Cement Testing in Africa – Conclusions from the First Africa-Wide Proficiency Testing Scheme

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Abstract. African cement infrastructure is quite complex. Apart from Northern Africa and South Africa in particular, cement plants are scarce resulting in highly unstable cement pricing. Clinker and cement are imported from overseas, e.g. from Portugal, Turkey, Pakistan, Indonesia, and China. Imports are typically determined by the lowest price, and as a result the countries of origin of products vary regularly yielding large scatter of properties. Quality control and a good quality infrastructure are thus of utmost importance for the safety of the populace, an issue, which is actually often neglected. With funding of the German Metrology Institute (PTB) and support of the SPIN project, a proficiency testing scheme for cement testing according to EN 196 was set up for African laboratories. Proficiency testing schemes, also called round robins, are inter-laboratory performance comparisons allowing participants to evaluate themselves against pre-established criteria. They are a powerful tool to help laboratories improve their performance as well as demonstrate their competences to accreditation bodies or customers. 26 laboratories from 20 nations, 18 of which from Africa, participated. The BAM Federal Institute for Materials Research and Testing acted as coordinator and provider of the scheme. The aim of the round robin was to interpret the submitted data further beyond the pure statistic analyses. The data provided a positive picture of the performance of the participants in general, but it also exhibited a number of technical fields that need improvement. The paper provides the general results of the scheme and analyses identified strengths and weak points based on the submitted and non submitted data as well as on discrepancies from the EN 196 procedures during measurements. The application of EN standards for material testing is critically discussed and since quality infrastructure is also always an issue between industrial and political stakeholders, suggestions for the mitigation of the identified shared problems are given.

1 Introduction

Many African economies are rising with rapid velocity and optimism is spreading. Along with the economic upswing comes the need for construction. In order to ensure safety of constructions for the population, quality issues of the raw materials that are being used for constructions are major concerns.

Transparency, reliability, and safety of materials and products can only be achieved, when a so-called quality infrastructure can be established, which is a narrow mesh of standards, accreditation, certification, metrology, and testing. Products' and materials' performances and qualities are major concerns in many African nations. This is particularly valid for cementitious materials, since cement is scarce, extremely expensive, and has to be transported over large distances. Furthermore, clinker and cement are imported from overseas, which means the range of performance scattering is large [1]. At the same time the societies' need for reliable quality control tools rises permanently. Many countries put a lot of interest in setting up functioning quality assurance institutions to the benefit of their society's safety.

The Physikalisch-Technische Bundesanstalt (PTB), which is the German national metrology institute, has been supporting international technology transfer since more than 50 years, and is involved into a Pan-African cooperation with laboratories and standardisation bodies.

The SPIN network (Spearhead network for clean and safe cement and concrete technologies), a scientific network of researchers from Europe and Africa has been developing feasible approaches towards reasonable construction technologies with cement and concrete for the sub-Saharan African boundary conditions [2].

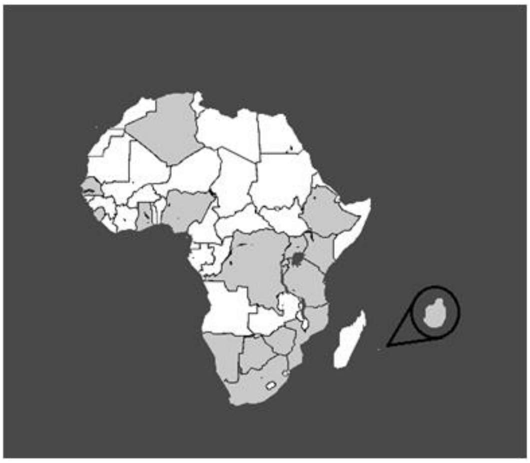

Fig. 1. Countries (marked in light grey) of which laboratories participated in the proficiency testing scheme

The conjunction of the two above mentioned networks yielded in the foundation of a first Africa-wide proficiency testing scheme, a so-called round robin, on the testing of cement. The participants were 26 construction materials testing laboratories from 18 African countries (see Fig. 1) and two European countries. Among the laboratories, national standardisation bodies, public laboratories, and universities each formed eight participants and two participants were private industry laboratories.

A proficiency testing scheme in the field of testing cement has not been conducted in this scope all over Africa before. It is considered as a highly important tool to improve the quality infrastructure all over the continent. Therefore, some relevant experiences resulting from the scheme as well as the way forward will be discussed in this paper.

2 Proficiency testing schemes

In proficiency testing schemes, the participating laboratories are provided with uniform testing items, which have to be tested according to pre-established criteria. The results of all participants undergo statistical analysis and are given back to the participants anonymously. Hence, each participant can compare its own performance against the average performance of the group as well as the reference results in order to identify strengths and weak points of the own performance.

Proficiency testing schemes are quality assurance tools for individual laboratories, which enable them to compare their performance with similar laboratories. The scheme indicates necessary remedial actions and facilitates future improvements. The participation is also a demonstration of competence and a regular participation is mandatory for accredited laboratories in accordance with ISO/IEC 17025:2005 and ISO/IEC Guide 58 (1993).

A regular participation in such schemes also enables laboratories to monitor their testing over time and longer term trends can be identified and corrective or preventive actions can be taken. Therefore, proficiency testing can be considered a powerful tool to help laboratories to demonstrate their competences to accreditation bodies and other parties and it is a criterion for customers to select qualified laboratories. Furthermore the benchmarking with other peer laboratories can facilitate laboratories with below average performance to convince administrations to invest in performance improvements.

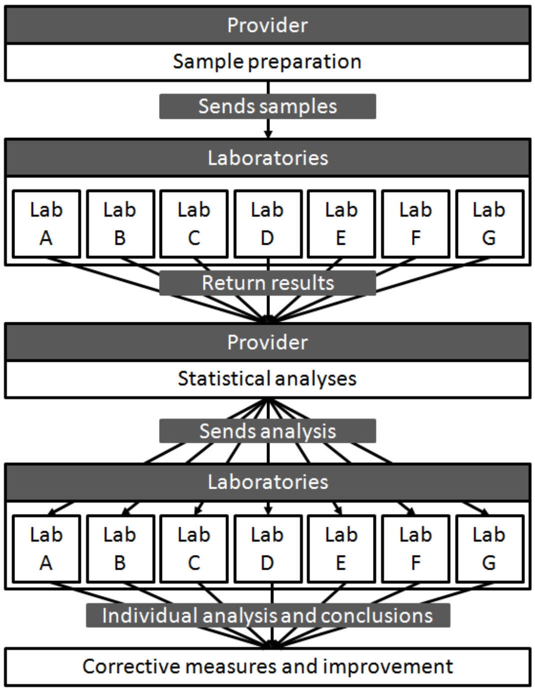

Fig. 2. Flow chart of a typical PT scheme and involved parties.

3 Specifications of the first Africa-wide cement proficiency testing scheme

3.1 Administrative setup

Proficiency testing schemes all over Africa for testing of cement did not yet take place before. Therefore, many of the participating laboratories did not have awareness about the necessary administrative and technical processes. In order to foster improved knowledge and particularly networking among the partners the round robin. Therefore, the round robin was supplemented by a kick-off workshop and a final workshop.

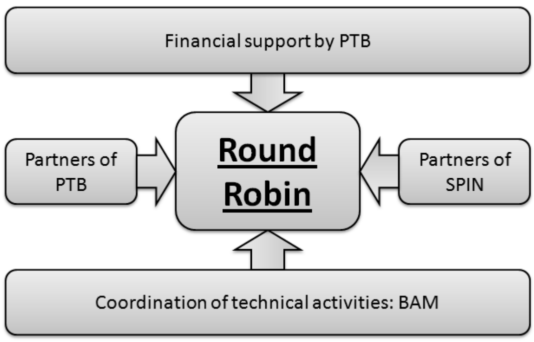

Fig. 3. Schematic diagram of the administrative setup.

The round robin was set up as shown in Fig. 3. BAM acted as provider and technical coordinator, PTB provided the funds for the activities, while as many synergies as possible were generated with activities resulting from the SPIN project. Therefore the kick-off workshop, which took place in Dar es Salaam coincided with student courses that were given for students from seven different universities in conjunction with SPIN [3]. The final workshop was organized in Berlin in conjunction with a public symposium at the BAM on cement and concrete quality issues in Africa and Europe.

3.2 Technical setup

For the round robin the following sample was provided for every partner:

- 1 bag with approx. 6 kg of homogenised cement
- 4 bags of CEN standardised sand (1350 g each)
- 3 cured mortar specimens 40 mm x 40 mm x 160 mm with predictable performance
- Instructions and relevant and actual EN standards, provided by the German Standardisation body DIN.

The testing regime and the boundary conditions were agreed upon jointly with all partners during the kick-off workshop in Dar es Salaam. The mandatory and optional investigations listed in Table 1 and Table 2, respectively, were to be conducted.

Each laboratory was supposed to only deliver the final results as according to the standards. No individual measurements were taken into account.

3.3 Statistical analyses methods

Mean values, standard deviations and coefficients of variation were calculated for each test method. Outliers were eliminated according to the Student distribution for a level of significance of 0.02. Furthermore the distribution of results and the 95% confidence intervals were further determined.

After reception of results, it was identified that a large set of data did not fully comply with the standards. The major problem field was that many laboratories either lacked equipment or could not adjust the climatic conditions for the testing.

Therefore supplementary observations were made concerning the influence of the temperature and that of the full application of standards. Furthermore a comparison to the results of BAM was made to identify whether the mean value of all laboratories lies within the range of an experienced peer laboratory.

4 Discussion of results

4.1 General information

The individual results of the laboratories are confidential, and shall not be discussed or published without agreement of the laboratories. Nevertheless, the information, which goes beyond the technical data or individual performance data, exhibits a number of interesting observations, which shall be discussed in the following paragraphs.

Table 1. Mandatory tests conducted during the round robin.

Test item	Specification
Loss on Ignition	EN 196-2:2005
Insoluble residue	EN 196-2:2005
Chloride content	EN 196-2:2005
Sulfate content	EN 196-2:2005
Specific surface (Blaine)	EN 196-6:2010
Standard consistence	EN 196-3:2005
Initial setting time	EN 196-3:2005
Final setting time	EN 196-3:2005
Flexural strength after 2 and 28 days	EN 196-1:2010
Compressive strength after 2 and 28 days	EN 196-1:2010

Table 2. Optional tests for the round robin.

Test item	Specification
Soundness	EN 196-3:2005
Flexural strength after 7days	EN 196-1:2010
Compressive strength after 7 days	EN 196-1:2010
Flexural and compressive strength of readily cured specimens	EN 196-1:2010

4.3 Submitted results

The results that were submitted gave a clear overview of the average equipment situation of the participating laboratories. As shown in Fig. 4, not a single test was conducted by the entire group of laboratories.

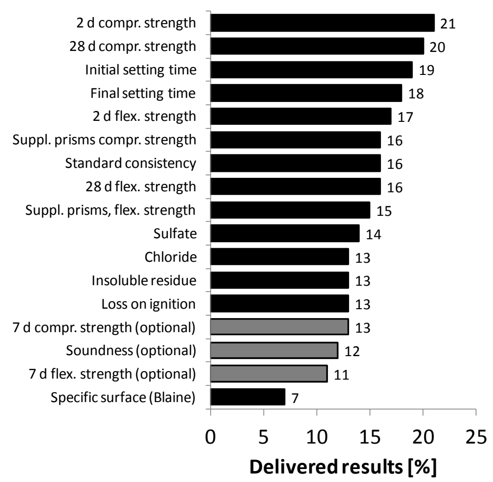

Fig. 4. Number of submitted results out of 26 participants.

Particularly, the majority of laboratories lacked the opportunity to conduct the chemical analyses. Some laboratories delegated these tests to cooperating external laboratories. The lack of inhouse facilities for chemical analyses can be considered as clear and critical disadvantage for construction material laboratories, since the cement market is becoming more and more sophisticated due to the increasing volumes of ternary or quaternary binder systems.

The evaluation exhibited clearly identifiable improvement potentials. Table 3 provides the overview of the scope of results submitted. Only three out of the 20 African laboratories that submitted valid results, were able to conduct all requested tests completely and fully according to the standards, only two of which were public laboratories. This means, the first step to improved quality infrastructure in the field of cement can be considered to be investment into testing equipment.

Table 3. Scope of submitted results.

Situation	Number	Percent
Equipment for at least one of the tests is missing	11	55%
Equipment is available but some tests cannot be conducted fully according to standards (modules/temperature)	8	40%
Some tests were not conducted according to other reasons (mainly human factor)	5	25%
Testing was conducted fully according to the standards	14	70%
- and of which some tests were missing	6	30%
- and tests were entirely conducted.	3	15%
- and which were public laboratories	2	10%
Observation only concerns the African laboratories. Numbers and percentages are related to the 20 African laboratories that delivered results. Assumtion: All deviations from standards correctly reported.		

4.2 Influence of the temperature

One of the major concerns already during the kick-off meeting was the fixation of the ambient temperature during preparation, storing, and testing. Most laboratories are not equipped with automatic climate regulation equipment, so that most laboratories expected higher ambient temperatures than that of (20 ± 2) °C as specified in the EN 196. Since the African climate is hotter than the European climate, it has been discussed critically, whether the application of EN standards may be suboptimal in Africa [4]. However, it is also a challenging task to identify a reasonable and representative alternative testing climate.

In the present round robin, each participant specified the climatic conditions, so that a comparative observation between the results with fully adjusted climate and deviating climate could be made.

The highest reported temperature was 26.5 ℃ and laboratory temperatures between 23 ° and 25 ℃ were reported regularly. However, nevertheless, no significant influence of the testing temperature could be observed for the tests listed in Tables 1 and 2 within the reported temperature ranges between 20.0 ℃ and 26.5 ℃.

4.3 Comparison of standard condition results and results from deviating conditions

The lacking possibility to precisely adjust the climatic boundary conditions was the major reported deviation from the standards. However, also other factors were reported, of which equipment not fully complying with the standards was the main reasons. Furthermore in some cases human factor was mentioned due to lack of experience with particular test methods.

The analysis of the coefficients of variation provides information about the robustness of the test methods. The lower this coefficient, the more robust the method against external influencing factors such as temperature, handling, deviations from standard equipment. The comparison of the coefficients of variation, when calculated from the entire data set and from only those data, which fully comply with the standards, furthermore exhibits information about how important it is to adjust standard conditions. This comparison is given in Fig. 5.

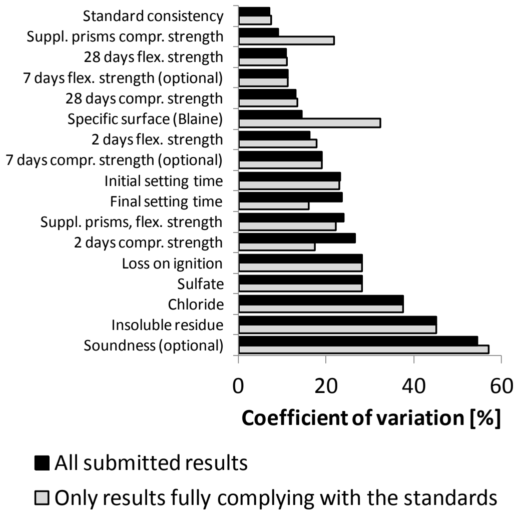

Fig. 5. Coefficients of variation depending on the test method and comparison between results generated under conditions that fully comply with standards and which deviate from that.

It can be found that the supplementary mortar prisms and the Blaine surface showed greater coefficients of variation for the data set based only on standard testing conditions. While it is difficult to identify the reason for compressive strength of the supplementary mortar prisms, the large variation coefficient for the Blaine surface can be explained by the low number of submitted results conforming to the standards (Fig. 4). For the final setting and the two days compressive strength showed significantly lower coefficients of variation, when the tests were conducted fully conforming to the standards. This can be explained by the strong influence of the ambient temperature particularly on the early properties.

All other methods did not exhibit strong differences in the coefficient of variation. In general the mechanical test showed lower values than the chemical tests.

4.3 Supplementary prisms

Supplementary to the standard materials, each laboratory was supplied with a set of standard mortar prisms that were cast and cured under defined conditions prior to the delivery of the materials. These specimens were delivered under sealed conditions to each partner, and thus supposed to show comparable mechanical properties. The idea behind was to use these prisms in order to facilitate laboratories to identify reasons for possible deviations from the mean value.

Fig. 6 shows the 28-d compressive strength results versus the compressive strength results of the standard mortar prisms, supplemented by the 95%-confidence intervals and the identification of outliers. Two basic trends can be identified, which are indicators for the laboratories. For the indicator line A, the supplementary prisms show similar results, while the prisms that were operated by the lab show deviations, which means, the lower strength of the 28 d strength can be attributed to the processing of these specimens. For the indicator line there is a systematic correlation for both strength values, which indicates that the processing of the specimens was conducted soundly, while the machine adjustment might not be optimal.

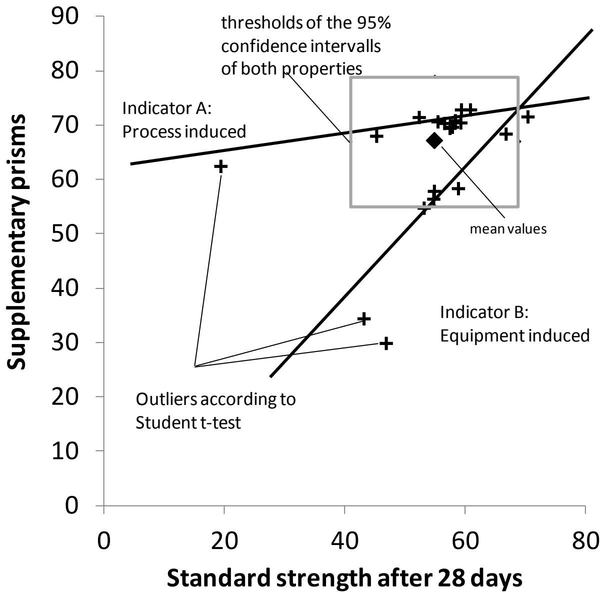

Fig. 6. Compressive strength results and confidence intervals for readily cured mortar specimens.

5 Way forward

The physical meetings among the partners during the kick-off and final workshops gave a unique opportunity to clearly discuss problems and solutions and to generate a good working atmosphere.

The individual necessities and problems were gathered and identified. One of the most positive results of the proficiency testing scheme is that three of the laboratories were directly facilitated to purchase new required equipment, since the benchmark between the laboratories gave unchallengeable information about each laboratory's technical gaps to their administrations.

Furthermore the decision was made for the foundation of an Africa-wide laboratory network, which shall foster future testing related solutions.

Finally, jointly with the funding body PTB, it was agreed upon that the round robin scheme will continue on a regular basis, first with further support of BAM and stepwise delegation of the coordinator's tasks, with the aim to generate a permanent and self-sustainable scheme. The aim is to increase the amount of participants and to incorporate more industry laboratories as well.

6 Conclusions

A first Africa-wide proficiency testing scheme on the testing of cement exhibited positive results. Most laboratories showed a sound performance but in many issues also a high potential for improvement could be identified.

Influences of the environmental temperatures and of slight deviations from the standard equipment or procedure pointed out to be less critical than expected, which is a positive signal for standardisation bodies in Africa to loosen the testing specifications particularly in terms of temperatures to make it fit better with the African climate. However, due to the strong temperature influence on the hydration, early test methods seem to be less robust than later test methods.

In order to facilitate the partners' performance improvement and in order to let a larger group of participants benefit from the scheme, further schemes will be set up in future. Beyond the technical and statistical information, the round robin pointed out to deliver valuable supplementary information, which helps laboratories to facilitate future improvements.

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