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EXTENDED ROUND ROBIN TESTING PROGRAM OF COST ACTION TU1404 – LESSONS LEARNED FROM THE INITIAL EXPERIMENTAL PHASE

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Abstract

The extended round robin testing program (RRT^+) is used in the Working Group 1 of the COST Action TU1404 as a fundamental mechanism: i) to validate advanced, non-standardised experimental techniques for testing cement-based materials and structures, ii) to benchmark different sustainable variations of concrete mixes prepared with mineral admixtures, recycled materials and/or by-products, and iii) to obtain input data for a range of concrete properties which could serve designers and engineers to better predict lifespan, durability, and serviceability of concrete structures. With a total of 45 laboratories from Europe, Japan and Canada, performing over 50 test methods on the same concrete mix, it presents one of the most extensive initiatives for joint testing of cement-based materials. The RRT^+ is divided into two phases: the initial and main experimental phases. During the initial phase, an ordinary concrete mix is prepared using the same constituting materials and following identical preconditioning, preparation, conditioning and test procedures. Even though the framework is identical and potential external causes of deviations are limited, concrete is prepared in different laboratories and some scatter in results can be expected. This paper describes the observations during the initial experimental phase and discusses methods including statistical analysis performed to understand the scatter and results obtained.

1. Introduction

In current design standards (e.g. Eurocode, fib Model codes) design and quality control during construction are based on classification of structural materials according to strength classes, with most of the other material properties being practically dependent only on such classes. Nowadays it is clear that this approach is not sufficient and that there is a need for performance-based approach, based on different parameters of concrete, relevant for the structural and environmental application. In order to successfully propose and deploy a performance-based approach, data on different properties of different types of concrete need to be known and validated and a database of material properties needs to be established. This is especially the case when incorporating by-products and waste materials in cement-based materials. Additionally, there are numerous advanced techniques continuously being developed, that can give answers to questions raised by modelling and limit the need for assumptions and uncertainties in current models. But to step out of the research framework and come to the wider practice, these techniques have to be validated at a pan-European level.

The main objectives of the extended Round Robin Testing (RRT^+) are twofold. The first objective is to provide better understanding of the CBM themselves (database of properties), especially high-performance and eco-concrete. This will offer new opportunities to simulation/predictive models both in terms of validation of modelling assumption/strategies and opportunities for the validation of simulation results. The second objective is the mutual validation of advanced, non-standardised experimental techniques developed in European laboratories. This will highlight the validity and added value of newly developed techniques, and lead to standardization of more precise and property targeted methods for testing CBM.

The RRT^+ is divided into two phases, the initial and main experimental phases. The initial experimental phase kick-started the RRT^+ and actually corresponds to a classical RRT. The approach employed in the RRT^+ was to ship the constituting materials from the same location in France to different participating laboratories in Europe, Canada and Japan and to ask participants to mix and test specified concrete in their laboratories. Participants received detailed guidelines on preconditioning, mixing, sampling, curing and testing of concrete. This initial experimental phase is a mandatory step for all participating laboratories to be fully included in the main phase. Even though the framework was identical and potential external causes of deviations limited, concrete was still prepared in different laboratories and some scatter in results was expected.

Results obtained by various laboratories which are presented hereafter are used to give a critical overview of the chosen approach to Round Robin Testing. The overall aim of the initial phase was to define procedures for preconditioning, mixing and curing of concrete well enough so that laboratories can create a comparable concrete. If a comparable concrete can be prepared, it will be possible to evaluate the efficiency and effectiveness of the novel and non-standardised test methods performed by different laboratories. Therefore, the statistical analysis was not performed to study the repeatability and reproducibility for each test method used in the Initial phase, since these methods are standardized and such a procedure is outside the scope of the Extended Round Robin Test. Rather, the aim was to determine if it is possible to make comparable concrete in across the different laboratories and identify the procedures that need to be defined to achieve the same.

2. Experimental program

2.1 Materials

The ordinary concrete mixture labelled OC which was used to achieve the objectives of the initial experimental phase is presented in Table 1. The mix is based on the mix used in the context of the Vercors project [4], an experimental mock-up of a nuclear reactor containment-building at 1/3 scale which has been recently built at Renardières near Paris by Électricité de France S.A. (EDF). The mix has effective water-to-cement ratio 0.52, high-strength Portland cement and addition of chemical admixture in the form of a plasticizer. The composition presented hereafter is based on the mass of fully water saturated gravel (both 4-11 mm and 8-16 mm), dry sand and water necessary to add to the mixer.

Table 1. Composition of ordinary concrete OC mix used in the RRT program

Basic Material	Type of the material	Amount [kg/m^3]
Cement	CEM I 52.5 N-SR3 CE PM-CP2 NF HRC	320
Sand	0-4 mm, REC GSM LGP1 (13 % of CaO and 72 % of SiO2)	830
Gravel	4-11mm, R GSM LGP1 (rounded, containing silicate and limestone)	445
	8-16 mm, R Balloy (rounded, containing silicate and limestone)	550
Admixtures	Plasticizer SIKAPLAST Techno 80 (water content 80%)	2.4
Added water*	Water that needs to be added in the mixer	170.9
w_{eff}/c		0.52

* Added water = Effective water (obtained from w_{eff}/c ratio) – 0.8*amount of the Sp (80% of Sp mass is water) + water theoretically absorbed by the sand (0.77% as coefficient of absorption)

2.2 Participants, material provision and logistics

During the launching of RRT$^+$ interested participants were requested to submit a commitment letter, on which they expressed their willingness to perform specific tests during this initiative. In total 45 laboratories submitted their commitment letters, coming from 19 countries worldwide. According to the requested material, around 100 tonnes of raw material were distributed from France among the participants. With respect to efficiency, the distribution was organized over 18 national contact points. These contact points received the whole request from one country and organized a domestic redistribution. Altogether, the whole distribution process took around 4 months.

In due time to the submission deadline of this contribution, 34 out of 45 laboratories could submit their Initial phase results, and are presented in the Table 2. All listed laboratories and contact persons are the authors of experimental data presented in this paper, while the authors of the paper present managing team of RRT$^+$. Additional laboratories submitted their results after the submission deadline and are not taken into account in this publication. Delays arose in a few cases due to transport issues in terms of delivery difficulties (e.g. laboratories with restricted access possibilities), transport damages, which had to be replaced as well as challenging overseas supply chains. Besides, a few other participants were confronted with structural changes or will participate only in a very specific part of the Main phase due to the restrictions of their resources.

2.3 Preconditioning procedures

For the preparation of fully saturated gravel, it was necessary to place needed amount of gravel in a sealed tank with enough water to reach full saturation at least 7 days prior to mixing. This procedure ensured that the aggregate had sufficient time to fully absorb water.

Regardless of these sealed conditions, an additional check of absorbed water was performed on the day of mixing. If the fully saturated state had not been reached, the water needed to reach such state had to be added in the mixer. Sand had to be oven dried at 60°C for 24 hours or until constant mass was reached. After the drying, container with the sand was taken out from the oven and kept in laboratory conditions at least several hours before mixing until the temperature of the sand was 20 ± 2°C.

Table 2. Laboratories that submitted results for the Initial phase in due time

No	Institute	Country	Contact person
1	Graz University of Technology	Austria	Joachim Juhart
2	Belgian Building Research Institute (BBRI)	Belgium	Benoît Parmentier
3	KU Leuven	Belgium	Özlem Cizer
4	Ghent University	Belgium	Philip Van den Heede
5	IGH Institute Zagreb	Croatia	Dalibor Sekulić
6	Faculty of Civil Engineering Osijek	Croatia	Ivana Miličević
7	IGH Institute Split	Croatia	Elica Marušić
8	University of Zagreb	Croatia	Ivan Gabrijel
9	Czech Technical University Prague	Czech Republic	Radoslav Sovjak
10	GeM - Ecole Centrale de Nantes	France	Emmanuel Rozière
11	Nantes University, GeM Institute	France	Stéphanie Bonnet
12	Lafarge	France	Arnauld Delaplace
13	University of La Rochelle, LaSIE	France	Philippe Turcry
14	OTH Regensburg	Germany	Ivan Parić
15	TU Braunschweig iBMB/MPA	Germany	Wibke Hermerschmidt
16	TU Dresden	Germany	Egor Secrieru
17	Queen's University	Great Britain	Sree Nanukuttan
18	Democritus University of Thrace	Greece	Souzana Tastani
19	Budapest University of Technology and Economics	Hungary	Katalin Kopecsko
20	TU Delft	Netherlands	Guang Ye
21	NTNU	Norway	Anja Klausen
22	Silesian University of Technology	Poland	Jacek A. Golaszewski
23	ISEL, High Institute of Engineering	Portugal	Carla Maria Costa
24	Nat. Lab. for Civ. Eng., Dep. for Materials (LNEC)	Portugal	Maria S. Sousa Ribeiro
25	University of Minho	Portugal	Miguel Azenha
26	Teixeira Duarte, Engenharia e Construcoes	Portugal	Ivo Rosa
27	Institute for Materials Testing	Serbia	Ksenija Janković
28	University of Novi Sad	Serbia	Vlastimir Radonjanin
29	University of Ljubljana	Slovenia	Violeta B. Bosiljkov
30	Slovenian Nat. Building and Civil Eng. Institute	Slovenia	Aljoša Šajna
31	Igmat Building Materials Institute	Slovenia	Gregor Trtnik
32	ITEFI Institute (CSIC), G-CARMA	Spain	Sofia Aparicio
33	Univesitat Politechnica Madrid	Spain	Jaime C. Galvez
34	Yeditepe University	Turkey	Altug Soylev

Using the procedure described above, it was expected that the sand would not bring additional water to the mix and gravel would not absorb water from the added mixing water. Aggregates of Vercors concrete have a relatively high absorption coefficient, especially the coarse 4/11 mm aggregate (2.61 %) and the 8/16 one (2.25%), which could lead to a significant differences in effective water-to-cement ratio, if classical correction of water was performed. In fact, in a previous round robin test of early age properties [5] with 11 laboratories that prepared the same mortar mix, no requirements were set for the moisture state of the aggregate prior to mixing, and the amount of water to be added directly into the mix was then given by a spreadsheet considering the given moisture content. Slump after mixing varied from close to 0 to well above 200 mm in these mortar batches. In the second round it was prescribed specifically that the aggregate was to be mixed with zero moisture, meaning pre-drying. In this second series, the slump after mixing varied from 150 to 255 mm. In the research performed by Cortas et al. [6] different concretes were prepared from the same concrete mixture by changing only the initial degree of saturation of limestone aggregates. Three degrees of saturation were studied, namely: 0% (dry aggregates), 50% (partially saturated aggregates) and 100% (saturated aggregates). In all mixes water content of aggregate was measured each time and the amount of added water adjusted prior to mixing. Results of autogenous and plastic shrinkage and porosity of these three mixes clearly showed that the early-age behaviour of concrete is significantly influenced by the initial water saturation of aggregates. Therefore, even though the procedure of preconditioning chosen in this RRT$^+$ was somewhat complicated, time consuming and somewhat deviated from usual practice, it was crucial that all participating laboratories adhered to it, and a spreadsheet was provided to help with the procedure and collect information at all critical levels to check compliance.

2.4 Testing methods

Just after mixing, it was requested to perform following mandatory tests on fresh concrete:

1) consistency - standard slump technique according to the procedure described in standard EN 12350-2:2009 [7],
2) air content –one of the two methods described in standard EN 12350-7:2009 [8],
3) density – using methods described in standard EN 12350-6:2009 [9],
4) initial concrete temperature,
5) visual appearance of the mixture (a photograph of fresh concrete immediately after mixing and report any peculiarities, e.g. segregation of coarse aggregates, bleeding, etc.).

Consistency, air content and density had to be repeated 3 times on the same mixture within the shortest possible time window in order to adequately perform statistical analysis of the obtained results. Time of each test needed to be noted in the provided spreadsheet.

From the concrete mix, six standard specimens were taken for determining the concrete compressive strength. Most of the laboratories used standard cubes with the dimensions of 150×150×150 mm. Some laboratories used concrete cylinders with dimension Ø110/220 mm and their results are approximated to that of standard concrete cube using the procedure given in the standard EN 206-1:2000. Specimens needed to be wet cured in water at 20±2°C or in controlled humidity environment at more than 95% relative humidity and temperature of 20±2°C, as per the procedure described in standard EN 12390-2:2009 [10]. Compressive strength test needed to be performed after 7 (3 replicates) and 28 days (3 replicates), following the procedure described in standard EN 12390-3:2009/AC:2011 [11]. This paper only presents and analyses the values of slump, concrete temperature and compressive strength at 7 days. Each participating laboratory was asked to complete the above-mentioned spreadsheet for collecting results, consisting various details including preconditioning, results of fresh and hardened state properties, as well as to provide several photographs of the concrete mix. Laboratories were required to highlight the deviations (if any) from the prescribed procedures for preconditioning, mixing and curing, as well as eventual deviations from the procedure of testing described in the required standards.

2.5 Analysis methods

For the analysis of results a basic statistical tool was utilised. Statistical analysis comprised of calculating the mean value and the standard deviation both for each participating laboratory and for the concrete properties and general mean of the group for each property, checking normality of obtained data, fitting distribution and checking for outliers using Mandel's statistics, all in accordance with the standard ISO 5725-2 [12].

Mean value, $\overline{y_{ij}}$, and standard deviation, s_{ij}, of each property were calculated for each laboratory, using following expressions:

$$\overline{y_{ij}} = \frac{1}{n_{ij}} \sum_{k=1}^{n_{ij}} y_{ijk} \tag{1}$$

$$s_{ij} = \sqrt{\frac{1}{n_{ij}-1} \sum_{k=1}^{n_{ij}} \left(y_{ijk} - \overline{y_{ij}}\right)^2} \tag{2}$$

where:

- n_{ij} – number of (replicates) test results, 3
- y_{ijk} – single result

Next, a general mean, $\overline{\overline{y_j}}$, and standard deviation, s_j, for each property was calculated, based on all mean values obtained by different laboratories, using following expressions:

$$\overline{\overline{y}}_j = \frac{\sum_{i=1}^{p} n_{ij} \overline{y_{ij}}}{\sum_{i=1}^{p} n_{ij}} \tag{3}$$

$$s_j = \sqrt{\frac{1}{p_j-1} \sum_{i=1}^{p_j} \left(\overline{y_{ij}} - \overline{\overline{y}}_j\right)^2} \tag{4}$$

where:

- p_j – number of laboratories

The relative distribution of obtained values was calculated for each tested property by grouping results in classes and determining frequency of certain obtained value. Once the relative distribution was known, it was possible to evaluate whether data was following a Normal distribution. Normality test was performed visually, by plotting Q-Q plots, showing empirical values vs theoretical values according to the Normal distribution function.

Outliers were identified using Mandel's k and h statistics. Mandel's h coefficient shows between-laboratory consistency statistics for each laboratory and is calculated using following equation:

$$h_{ij} = \frac{\overline{y_{ij}} - \overline{\overline{y_j}}}{\sqrt{\frac{1}{(p_j - 1)} \sum_{i=1}^{p_j} \left(\overline{y_{ij}} - \overline{\overline{y_j}}\right)^2}} \quad (5)$$

For the number of laboratories involved , $p > 30$, a number of replicates within each laboratory for each property, $n = 3$, and a significance level 5%, the h coefficient for each laboratory should be lower than 1.91 [12]. If the coefficient estimated from the data is beyond 1.91, value obtained by this laboratory was considered to be an outlier. This between-laboratory consistency is of actual interest in the RRT+, since it shows how consistent the results are for each laboratory, as compared to the whole group. Mandel's k coefficient shows within-laboratory consistency and it is calculated using the following equation:

$$k_{ij} = \frac{s_{ij}\sqrt{p_j}}{\sqrt{\sum s_{ij}^2}} \quad (6)$$

For number of laboratories, $p > 30$, a number of replicates within each laboratory for each property, $n = 3$, and a significance level 5%, the k coefficient for each laboratory should be lower than 1.72 [12]. If the calculated coefficient is beyond 1.72, the analysed value is considered to be an outlier. This within-laboratory consistency is potentially more of an interest for the individual laboratories, since it shows how their own deviation within one specific property is consistent with the deviation of the group.

3. Results

3.1 Consistency

Consistency using slump value was considered as one of the main parameters for determining if the participating laboratories used the same procedure and whether the same concrete was obtained. Consistency is very sensitive to even a small difference in water content, therefore it was expected that any potential difference in effective water-to-cement ratio would be evident in the slump values. The individual mean value for each participant and the standard deviation calculated from three reported values of obtained slump are presented in Figure 1.

The horizontal line in Figure 1 indicates the value of the general mean of all slump values for the entire group, calculated according to eq. (3), whereas the dotted lines correspond to the mean value ± two general standard deviations, calculated according to eq. (4), which should present 95% of all obtained values in the case behaviour follows Normal distribution. In total only 32 values of slump are presented, because the values of two laboratories were not taken into account for statistical analysis. One laboratory indicated spread value instead of slump value and the second had extremely high air content, which influenced all other properties and was at this point considered as an internal error during mixing.

Reported values of slump are between 184 to 258 mm, with general mean of the group being 219 mm and standard deviation 15.8 mm. Therefore, all concrete mixes fall into consistency class S4 or S5, with most laboratories achieving concrete consistency class S5. Concrete was found to have critical stability and some laboratories reported that it was prone to segregation.

Indeed, only after the experimental results were collected, it was realized that the cement that was shipped to participants was not the same cement used for the optimisation of the mixes. Even though they are both Ordinary Portland cement with strength class 52.5, produced in the same cement plant, they differ in the amount of C_3A. Cement used during the optimisation process was CEM I 52.5 N CE CP2 NF, with 9% of C3A and Blaine area 4400 cm^2/g, while cement actually shipped to participants ended to be CEM I 52.5 N-SR3 CE PM-CP2 NF HRC, with 2% of C3A and Blaine area 4150 cm^2/g. It is exactly this difference in the cement that caused the mix to show signs of segregation, since the amount of superplasticizer and water was not optimised for this cement. During the Main phase the mixes will again be optimised, taken into account this new type of cement.

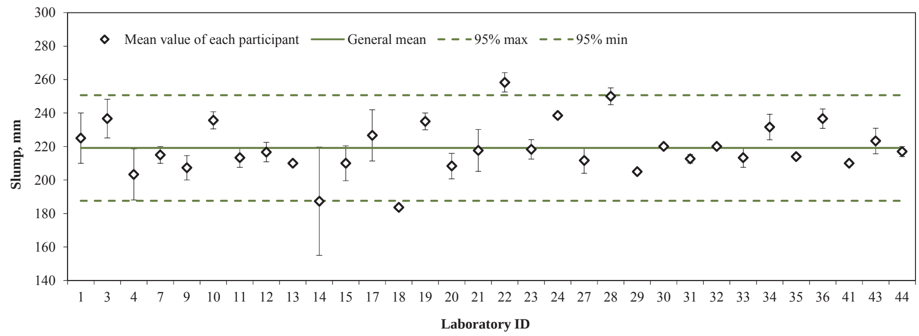
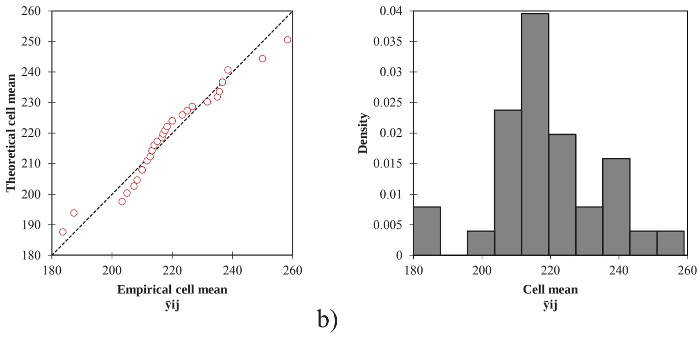


Figure 1. Individual mean values and standard deviation of obtained slump values

Figure 2. Different visual appearance of fresh concrete in different laboratories

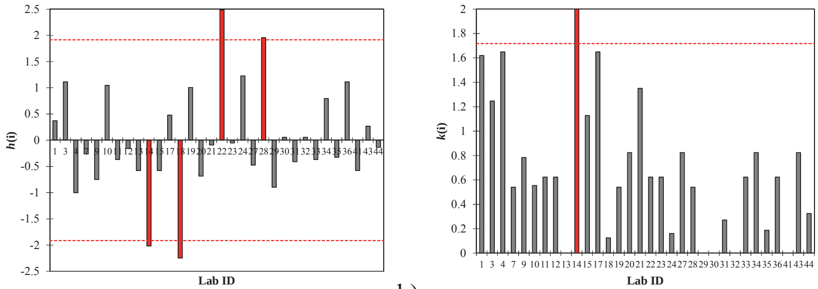
Q-Q plot for testing normality and relative distribution of the slump values are presented in Figure 3 a) and b). It can be observed that values are normally distributed, since there is a linear relationship between the empirical value of general mean and the theoretical value according to Normal distribution. Furthermore, if relative distribution is observed, it can be concluded that the obtained values follow a Normal distribution, with the mean value having the highest frequency.

Mandel's *k* and *h* coefficients were calculated for each laboratory and are presented in Figure 4. The limiting values for both coefficients are indicated with dotted lines (significance level 5%). Since values of slump obtained by participants can be higher or lower than the general mean, the *h* coefficient can have positive and negative value. Some participants did not report all three values of slump, or obtained the same value three times, leading to *k* coefficient equal to 0.



a) b)

Figure 3. a) Q-Q plot and b) relative distribution of slump values



a) b)

Figure 4. a) Mandel's *h* and b) Mandel's *k* coefficients for slump values

According to Mandel's *h* coefficient, the slump values obtained by 4 laboratories are considered as outliers, since they have significantly different values (statistically) than the general mean, which led to *h* coefficients bigger than 1.91. Laboratory 18 obtained a significantly lower value of slump (184 mm) compared to other laboratories and to the general mean (219 mm). From the report obtained by this laboratory, it became obvious that the recommended procedure for preconditioning of materials was not followed, and that concrete was actually mixed with dry gravel and dry sand, instead of fully saturated gravel and dry sand. Even though the amount of water added to the mix was corrected accordingly, which led to the concrete with the same effective water-to-cement ratio, nevertheless the concrete obtained had significantly different consistency and was therefore recognised as outlier. This example strongly highlights the effect of aggregate state concerning water content and the effect it has on concrete fresh properties.

Laboratory 14 obtained slump values with significantly higher with-in laboratory deviation, which led to this value being an outlier also according to the limiting value of Mandel's *k* coefficient. The reason for this high deviation is the loss of workability of mix during time. Mainly, laboratory 14 obtained two first values of slump similar to the general mean value. It is only the third value of slump that was lower than the general mean, which indicates that the slump testing was performed at the time when mix was starting to lose its workability. Therefore, for future testing, it should be strictly prescribed at what time certain testing needs to be performed, in relation to the instant at which cement and water were mixed.

Finally, laboratories 22 and 28 had somewhat bigger values of slump, 258 and 250 mm respectively, compared to other laboratories. Both of these laboratories followed the prescribed procedure. At the same time, in the case of both laboratories, after 7 days of preconditioning gravel, the amount of water in the gravel was higher than reported water absorption. This additional water was not subtracted, and was added to the mix together with the gravel. It is therefore possible that this additional water, added together with the gravel, caused slightly higher values of slump. However, these obtained values should be looked at from the practical point of view. Difference of 20 – 30 mm in slump value on mean slump higher than 210 mm should not be considered as significant and the slump should actually be considered as falling to the same consistency class [13].

3.2 Concrete temperature

Another important parameter, used to critically review the preconditioning procedure, was the temperature of fresh concrete. Similarly to the water content, the temperature of fresh concrete has a significant influence on its fresh state properties. The individual mean value for each participant and standard deviation calculated from three reported values of reported concrete temperature are presented in Figure 5.

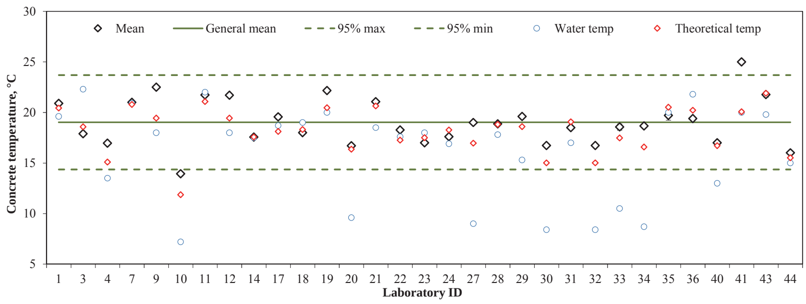
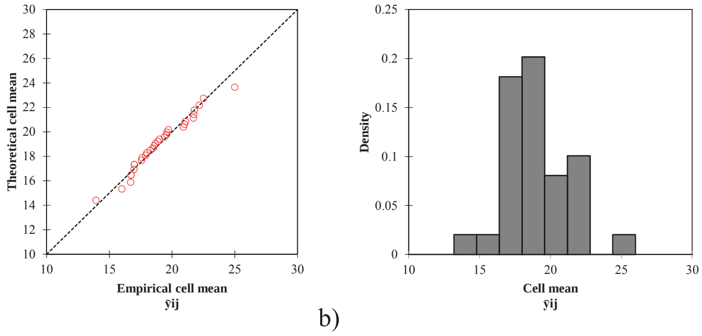


Figure 5. Individual mean values and standard deviation of obtained concrete temperature

Similar to Figure 1, the horizontal line in Figure 5 indicates the general mean of all temperature values for the entire group, calculated according to eq. (3), whereas the dotted lines represent the mean value ± two general standard deviations, calculated according to eq. (4), which should present 95% of all obtained values in the case behaviour follows Normal distribution. Figure 4 presents also temperature of water, since preconditioning of water was not strictly prescribed in the RRT^{+} procedures. Additionally, the theoretical temperature of fresh concrete is also indicated for each laboratory, calculated using known initial temperature of each constituent, its mass in m^3 of concrete and its specific heat capacity.

In total, 31 values of fresh concrete temperature were collected. The data shows that concrete temperatures were between 13.9° and 25°C, with the general mean of the group being 19°C and standard deviation 2.3°C. The relative distribution and Q-Q plot for testing normality of obtained values are presented in Figure 6.

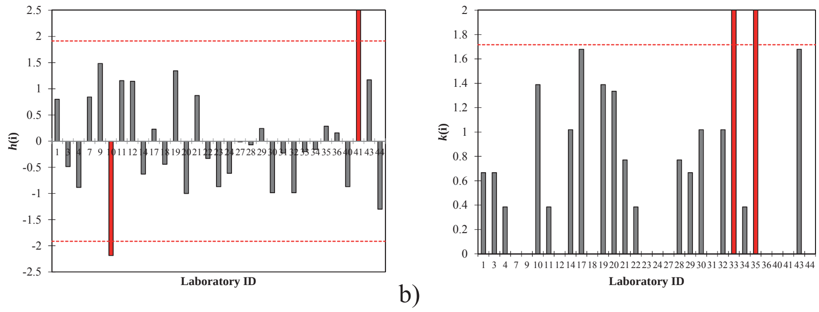


a) b)

Figure 6. a) Q-Q plot and b) relative distribution of concrete temperature

It can be observed that values are normally distributed, since there is a linear relationship between empirical value of general mean and theoretical value according to Normal distribution. Furthermore, if the relative distribution is observed, similar to slump values, it can be concluded that the temperature values follow the Normal distribution, with the mean values having the highest frequency.

When values of temperature are considered in more detail, it can be observed that several laboratories used very cold tap water (around 8°C), while the rest of the laboratories used preconditioned water at 20°C. Regardless of the fact that there is a significant difference in temperature of water, the resulting temperature of concrete is still comparable. This is highlighted using laboratories 24 and 27 as an example. In laboratory 24, water was preconditioned and had temperature similar to other constituents (17-18°C), while in the case of laboratory 27 tap water was used (9°C). Regardless of this difference of almost 10°C temperature of fresh concrete of laboratories 24 and 27 is similar (18 and 19°C respectively). But when laboratories used cold tap water and also did not precondition constituting materials to 20°C, there was an obvious difference in the achieved temperature of concrete. For example, in the case of laboratory 10, the constituting materials had temperature of 11°C and cold tap water of 7°C was used. The resulting temperature of concrete for this laboratory was 14°C, which is below 95 percentile of temperature values. This value is also recognised as outlier using Mandel's *h* statistics, Figure 7 a). Additionally to laboratory 10, the temperature value of laboratory 41 was also considered as an outlier. In the case of this laboratory, all constituents had temperature around 20°C, and the resulting concrete temperature was around 25°C, which is higher than 95 percentile of the group value. Mandel's *k* statistics indicated values of laboratories 33 and 35 as outliers, since their standard deviation had somewhat higher values compared to other laboratories. However, it should be noted that some laboratories performed only one measurement, instead of prescribed three measurements, consequently having misleadingly low standard deviation and Mandel's *k* coefficient.



a) b)

Figure 7. a) Mandel's *h* and b) Mandel's *k* coefficients for concrete temperature

3.3 7-day compressive strength

Compressive strength is one of the most important performance indicators to assess the similarity of concrete mixes. In the frame of the Initial phase, both 7-day and 28-days strengths were requested from the participants. However, hereafter results of only 7-day strength will be presented and discussed. Figure 8 shows values of mean compressive strength for each participating laboratory, together with a general mean of all values for the entire group, calculated according to eq. (3) and two-sided 95 percentile.

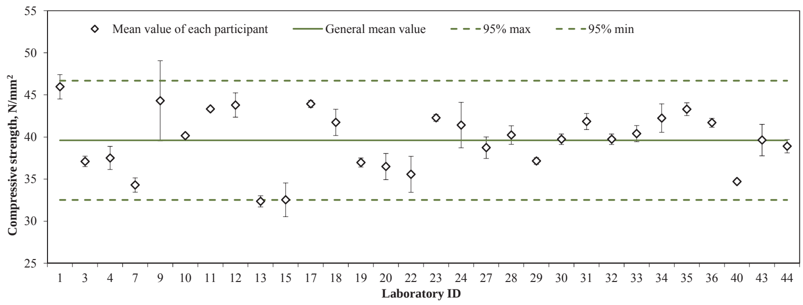
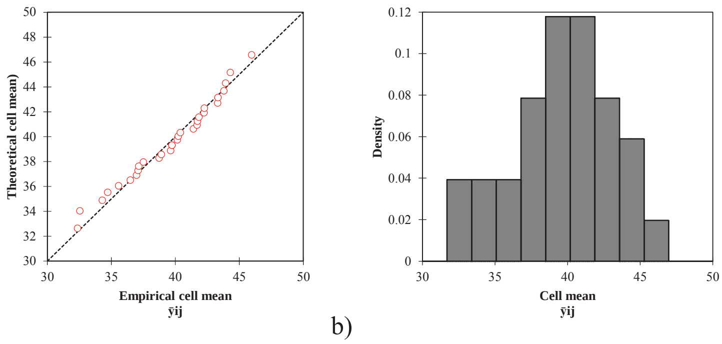


Figure 8. Individual mean values and standard deviation of obtained 7-day concrete compressive strength

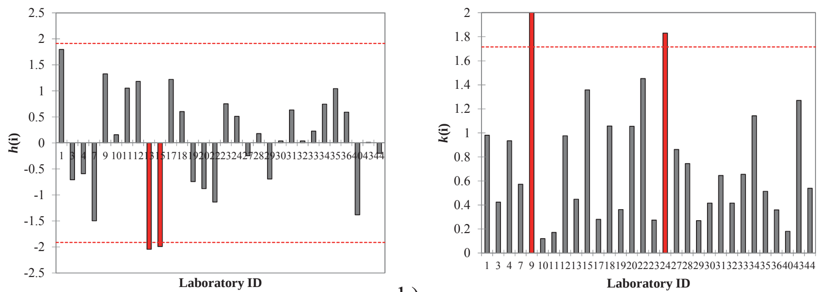
In total, 30 values of 7-days compressive strength were collected. The obtained values of 7-days compressive strength are between 32 and 46 N/mm^2, with the general mean of the group being 39.6 N/mm^2 and standard deviation 3.5 N/mm^2. The coefficient of variation was 8.8%. It can be observed that most of the values reported by different laboratories fall into the range of 95 percentile. Looking at the Q-Q plot and histogram, shown in Figure 9 a) and b) respectively, it can be observed that values also follow a Normal distribution.

Even though no obvious outliers could be detected from the Q-Q plot, 4 values were identified as outliers by using Mandel's *k* and *h* coefficient, as shown in Figure 10. Both laboratory 13 and 15 obtained somewhat lower values of compressive strength (32.8 and 30.4 N/mm^2) compared to the mean value of the group (39.6 N/mm^2). The reason for this lower strength could not be found in any of the steps of procedure, since both laboratories followed the procedure in detail. Laboratories 9 and 24 are recognised as outliers according to their Mandel's *k* coefficient, since they obtained higher standard deviation with-in their results, compared to the group.



a) b)

Figure 9. a) Q-Q plot and b) relative distribution of 7-days compressive strength



a) b)

Figure 10. a) Mandel's *h* and b) Mandel's *k* coefficients for 7-day compressive strength

Even though values of compressive strength seem to have high dispersion, data reported should be reviewed from practitioners' perspective. According to European standard EN 206-1 and conformity control procedure for acceptance of concrete during production, mean value of tested concrete should be greater or equal to characteristic compressive strength + 1.48 x standard deviation, while minimal value obtained should be greater or equal to characteristic compressive strength minus 4 N/mm^2. Taking into account that by 7 days around 70% of 28-days strength is achieved, expected general mean of 28-days strength is around 52 N/mm^2 and minimal value around 39 N/mm^2. Therefore, it can be conclude that all concrete mixes prepared in different laboratories complying with the same concrete class C30/37.

4. Conclusion

This paper presented part of the results gathered during the Initial phase of RRT^+, together with the statistical analysis employed to compare values obtained by different laboratories. Results during this phase were collected in predefined format, consisting of all details concerning different steps in preparation and testing of concrete. The results and statistical analyses that were presented strongly highlight the paramount importance of detailed and rigorous preparation of the experimental campaign. The more details are prescribed, the less of a difference is obtained in the final values of different concrete properties. This is especially the case for water saturation level of aggregates and its influence on the resulting consistency of concrete. Further, it was observed that it is of crucial importance to have all information from participants over the concrete preparation. Such details become crucial when trying to explain significant differences occurring within the laboratories. Finally, it can be concluded that if all the details are prescribed and all participants follow the guidelines, the approach to RRT employed in this initiative is valid; meaning that concrete with similar properties can be prepared. Experience gathered during the Initial phase will be used in the Main phase of RRT^+ where the focus will be on non-standardized and advance techniques for testing cementitious based materials and structures.

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