were cast with cooled concrete through the use of ice instead of water in the mix and were subjected to post cooling through embedded pipes of flexible PVC. Tests are being conducted on extracted samples from the blocks, compared with laboratory cylinders and prisms casted with the same concrete mix design and also with pastes and mortars produced with the same materials.

## 2. BLOCK SITES IN BRAZIL

### 2.1 General information of concrete blocks

This program under progress in Brazil contemplates the study on ASR, DEF and coupled attack of DEF&ASR [13].

This research is part of ANEEL R&D Project from FURNAS encompassing the primary study of concrete samples cast in laboratory followed by multi-level investigations over time of large concrete blocks. For some of them, it was purposely induced high temperatures due to the hydration process in order to promote DEF, with aggregates (coarse and fine) considered non-reactive. For ASR and ASR&DEF, it was used a known ASR reactive coarse aggregate and a non-reactive fine aggregate. Blocks were well instrumented and their behaviour throughout the years, as well as a number of nondestructive and also destructive tests, are being performed aiming to detect minor changes inside concrete and also impacts on their properties and performance while they supposedly will expand.

Table 2.1 presents the main program established by the technical team considering the concrete placed in the blocks. Up to now, it has been settled 26 concrete blocks: 14 at Goiás state (Brazil Midwest region) and 12 at Paraná state (Southern Region) of Brazil. There is a prevision of more 6 blocks to the placed, totaling 20 blocks at Goiás state, and for the global program, 32 blocks.

The sites were constructed with support of ANEEL R&D Program of FURNAS and LACTEC as partner.

Table 2.1: General information – Concrete Blocks.

Attack Studied	Site & N. of Blocks		Aggregate	Cement type	Mineral Admixture	Ice Cooled
	Central-West (Furnas)	South (Lactec)				
REF.	1*	1	NR	HSPC		Y
DEF	4	3	NR	HSPC		N
DEF	2*	-	NR	Pozz.C	FA	N
DEF	-	1	NR	HSPC	NS	N
ASR	2	2	R	HSPC		Y
ASR&DEF	3	3	R	HSPC		N
ASR&DEF	2*	1	R	Pozz.C	FA	N
ASR&DEF	-	1	R	HSPC	NS	N
Sum	14*	12				

\*4 Blocks are still being prepared for concrete placing at Furnas Site (2020); moreover, there is an additional prevision of more 6 blocks to the placed, totaling 20 blocks at central-west.

Concrete mixtures were cast considering a mix of 1:1.6:1.8:0.46 (cement: fine aggregate: coarse aggregate: water-cement ratio), based on a field real concrete element that is distressed with DEF in

Brazil. It is a pumped concrete commonly used on trunnion beams of hydroelectric power plants; thus, cement content was of 471 kg/m<sup>3</sup> and a percentage of about 48% of sand was used. A 1.5 m<sup>3</sup> concrete mixer was used in order to produce the total volume of concrete for one block, each time (Figure 2.1). Two Portland cements were used in the experimental program, as follows: a high early strength Portland cement – HSPC (Brazilian standard CPV ARI - similar to type III of ASTM) and a Portland Pozzolanic cement with fly-ash (Brazilian standard CPIV ARI - similar to type IP of ASTM). Nanosilica was also used as mineral admixture besides fly-ash in order to evaluate the mitigation process. Concrete slump was 200 mm, and air content equal to 1.3%. A water-reducing admixture was also used in order to set the consistency of concrete mixtures (Figure 2.1; 2.2). Supposedly the admixture that was used will not affect neither DEF nor ASR reactions that will occur.

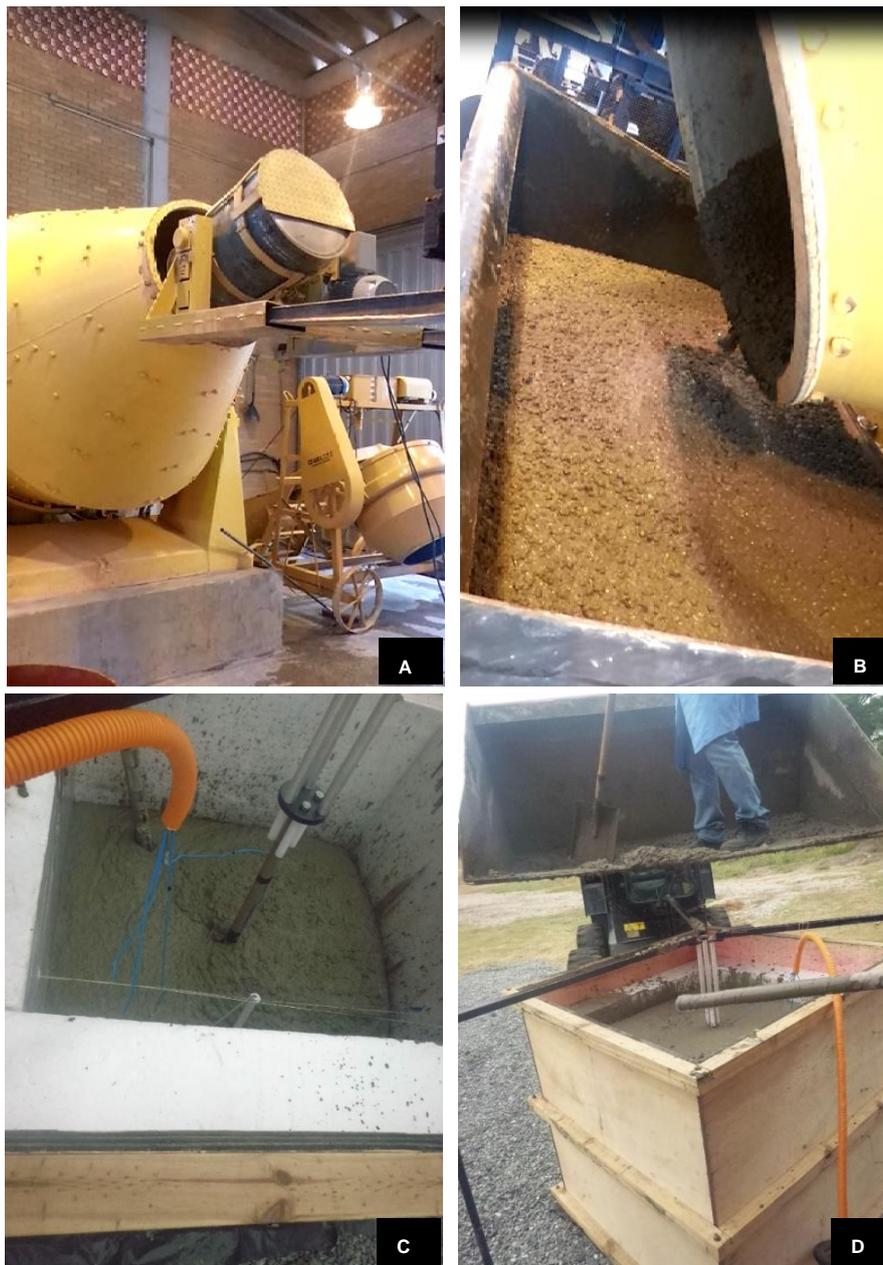


Figure 2.1: Sequence of casting and placing concrete: A) Mixer; B) Concrete aspect; C) Concrete being filled in the block, inside the polystyrene wall formwork; D) Overview of block with fresh concrete.



Figure 2.2: Concrete block completed and the project team (A) immediately after placed (B), after hardening and formwork removal in Curitiba-Paraná and Goiânia-Goiás, respectively (C).

## 2.2 Details of blocks and instrumentation

All blocks are cubes with dimensions 0.80 m x 0.80 m x 0,80 m. Wooden formwork was used and in order to retain heat and simulate mass concrete polystyrene plates were placed inside the formwork, in the sides and also at the bottom and top. A proper plate thickness of 0,15 m was required, according to a previous thermal modelling study involving concrete characteristics and heat dissipation. Instruments were meticulously installed, such as Carlson type strain meter and also a rod extensometer, according to Figure 2.3. For the first blocks, four thermometers (thermocouple type) were also inserted at fixed points to measure the blocks internal temperatures (Figures 2.3 and 2.4). Carlson instrument measures deformation and temperature and rod extensometer allows monitoring vertical displacements in the center of blocks. Those instruments are currently used in the hydroelectric power plants during the auscultation campaigns of the concrete structures, according to the requirements fixed on the national standard for dam safety. For the reference blocks and also ASR evaluations, temperatures were not allowed to rise above 60°C. To achieve this a pre-cooling system with ice replaced water in the mix and a post-cooling system was used by embedding pipes inside the block and circulating water cooled with ice to prevent high temperatures (see Figure 2.4). Also, for those situations, the polystyrene plates were not used inside the formwork. After the temperatures reached their maximum, the formworks were removed and pre-defined areas for NDT were marked in the surface of all concrete blocks. The rod extensometer is adjusted and positioned at the top of blocks in order to register the first measurements. Data of temperatures from the thermocouples and deformations measured by Carlson type strain meters are continuously read through dataloggers.

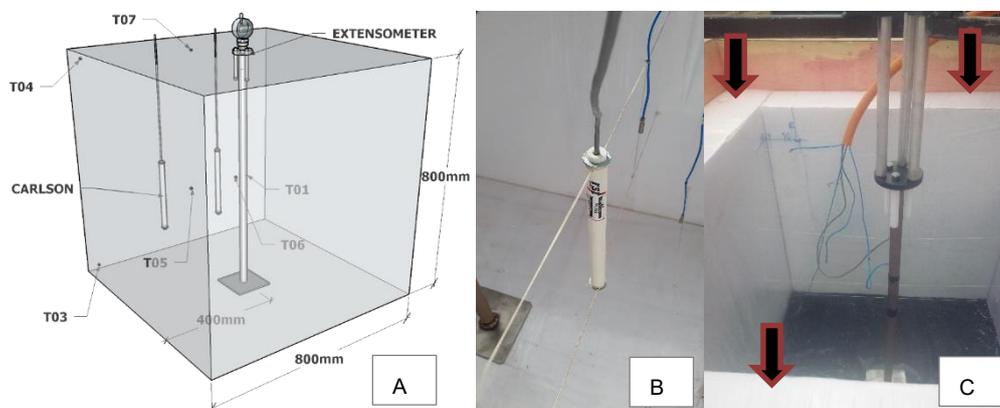


Figure 2.3: Schematic location of each instrument: A) Schematic figure of measuring instruments; B) Carlson type strain meter; C) Rod extensometer with a view of the white polystyrene plate (see arrows).

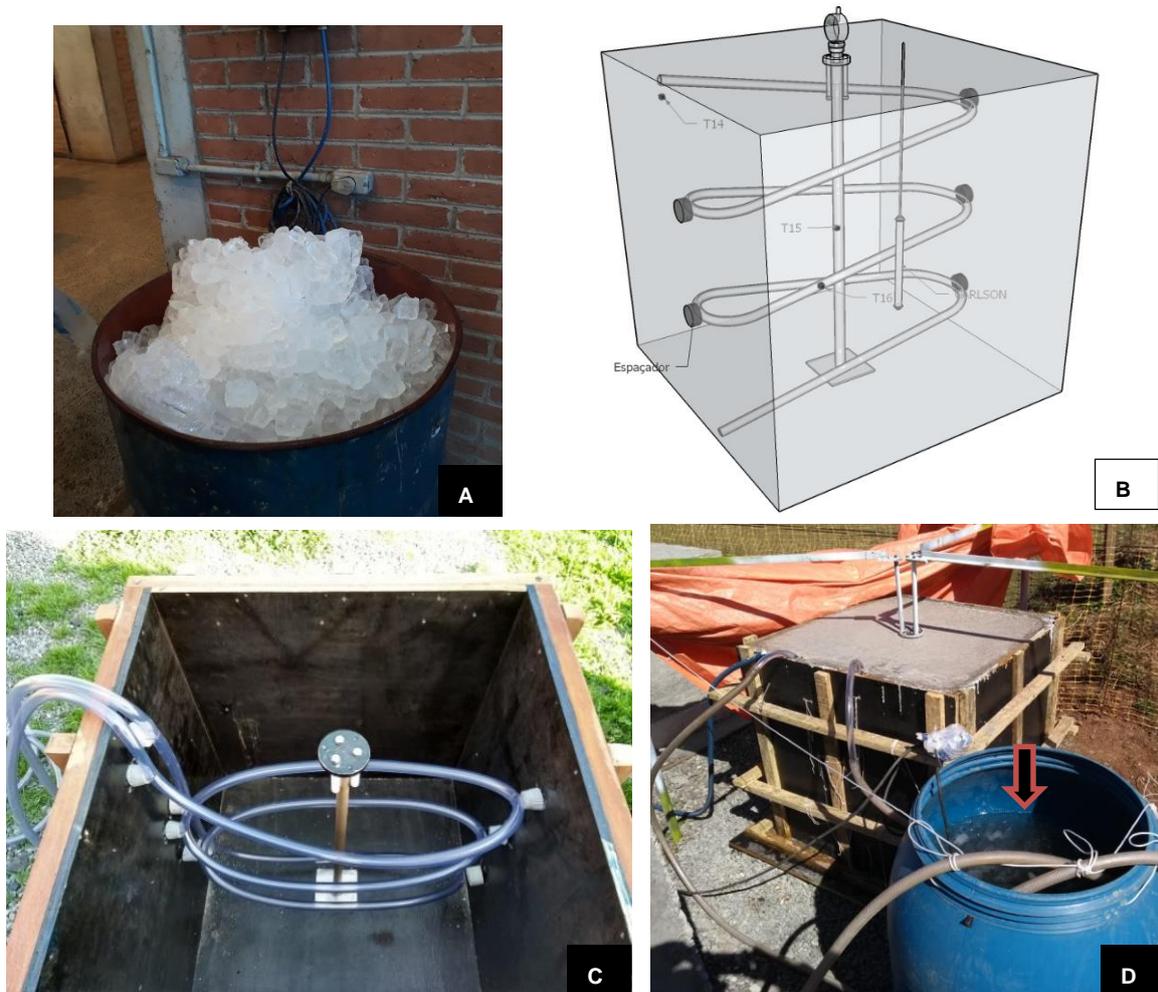


Figure 2.4: Details of pre-cooling with ice (A) and pos-cooling system (B;C) with ice water (D), see arrow (block without polystyrene plates).

### 3. ONGOING STUDIES AND INITIAL RESULTS

#### 3.1 Program of studies

The program under progress involves evaluation by multi-level activities and investigations over time, focused on ASR, DEF and coupled attack of DEF&ASR, as follows:

- Visual inspection
- NDT
- Measurements of deformation and temperature
- Measurements of length to obtain expansion
- Register of moisture and temperature
- Drilling concrete cores from blocks
- Mechanical tests of cores
- Microstructural analyses of cores

There is a periodicity of above investigations: for the mechanical and microstructural analyses of concrete cores, it will depend on the symptoms observed along time with, at least, one drilling per year. Each age of drilling considers 1 sample able to be divided into 2 specimens for mechanical properties; after tests, the material will be analysed by SEM/EDS and other techniques, if possible. A reference sample is always taken from each block at about 4-6 months, before considering damages from the expansive reactions (Figure 3.3 and 3.4). NDT tests involve Ultra Sound tests and Electrical Resistivity

measurements for performance-based evaluation of concrete blocks. Other NDT techniques are outlined but will depend on the financial availability. The following figures (3.1-3.4) present some photograph registers of the blocks and the program under progress.



Figure 3.1: Some blocks placed: A) Goiás State – FURNAS; B) Paraná State – LACTEC

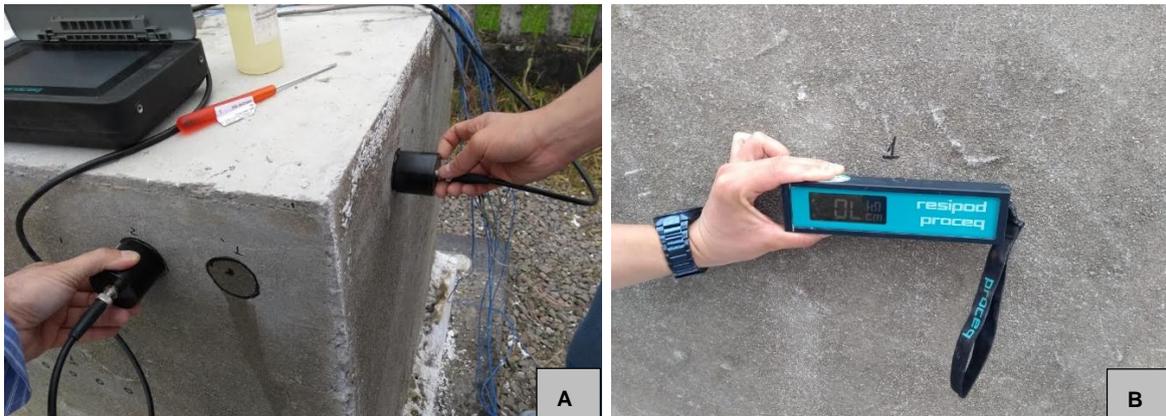


Figure 3.2: NDT ongoing measurements: A) Ultrasound; B) Electrical Resistivity.

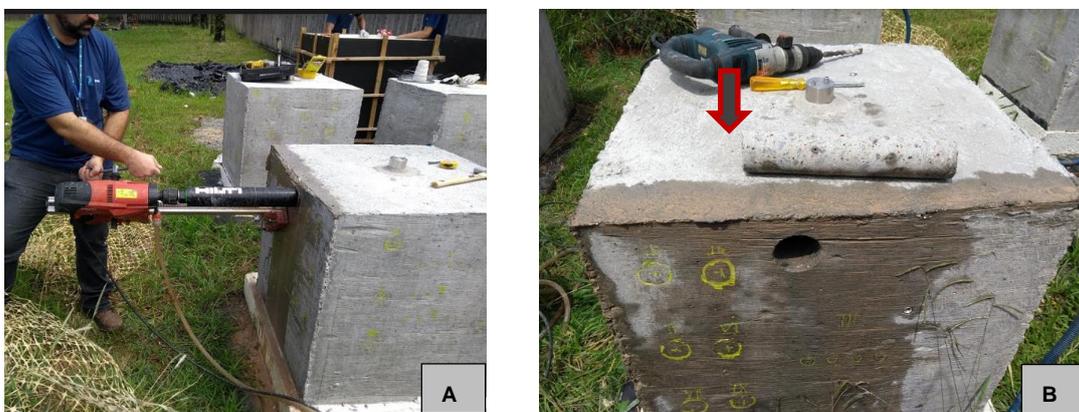


Figure 3.3: Core drill in operation & concrete core drilled.

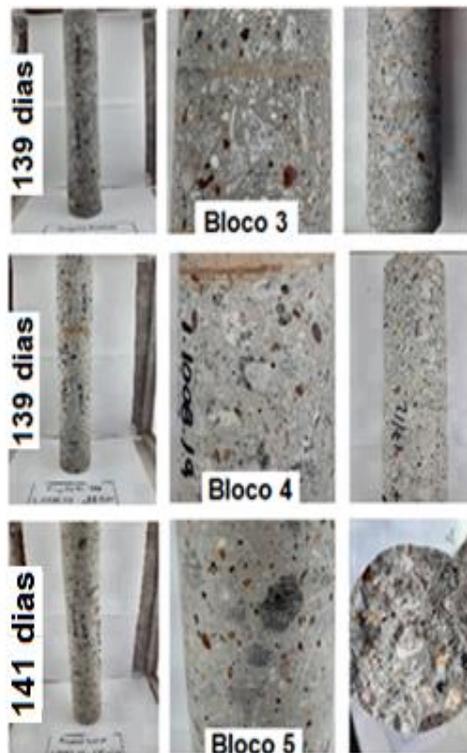


Figure 3.4: Some concrete cores drilled from blocks.

### 3.2 Preliminary results

Figure 3.5 presents temperature peaks (maximum values) achieved for each concrete block. It is important to highlight that the blocks with peak temperatures below 60°C were those submitted to pre-cooling and post-cooling. Some were destined to be reference concrete for DEF tests (with non-reactive aggregates). Others were reference concrete for ASR (with reactive coarse aggregate). Concrete cast with Portland pozzolanic cement with about 26% of fly-ash reached temperatures about 75°C. Concrete produced with high early strength cement reached an average temperature of 92°C, being therefore able to trigger DEF and also DEF&ASR. Thus, the initial simulation of temperatures provided by the finite element method modelling proved to be adequate, since the objective of obtaining a high temperature was attained favouring the DEF attack.

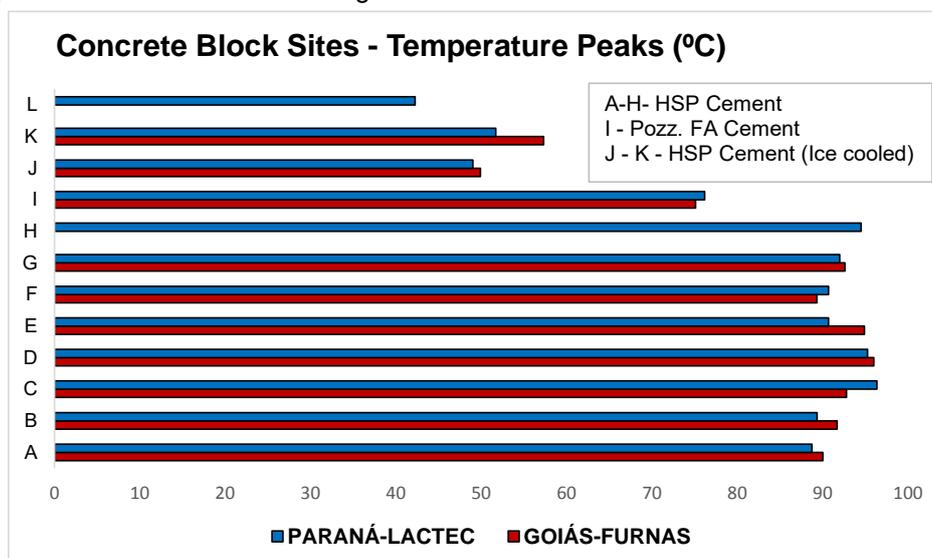


Figure 3.5: Maximum temperatures achieved in the centre of block.

In the Figure 3.6 the temperatures that were collected from the datalogger, after casting concrete blocks, and also the behaviour of thermocouples installed in different points are presented. The ambient temperature was also registered (in blue). It is interesting to observe in the figures the heating and cooling rates. The pre-cooled and post-cooled concrete mixtures (a;b) show that both rates are smaller when compared to the others (concrete casted in the presence of the polystyrene plates) (c;d), that achieved temperatures next to 90°C.

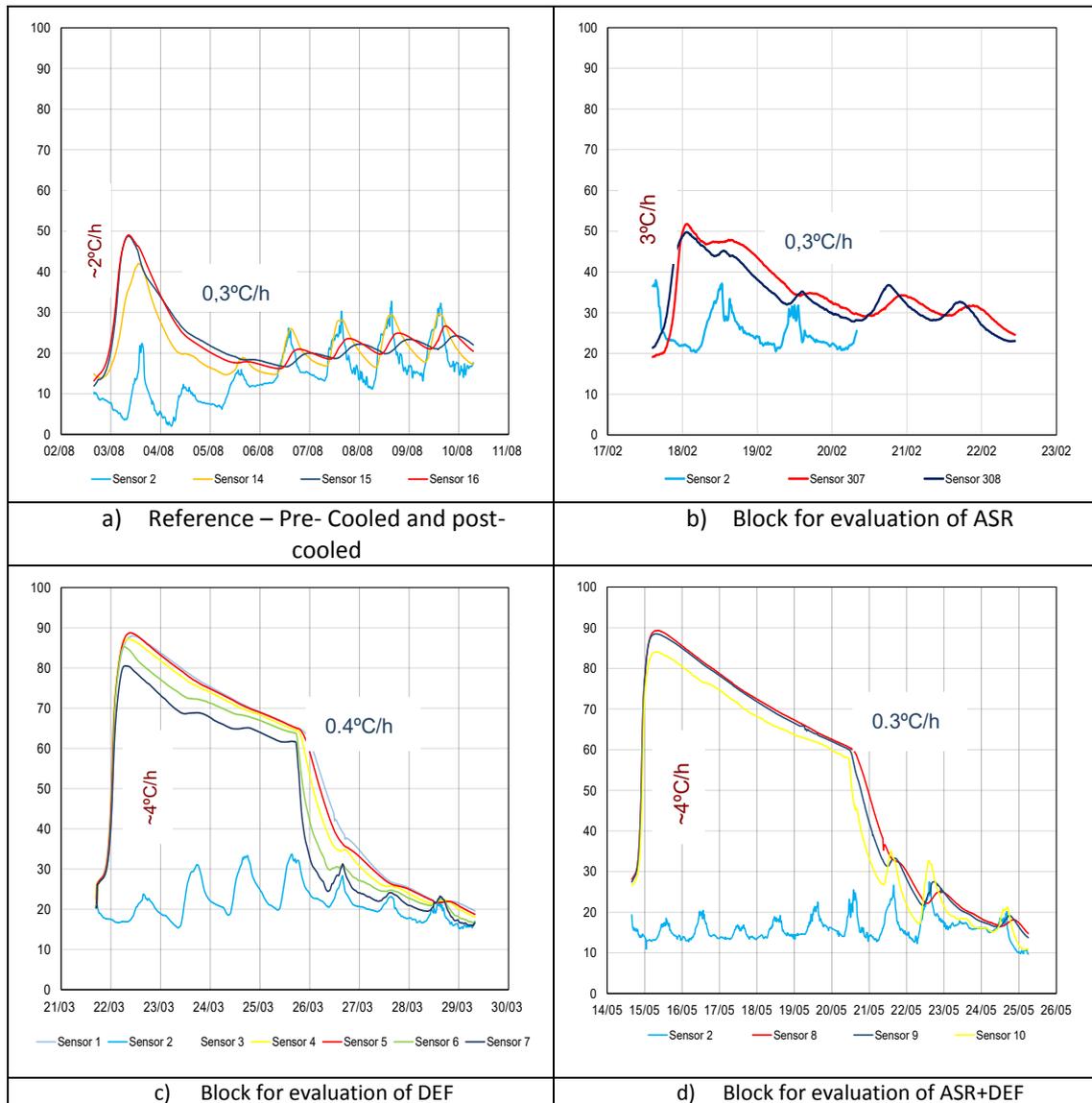


Figure 3.6: Temperatures collected after casting concrete and their behavior between the four thermocouples installed inside some blocks.

It is important to state that typical symptoms of expansive reaction such as cracks can delay a long time to appear. In relation to the visual inspections, the monitoring over time and up to now was not capable to indicate presence of expansive reactions. Concrete blocks did not achieve one year yet and specially ASR with granitic rock as aggregate usually exhibit a slow reactive behavior.

As for NDT, some results from US velocity are presented (Figure 3.7). The direct method and two locations at each block were used (n.1-1 and n.4-4). The lowest values of ultrasound velocity were achieved for DEF situation. By comparing the average between all blocks, once more, no important variation was perceived until the last age of evaluation (Figure 3.8) neither for both tested points. The main purpose of using US is to follow the occurrence of cracks in the blocks that will be subjected to DEF. It is important to notice that no cracks are visible in the blocks yet.

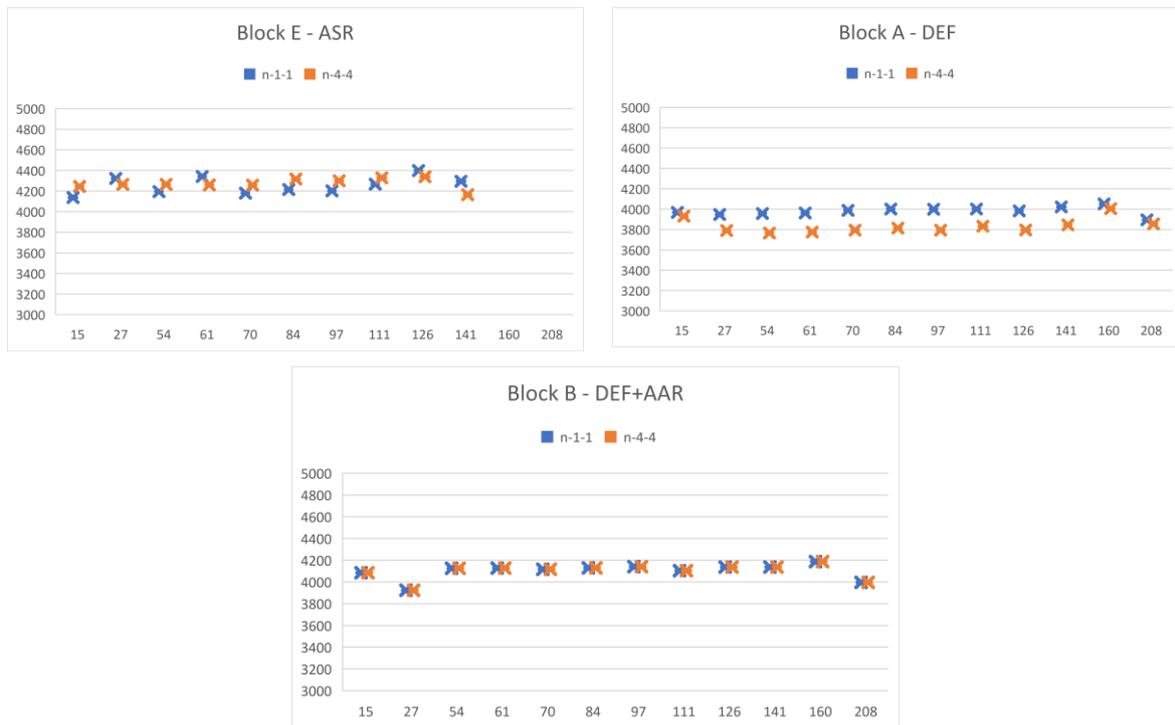
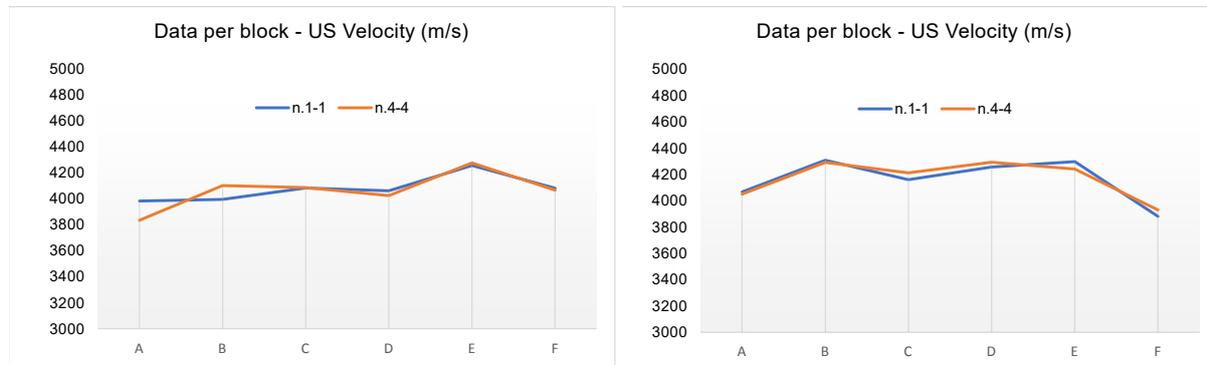


Figure 3.7: US data over time for ASR, DEF and ASR&DEF situations of blocks. (Site: FURNAS-Goiás)



Data from Furnas concrete blocks.

Data from Lactec concrete blocks.

Figure 3.8: US average data per block

Concrete cores were drilled from the blocks at about 4-6 months as reference samples for comparisons at further ages of monitoring. Results of elasticity modulus and compressive strength are presented hereinafter (Figure 3.9). It is important to inform that REF (Reference concrete) was not subjected to high temperatures. Compressive strength and also elasticity modulus are higher for REF., followed by the block made with Portland pozzolanic cement, as expected. For both studied conditions (DEF and DEF&ASR) involving HSC (high early strength Portland cement), results are almost the same and lower than the formers mentioned.

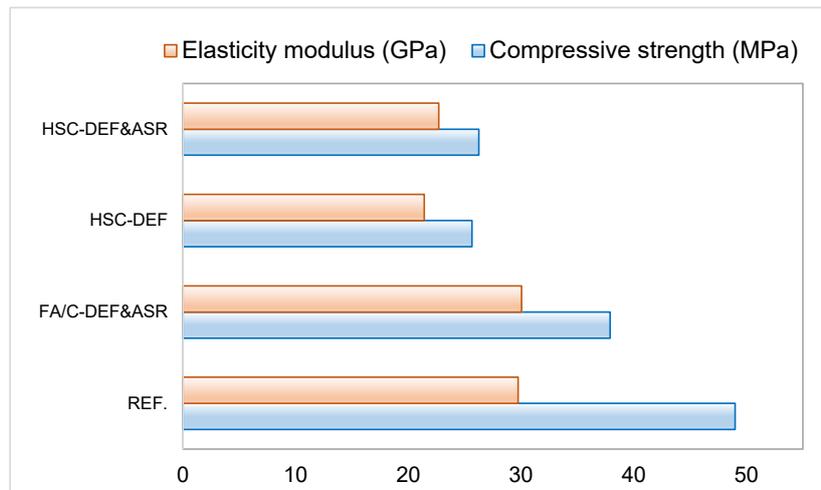


Figure 3.9: Mechanical properties of some concrete cores drilled from blocks.

A few microstructural analyses of concrete cores were performed due to the early age of concrete blocks. Figure 3.10 (a-c) presents initial images and EDS spectra for three situations analyzed by MEV/EDS in fracture samples (i.e.: DEF and ASR+DEF). In the concrete mixtures with reactive aggregate no ASR gel was detected yet, probably due the recent age of concrete; besides some ettringite crystals were seen (a;c). For concrete with fly-ash, the incidence was minimal, and solely in the void bottom. In the presence of high strength cement, some ettringite was detected inside an aggregate cleavage, filling it (see arrow). Considering the analyses in the concrete condition for DEF, individually, several crystals appeared concentrated inside voids and next to the ITZ (b).

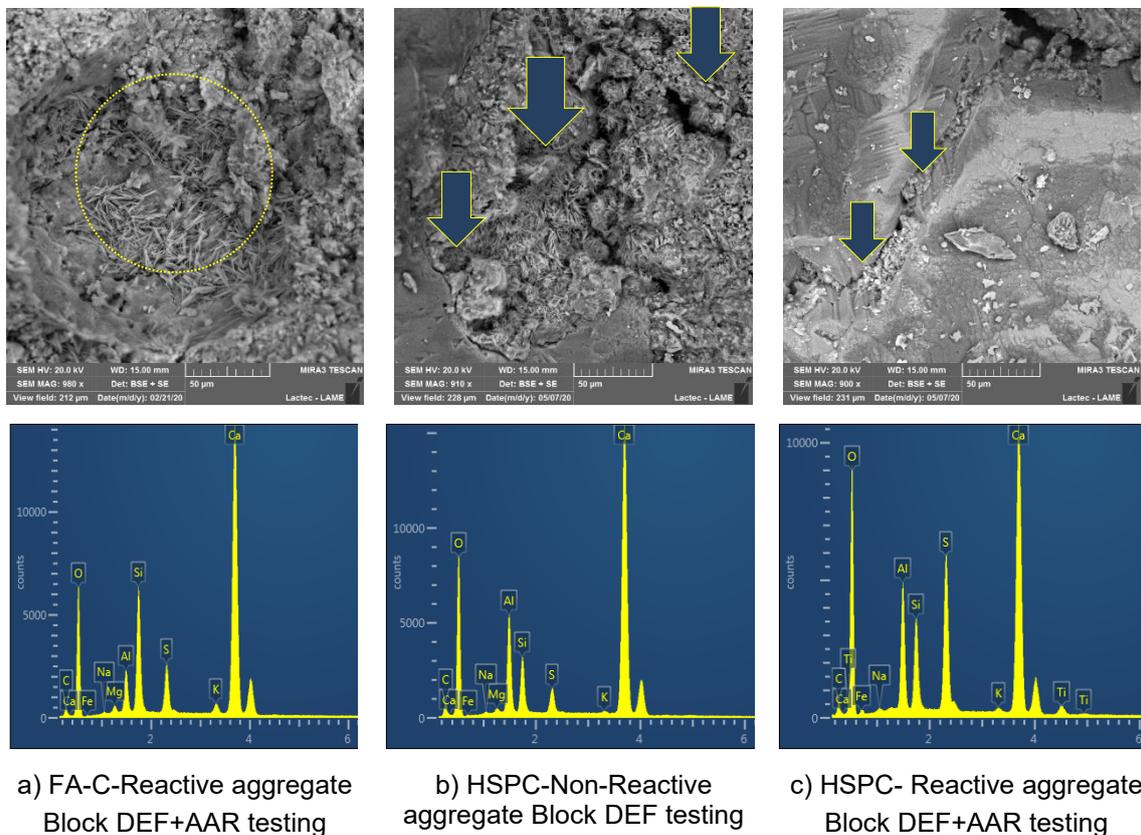


Figure 3.10: SEM/EDS analyses.

## 4. PROSPECTIVE STUDIES

Throughout the years deformations and cracks are expected to occur in the blocks that are either prone to ASR, DEF or the combination of both ASR and DEF. It is expected that the embedded instruments will show these strains and minor volume changes will occur before cracks start to appear. At the same time nondestructive tests and microstructural analysis will be carried out to check the evolution of the chemical reactions. When these reactions start to significantly affect the concrete properties new studies will be performed aiming to validate procedures of intervention that can help in stopping the reactions or at least increasing the concrete durability and extend service life of blocks. These procedures will probably involve the use of reinforcements, prestressing, injection of products, among others.

## 5. ACKNOWLEDGEMENT

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