Development of a quality control system for the supply of silica refractory material from China

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Abstract: This document describes how to perform a quality control management of refractory silica material purchased in China. Silica refractories are key actors in the lifetime of the equipment and they are fundamental to ensure the adequate operation of the plant. The objective is to plan the sampling, minimising the number of tests to obtain an assessment of the quality of the consignment with the greatest precision. The types of destructive and non-destructive tests, the number of pieces to be inspected per batch and the acceptance criteria will be defined in this article. The quality control will be carried out at three levels, one to be performed by the manufacturer and the others by the buyer and the final client. The approval of the lots by the three parties ensures that the quality of the product is in accordance with the specifications. It will be achieved by dividing the order into different batches to treat them as independent units for acceptance or rejection. To avoid the loss of “see freight time” in case of rejection of any consignment, the customer's quality control must be performed before shipping the batches.

Keywords: Quality control, Refractories, Silica bricks, Sampling.

1. Introduction

This study deals with siliceous refractories, whose name results from their high SiO₂ content. These products have their main application in steel and glass industries. Most of the manufacturers of silica bricks are located in Asia, mainly in the Chinese provinces of Shandong and Henan. Most silica bricks (siliceous) are used for refractory lining, due to their excellent characteristics and behavior. Their high melting point, their adequate cold compression strength and their good resistance to chemical attack make this type of bricks suitable to be used in steel and glass furnaces, without having to be repaired for years of operation. The useful life of the equipment where silica refractory is installed depends mainly on its quality. Therefore, it is vital to make sure the bricks fulfill the standards.

Traditionally, it has been common practice that the producers themselves accomplish the quality control of silica bricks and only on some occasions does the final client carry out any type of control in destination after reception of the lots.

The existing literature on the quality control management of refractory products manufacturing deals only with the application of the ISO 5022 [1]. The novelty and relevance of this article is, therefore, based on the design of a deep quality control procedure with a double aim: to guarantee that the refractory material complies with the required specification and to avoid delays due to batch rejection at erection site. Thus, to achieve a suitable performance of silica refractory bricks, which can ensure
long lifetime in the equipment, it would be convenient to design a quality control procedure affecting both the manufacturing process and the final bricks.

A three-level control is suggested with such a purpose:

- Audit of potential brick suppliers. The aim is to validate the companies that follow an accurate traceable process and have appropriate technology machinery, as well as a satisfactory managing system
- Internal quality control of the refractory manufactured. It is to be done by the supplier following ISO 5022 & DIN 1089-1 standards [1,2]
- External quality control of the refractory manufactured. This will satisfy an agreed definition of the conditions between the buyer and the final client

The quality control management will be accomplished assuming that the three parties below are involved:

- The company that produces the refractory, which will hereafter be referred to as “the manufacturer”
- The company that purchases the refractory from the manufacturer, (engineering or intermediate company), which will be called “the buyer”
- The company owning the facilities where the refractory is going to be installed, hereafter “the final client”

The manufacturer will carry out the internal quality control, whereas the external control will be simultaneously accomplished by the buyer and the final client.

To avoid delays in refractory installation, caused by rejection at erection site, the quality control of the bricks must be done before shipment.

2. Suppliers validation

Before validating a refractory company, it is necessary to audit the next process points as shown in table 1:

- Raw materials selection
- Raw materials grain size adjustment by crushing
- Blend preparation by mixing of raw materials in suitable amounts
- Blend pressing to obtain the green bricks with required shape
- Green bricks drying to remove extra water
- Dried brick firing to develop the bindings and obtain the final product
- Palletizing of bricks for transport

| Table 1. Control points of manufacturing process. |
|--------------------------------------------------|
| Selection of raw materials | Chemical analysis |
| Crushing                   | Grain size       |
| Mixing                     | Chemical analysis, Humidity content |
| Pressing                   | Dimensions of green brick |
| Drying                     | Time, Temperature |
| Firing                     | Time, Temperature, Final piece dimensions |

3. Standards followed in manufactured bricks quality control

Two standards will serve as the framework or base for this study, the ISO 5022:1979, which will be chosen for sampling and acceptance of batches of refractory pieces [1], and the DIN 1089-1, which
defines the physical and chemical characteristics of refractory silica bricks [2].

3.1. ISO 5022, shaped refractory products, sampling and acceptance testing
This standard provides information for sampling of shaped refractory products and how to obtain an assessment of the lot, as accurate as possible, from a sample of the smallest possible size. This ISO shows information for dimensional and visual inspection as well as for destructive testing.

3.2. DIN 1089-1 silica bricks requirements and testing
This DIN Standard specifies the values that shall be tested for each type of silica refractory material and the dimensional control that shall be done to ensure the quality of the refractories.

Each type of material and grade must comply with specific physical properties, which are specified in this standard. For the case of the visual and dimensional control, the requirements will be different depending on the area where the refractories are to be installed (i.e. in contact with gases, coal, etc.).

4. Quality control definition
Figure 1 shows the quality control procedure defined by the buyer and the final client:

- Steps 1, 2 & 3 are the dimensional and visual inspection to be done by the manufacturer during the production process
- Steps 5, 7 & 8 indicate the visual and dimensional inspection to be done by the buyer
- Step 4 shows the laboratory test to be done by the manufacturer
- Steps 6 & 9 show the laboratory test to be done by buyer

Besides the control done by the manufacturer and the buyer, the final client will also carry out its own quality test:
• Dimensional and visual check at manufacturer site, by means of random selection of samples during plant visits for inspection
• Same destructive tests as the buyer
• Final inspection at erection site

4.1. Manufacturer quality control

4.1.1. Non-destructive tests. The manufacturer will perform a complete inspection of each lot, where 100% of the samples will be visually and dimensionally inspected.

4.1.2. Destructive test. For the destructive test, the number of tested samples will depend on the total mass of the batch. In this case only batches up to 400 tons will be allowed.

The ISO 5022 specifies the sample size for each batch size; the supplier will test different numbers of samples depending on whether the parameters are critical or not [1].

For the critical parameters specified in the DIN 1089 the total number of samples indicated in the ISO 5022 will be used.

For the non-critical parameters, an abridged sample testing will be done. Table 2 summarizes the samples that will be tested in each lot, depending on material type and quality.

4.1.3. Acceptance criteria. For dimensional inspection (non-destructive testing), individual samples will be measured. The tolerance criterion will be extracted directly from the DIN 1089, which mainly depends on brick size [2].

For visual inspection, all the parameters that must be checked will be extracted from the DIN 1089, where the criterion tolerances for each material and for each zone are specified [2].

For destructive testing, the definition of the acceptance criteria of sampling plan to be followed must be agreed with the manufacturer.

• For the guarantee value ($\mu g$) for the mean value of the property measured, the sampling plan agreed is: “sampling plans in the case of a guaranteed value for the mean value and a known standard deviation (ISO 5022 sub-clause 5.3)” [2]
• For the case when one limit is specified, the sampling plan agreed is: “Single sampling plans with a fixed unilateral limit for individual values and a known standard deviation” (ISO 5022 sub-clause 5.4) [2]

4.2. Buyer & final client: external quality control before lot shipment

The main objective of this external quality control is to verify that lots fulfill the specifications to reduce lot rejection at erection site to a minimum.

4.2.1. Non-destructive test

• Buyer: Visual & Dimensional. The buyer will perform visual and dimensional inspection according to the previously shown diagram (figure 1) and the following tables (Table 3 A & B), which indicate the total number of samples to inspect, depending on lot size and number of acceptable defective samples.

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### Table 2. Manufacturer’s laboratory test.

| Quality | Quantity (tons) | Lot Dimension (tons) | Number of lots | Number of samples for each lot | Chemical analysis | RQC | AP | CCS | Creep in compression | AR | BD | Expansion curve |
|---------|-----------------|----------------------|----------------|-------------------------------|------------------|-----|----|-----|---------------------|----|-----|-----------------|
| SILICA  | 750             | 400                  | 19             | 22                            | 2                | 11  | 22 | 2   | 0                   | 11 | 1   |                 |

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Final client: Visual & dimensional. For non-destructive tests, the final client will perform a series of visual and dimensional checking during the inspections on manufacturer’s plant, where random pieces will be examined according to the acceptance criteria previously described.

**Table 3.** Samples and acceptable defective pieces.

| Lot size (pcs) | Sample size (pcs) | Pass | Fail | Lot size (pcs) | Sample size (pcs) | Pass | Fail |
|----------------|-------------------|------|------|----------------|-------------------|------|------|
| 51-90          | 5                 | ≤ 2  | ≥ 3  | 51-90          | 13                | ≤ 2  | ≥ 3  |
| 91-150         | 8                 | ≤ 3  | ≥ 4  | 91-150         | 20                | ≤ 3  | ≥ 4  |
| 151-280        | 13                | ≤ 4  | ≥ 5  | 151-280        | 32                | ≤ 4  | ≥ 5  |
| 281-500        | 20                | ≤ 5  | ≥ 6  | 281-500        | 50                | ≤ 7  | ≥ 8  |
| 501-1200       | 32                | ≤ 7  | ≥ 8  | 501-1200       | 80                | ≤ 10 | ≥ 11 |
| 1201-3200      | 50                | ≤ 9  | ≥ 10 | 1201-3200      | 125               | ≤ 14 | ≥ 15 |
| >3200          | 80                | ≤ 12 | ≥ 13 | >3200          | 200               | ≤ 21 | ≥ 22 |

**Table 4.** Buyer’s laboratory test.

| Quality  | Quantity (tons) | Lot Dimension (tons) | Number of lots | Number of samples for each lot | Chemical analysis | RQC | AP | CCS | Creep in compression | AR | BD | Expansion curve |
|----------|-----------------|----------------------|----------------|-------------------------------|-------------------|-----|----|-----|---------------------|----|-----|-----------------|
| SILICA   | 7500            | 400                  | 19             | 3                             | 2                 | 3   | 3  | 3   | 1                   | 0  | 3  | 1               |

4.2.2. Destructive tests. According to silica DIN standards, the tests to be done are the following: residual quartz content, apparent porosity, cold compressive strength, creep in compression, abrasion resistance, refractoriness under load, bulk density, expansion curve.

**Figure 2.** Sample preparation.

The “critical parameters” are shown in bold on the list above. Table 4 shows the number of tests per lot that will be carried out by the buyer and the final client (as agreed by both companies).

Sample preparation and test location. The sample preparation must be done in accordance with figure 2; the supplier, the buyer and the final client will receive a quarter of the sample, and the remaining quarter must be stored for further analysis. The center of the brick, the pressing direction and the surface in contact with coal (if any) shall be marked on each sample collected. Apparent porosity must be determined on surface in contact with coal (if any contact). Residual Quartz shall be tested in the center of the brick as shown on the drawing. Samples for external
laboratory tests must be delivered promptly and simultaneously to both the buyer and the final client laboratories. Results must be obtained before lot’s shipment.

Acceptance Criteria. The acceptance criteria for each parameter, taking into consideration that the sampling is an abridged one, are based on the DIN Standards [1] and the ISO [2]. Based on this acceptance criteria, a lot can be rejected if any of the “critical parameters” described above does not fulfill the specifications. The acceptance criteria procedure agreed by the buyer and the final client is shown in figure 3.

Table 5. Silica values in critical parameters.

| Silica                               | Assured values for acceptance |
|--------------------------------------|-------------------------------|
|                                      | Mean | Sigma | T lower | T upper |
| Residual quartz content (%)          |      | 0,5   |         | 1,5     |
| Apparent porosity (%)                | ≤ 24,5 | 1,3 | 25,7 |
| Cold compressive strenght (N/mm²)    | ≥ 28 | 10 | 20 |

Figure 3. Critical parameters acceptance criteria.

To accept a lot, all the samples analyzed must fulfill the specification; in the case that not all the samples were in accordance, the ISO 5022 would be applied to decide whether the lot is accepted or rejected.

In case of deviation from the non-critical tests, regarding the results defined in specifications, the following actions will be followed:

1. The final client will evaluate the potential impact on its process.
2. If negative impact which can lead to thermo-mechanical stress and, as consequence, a decrease in equipment lifetime can be expected, decision about rejection of the lot should be taken.

4.3. Lot final acceptance for shipment

A lot will be accepted for shipment only if internal and external quality controls fulfill the specifications defined for each item, as shown in table 6.

- In case of discrepancy between manufacturer and buyer concerning the results of a lot, a new batch quality control, following the ISO5022 will be carried out by a third laboratory. If results are not in conformity with specifications, the lot will be finally rejected.
In case that the manufacturer’s results are not in conformity with the specifications, the lot will also be rejected although the buyer results are positive.

Table 6. Acceptance criteria.

| MANUFACTURER’S LAB  | EXTERNAL LAB  | ACTION                                               |
|---------------------|---------------|------------------------------------------------------|
|                      |               | In accordance with Buyer Spec.                       |
| In accordance with   | In accordance with Buyer Spec.                       | Lot conform for lab test                              |
| Buyer Spec.          | Not in accordance with Buyer Spec.                   | A second batch must be tested as per ISO5022 par. 5.3. If not conform, lot is rejected |
| Not in accordance    | In accordance with Buyer Spec.                       | Lot is rejected                                       |
| with Buyer Spec.     | Not in accordance with Buyer Spec.                   | Lot is rejected                                       |

4.4. Quality control at erection site

Once a lot is accepted for shipping, a new random quality control at erection site will be carried out by the final client for final acceptance. This further inspection is especially necessary to check that the pieces have not been damaged during the transport from the manufacturer’s facility to the erection site. Figure 4 summarizes the whole Product Quality Control (PQC) scheme.

Figure 4. PQC Scheme.

5. Conclusions

- Before ordering the purchase of a lot it is necessary to make sure that the manufacturer has the appropriate equipment and a good control of the process.
- To ensure adequate quality in the refractory, it is necessary to carry out a three-level control, by the manufacturer, by the buyer and by the final client. The control carried out by the manufacturer must be adapted to the scope of the ISO 5022, but the control carried out by the other parties will have a reduced scope to minimise destructive test.
- To avoid the loss of “see freight time” in case of rejection of any consignment, the quality control by the customer must be performed before shipment.
- Quality control will be done by dividing the order into batches to treat them as independent units for acceptance or rejection. The size of a batch should not be greater than the oven capacity. All the bricks in a batch must be cured at the same time.
- Failure to comply with any of the critical parameters means immediate rejection of the batch. If a “non-critical” parameter fails, the final client will evaluate if it permits the correct operation of the equipment.
In case of discrepancy of the parties, an external and independent laboratory will carry out a new test.

The final client will approve the lot at erection site after verifying that it has not suffered damage during transport.

The performance of the QC proposed will reduce the number of defective pieces arriving at erection site to a minimum and, consequently, it will also prevent the useful life of the equipment to be shorter than expected.

Yet, the lack of enough qualified inspectors to carry out visual and dimensional inspection should be considered as a limitation.

The use of ultrasonic devices to detect internal microcracks in the pieces, instead of using traditional “hammer sound”, which always depends on the subjective interpretation of the inspector, can be suggested as an area for improvement for future works.

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