UNCERTAINTIES AND INFLUENCES REGARDING MEASUREMENTS IN CERAMIC PRODUCTIONS

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ABSTRACT

Today the achievement of the required level of quality in ceramic products with a minimized level of production costs is more than ever a decisive factor for the competitive strength of producing companies. The use of state-of-the-art process control and organization of workflow is necessary to guarantee the optimum quality needed for customers while increasing profits.

A wide variety of tests and measurements methods, which are necessarily associated with quality assurance, are used throughout the whole manufacturing process. The test methods used have often grown historically, are focused on local settings and cannot be used for process control due to their limited reliability and/or reproducibility. Most measurements are indicative and have to be translated to indicate the changes in important parameters. To increase process reliability and reduce scrap rates in ceramic production, stronger correlations are necessary between the parameters, based on valid measurements. Definition of the relevant parameters to be measured is needed, for the raw materials as well as for intermediate and end products. Available test methods to define the reliability and reproducibility of measurements have to be used, to define the improvement options for ceramic production control and to develop adequate control strategies. Once the reliability and reproducibility of the measuring methods have been validated, the ceramic process control can be upgraded to the state of the art, as used in other industries.

The operator, the equipment and the environment can introduce disturbing influences in measuring accuracy. These influences can lead to a situation, especially where these measurement are used for process control, in which the controller reacts to non-representative signals, which can not always be related to actual process variations. Two statistical methods are discussed to define the validity of measurements as a basis for process control by defining the magnitude of the different influences. The first method focuses on the analysis of the possible magnitude of disturbance by intentionally disturbing the process: ***target measurements****. Practical tests have shown that temperature is one of the most important parameters during the testing period for many parameters. But not only the temperature of the objects themselves influences the result, environment temperature and the temperature of the equipment can also disturb the results. These factors are known, but only in some cases are they taken into account. Measurement and sampling location also influences the measurement results, and has to be taken into account while evaluating results. Changes in the performance of the measurement can also disturb the results. An example in which these influences are known, but seldom quantified for process control, is the measurement of rheological characteristics for casting slips. The second method for defining the variation introduced by the measurement on the variation in the process is the so-called* ***R&R analysis****. R&R-Analysis is a statistical method by which disturbing influences acting upon a measurement system can largely be apprehended. Typical examples from ceramic production are presented.*

The translation of these results regarding typical influences, which have been identified, to optimization measures, minimizing the influences, thus leading to a reduction in failure costs and scrap rates, is illustrated.

Improvements, which have proven their validity in practice, are shown for the three discussed sources of disturbances, which act on the test methods.

1. BASIC PRINCIPLES

For the definition of disturbance, two typical definitions are given. These are formulated as follows:

- A variable disturbance is a variable, whose influence on a result is known, of which however it is unknown to which extent the result may change in individual cases.[1]
- A variable disturbance is the influence of a disturbance on the reference value.[2]

With these two statements the term variable disturbance can be clearly described and understood. The causes of a change in a measured value are, besides the actual changes in the test item, also these variable disturbances which can arise due to different causes:

- Local conditions (environment)
- The measuring instrument
- The operator (handling)

Now it will be possible to determine the error portions in the measuring system as a result of the three possible causes by using different test procedures. Here the sequence of application is a very important aspect, in order to avoid distortion and/or overlapping of errors.

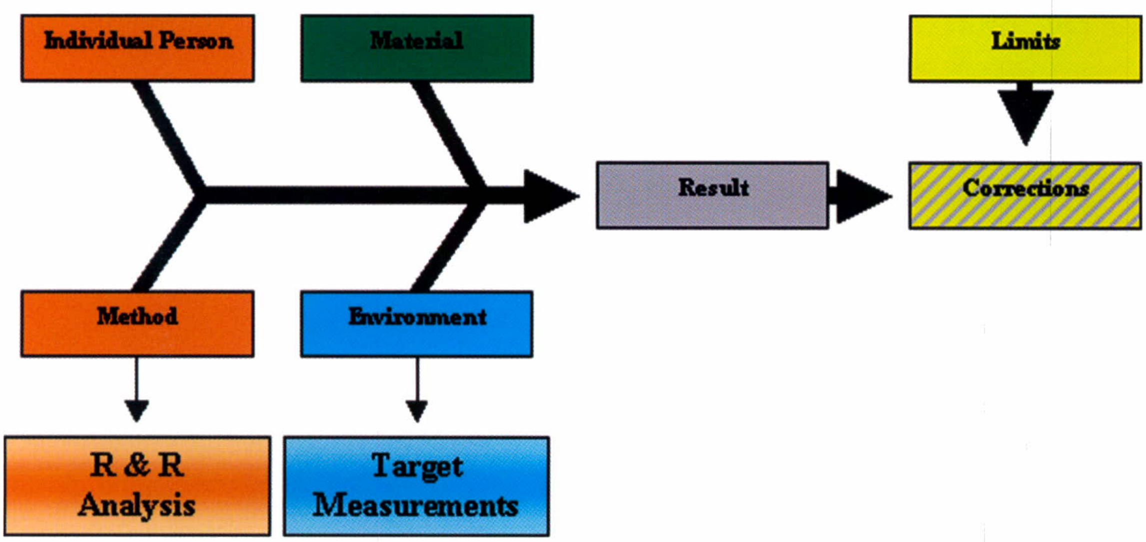

Figure 1. Influences on the results and coerrections

2. TARGET MEASUREMENT

The variable disturbance portion caused by the local conditions can be determined by target measurements. The environment of the measuring system is affected by the actual place of the measurement: laboratory, factory laboratory or factory. In addition, the exact place of assembly within these premises also contributes to the achievement of correct measurement results. Further influences by the environment are time and above all temperature. These disturbances by the environment arise individually in the rarest cases. Usually they overlap and thus make exact analysis of the influences more difficult.

At the beginning of each investigation of variable disturbance influence a detailed work plan should be provided. This contains data concerning the object, testing method, examiner(s), timetable for measuring and a description of the present valid measuring expiration, including a description of the sampling, which can be accomplished.[3] If these features are established, the actual measurements can start. How to conduct such measurements is shown on the basis of examples from FGK practice, set out below.[4]

3. R&R ANALYSIS

R&R analysis is a statistical procedure, by which the influences acting upon a measurement system can largely be apprehended.[5] The following influences have to be identified and minimized by optimization measures.

- Deviation of the characteristic, which can be measured
- Errors with the measurement causes errors by the measuring instrument
- Faults arising by handling of the measuring procedure by the operator

R&R stands for Repeatability & Reproducibility. Sometimes the system is also called measurement of repeating and comparison precision. Reproducibility refers to the error portion caused by the operator. Repeatability determines the error portion caused by the measuring instrument. Both values are indicated by abbreviations:

- EV (equipment variation)
- AV (appraisor variation)

Summation of these two values establishes the total error influence.

- TV (total variation).

The determination of the R&R values is based on the execution of measurements of several test items by several persons. The test items planned for measurement are to be unknown for the persons and should be measured in random order. Species interspersed by chance and non-identified samples yield the best results during practice tests. During the whole measurements it is to be ascertained that the persons cannot exchange the results of measurement or that of the measurement of another person who is not present. The benefit of R&R Analysis is greater, if more inspection items by as many persons as possible are measured. The measurements are all recorded in a prepared table and evaluated afterwards statistically. With the computation of the R&R values, which can be accomplished at the end, the given and/or necessary tolerances must be considered. On the basis of the computed results it can now be recognized whether an assigned measuring procedure is useful or not. With EV and AV, the values can be determined, in addition to whether a procedure is more susceptible to systematic or operator-conditioned influences.

In practice the following limit values for the evaluation of a measuring procedure worked satisfactorily:

- TV < 10 % very good procedure
- TV = 10 - 30 % useful procedure with small optimization need
- TV > 30 % useless proceeding and/or proceeding with very high optimization need

4. EXAMPLES IN PRACTICE

To analyse the influence of the local conditions, measurements have to be made with same material and examiners with same operational sequence at the different measuring points. In the case of investigations in different manufacturing plants, the largest influences arose as a result of vibrations, skew of the measuring instrument or also direct sunlight at the place of assembly of the measuring instrument.

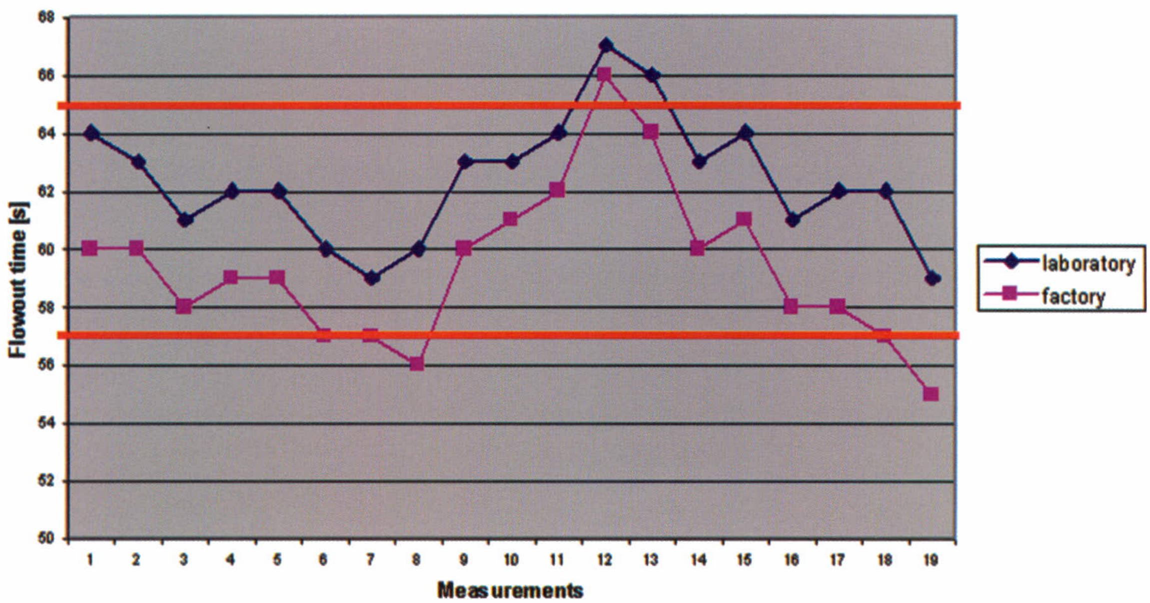

Figure 2. Comparsion between results from the same slurry, measured in laboratory and factory with a Lehmann cup

The influence of temperature on the complete measuring system is examined in the next work procedure. During these measurements, not only the temperature of the environment is important, but also the temperature of the test item, e.g. the suspension and the temperature of the measuring instrument. With these target measurements the temperature ranges actually occurring in operational practice should be considered. Temperature breakdowns of 10°C to 40°C with slurry for spray-dryers, owing to the season causing outside temperature fluctuations, and different times in blungers, causing heating, are no rarity. How large the difference in the results of measurement could be, is shown in figure 3 with the temperature influence on litre weight and viscosity of a slurry.

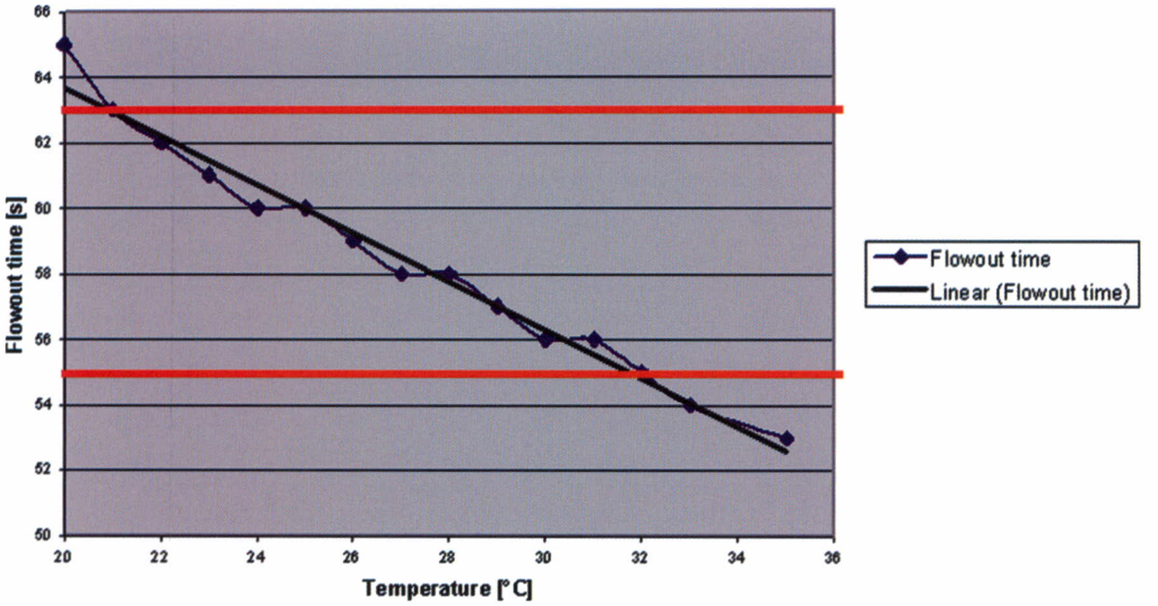

Figure 3. Flowout time using a Lehmann-Cup in relation to temperature

To determine the disturbing influence of temperature of the measuring instruments as a whole is the next step in performing target measurements. Not only the ambient temperature, but also the temperature of the sample and the temperature of the measuring instrument should be mentioned. They all influence the measurement result. Thus, the flow-out time of a ceramic slurry of 43 s at an equipment temperature of 25°C changed to a value of 41 s at an equipment temperature of 35°C, for example. Such a rise in temperature from 25°C to 35°C can be reached by rinsing out with warm water instead of cold one.

Time as the third factor of influence is much more difficult to control compared with the other two. Here it is important to separate the fluctuations of the temporal operational sequence caused by the environment from fluctuations caused by different handling by the operator. The latter are controlled and described by the R&R analysis. Environmental temporal fluctuations are, for example, transportation routes of different lengths from the sampling point of a slurry to the measuring point.[6] During this transport the slurry can change concerning its rheological characteristics very strongly.

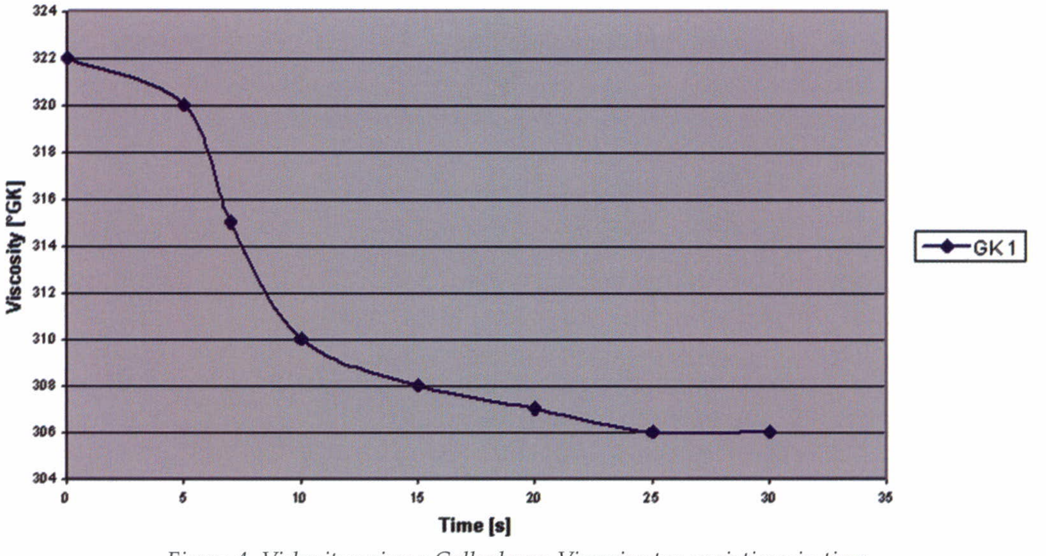

Figure 4, Viskosity using a Gallenkamp Viscosimeter; variations in time

When the target measurements for the range of the environmental variable disturbances are finished, the R&R analyses can be made.

For example, the litre weight of slurry used for spray drying:

The litre weight is determined by means of a glass flask (1 litre nominal volume), removing the calibration mark, and an electronic set of scales (a subsequent development for the purpose). The tolerance specified is 5 g.

An R&R-Analysis was carried out with three persons, in five runs and with four different test objects. The measurements were all in a range of about one gram.

Result of R&R-Analysis:

- EV: 13.99 %
- AV: 21.77 %
- TV: 35.76 %

The TV value clearly indicates that the established measurement method is unreliable and a greater need for optimization exits.

For another slurry in the production of the same manufacturer, the same method and the same scales were used. The tolerance for this slurry was given as 15 g instead of 5 g. In the R&R-Analysis carried out the results obtained were:

- EV: 8.93 %
- AV: 15.51 %
- TV: 22.44 %

The same measurement method is still reliable for this measured object and only needs little optimization.

Some other R&R values from typical traditional ceramic measurement methods are shown in the following figure:

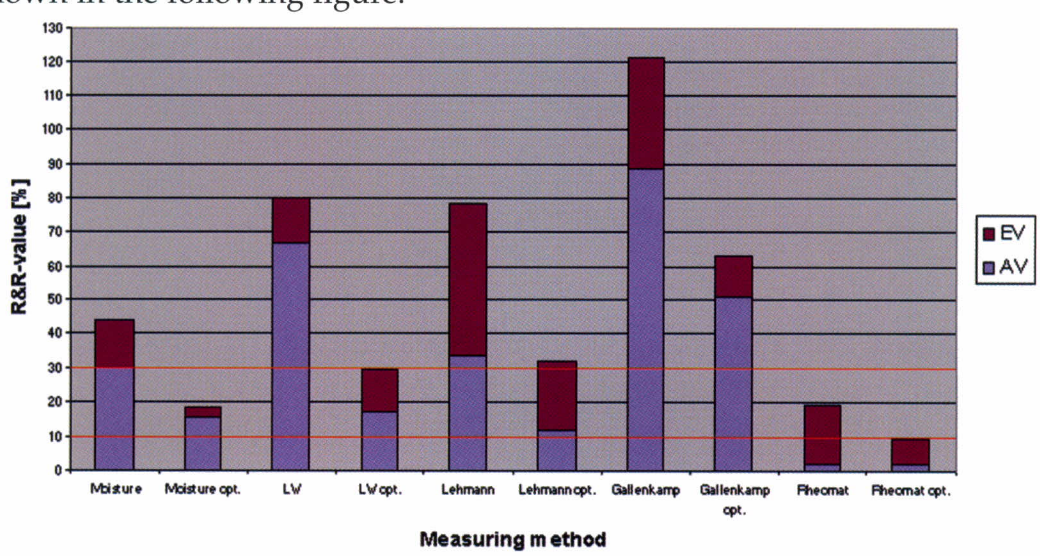

Figure 5. Typical, traditional measurement in the ceramic industry; R&R values before and after optimization

5. CONCLUSIONS AND OPTIMIZATION

- The test methods investigated are very poor and require urgent revision.
- With these measurement methods process reliability cannot be achieved.
- The corrections performed are often carried out on the basis of wrong measurements.
- Actual variations of the measured values are often not observed and the resulting corrections not made.
- There is no reliable basis for research and development.

The measures set out below outline the proposed steps to improve the investigated measurement methods:

To minimize the influence of the disturbance by local conditions, determined by the target measurements, the following principles should be considered:

- Measurements should always be performed there, where the test item is found. This will avoid long transportation routes, which can change the temperature or favour reactions in the sample. If this is not possible, the eventually occurring changes during transport need to be observed.
- The temperatures of the test item, measuring instrument and measuring instrument environment are to be kept constant and adapted to each other to prevent mutual heating or cooling. If this cannot be ensured in sufficient measure, the coefficients of correction need to be determined and taken into consideration.
- Assembly locations that may influence the measurement result: Direct sunlight, draft, underground vibrations and skew of the measuring instrument are to be avoided.

To minimize operator-conditioned influences the following points can lead to success:

- Attention to the respective operating instructions of the measuring instrument
- Operating personnel need to be trained to provide them with the necessary knowledge concerning the measurement and the determined measured values. Without this background knowledge no well-founded decisions can be made and no necessary corrections should be initiated.
- Before new personnel use equipment, these have to be extensively instructed in the equipment by well-trained persons.
- There should be sufficient and well-trained replacement personnel to cover cases of vacation and illness.
- The measured values should always be submitted to plausibility checks.[7]

Equipment-conditioning influences can be prevented by attention to the following points:

- Maintenance of the measuring instrument is to be selected in such a way that over the entire period of use, no disguised wear of the equipment can occur.

For this, an inspection management approach practised by quality management systems is very helpful.[8]

- Wearing parts in measuring instruments and auxiliary facilities need to be immediately exchanged
- Depending on the measuring procedure used, before each measurement and / or at regular intervals, an adjustment of the devices needs to be performed
- For the selected measuring procedure, the optimal location is to be specified
- If all measures implemented under this point do not lead to success, the measuring instrument has to be replaced by another. This can involve replacement of old equipment by a newer instrument, besides replacement of one procedure by a completely different one
- For additional security, regular participation is recommended in interlaboratory tests with the measuring procedures used.[9]

6. SUMMARY

The examples given show which measurement methods are suitable and where the weak points lie in the individual test methods. By means of the target measurement and R&R Analysis carried out, influences or faults can be discovered and in most cases definitely specified. If a measurement method displays high susceptibility to error in the range of the appliance, the EV value can be improved by customized optimization measures adapted to the respective method, such as for example equipment calibration and planned maintenance, or also by replacement with new appliances.

A very high AV value of a measurement method could be reduced by a detailed, validated testing instruction and personnel training effected in parallel. It was apparent that training of the substituting personnel is very important. Untrained substituting personnel produce a lower R&R value.

R&R Analysis is a tool by which weak points can be quickly and easily apprehended and deliberately reminded. In the evaluation of the results however the following should be carefully observed:

- If a method has an R&R value of well over 100%, optimization measures do not immediately produce values of less than 10%. Often a number of stages coordinated with each other are required to reach the aim in view. If all the optimization measures do not result in this aim, it is better to remove the measurement appliances used and suppress the measurement method used in favour of a new method.
- Many of the measuring procedures used at present in the ceramic industry fail to supply correct values. They are disturbed by the influence of the variable uncertainty and cannot hold the quality requirements placed on the product and / or the manufacturing process. Here urgent action is needed to achieve better results, since otherwise no process security can be obtained. If the problem described is disregarded, this will inevitably lead to corrective actions, which are introduced only by wrong measurements. Without optimized testing methods there will also be no basis for innovative developments and research projects.

- The described connections however also clearly show how the measuring procedures used can be optimized. With target measurements and by afterwards performing R&R Analysis, influences can be uncovered and orders of magnitude assigned. The examples described from practice also make it obvious that it would be dangerous to rely blindly on certain measuring data. The optimization shows that it is not always necessary to replace common measuring procedures by expensive newer ones. Often the assigned procedures can be optimized by performing targeted and yet cost-effective measures, provided they supply reliable and meaningful measured values. Whether and for which application a given measuring procedure is the best is something each user must ascertain for himself. By correct and consistent applications, the tools described here can provide valuable assistance to obtain useful measurement results in ceramics.

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