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This proceedings contains 231 manuscripts that were submitted and approved for the 13th biennial worldwide refractories congress recognized as the Unified International Technical Conference on Refractories (UNITECR), held September 10-13, 2013 in Victoria, British Columbia, Canada.

UNITECR has become the premier worldwide congress on refractories and is the most prominent international technical conference on refractories. This was the first time the conference was held in Canada. UNITECR 2013 was organized by current and previous members of the North American Executive Board of UNITECR comprised of Tom Vert, Rob Crolius, Jeff Smith, Dana Goski, Nancy Bunt, and Mike Alexander with the assistance of The American Ceramic Society (ACerS). The organizers want share a special thank you to Mark Stett, Lou Trostel, Jr. and Charlie Semler for their continuing support, providing both historical details of previous UNITECR meetings and offering new suggestions to continually advance the meeting to benefit attendees, authors and industry.

Two new communication opportunities were created for authors this UNITECR. Authors were provided the option to have manuscripts peer reviewed, a new approach for UNITECR that was implemented in the expectation to further elevate the quality of the congress and proceedings. Fifty manuscripts were peer reviewed and are identified in the table of contents with a bold title. The second new opportunity was to include a poster session. Over 30 authors presented their poster during this special session.

The editors want to thank the 34 symposia organizers listed in the table on the following page, the authors for their contributions, the manuscript reviewers and the publication staff at ACerS.

We were pleased that the congress advanced the understanding of refractory technology and promoted international exchanges in research, education and industrial practice. The editors envision that this proceedings volume will serve as a useful resource for research in a field which has limited global publications.

DR. DANA G. GOSKI
UNITECR 2013 Technical Program Chair

DR. JEFFREY D. SMITH
Chairman, North American UNITECR Executive Committee
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Advanced Installation Techniques and Equipment
ABSTRACT

In conventional wet-gunning it is not easy to decrease the amount of water in the gunning mix because the mix has to be pressurized and transported smoothly through hoses. An excessive amount of water in the mix often results in a poor durability of the body of gunned material. The newly developed method, Continuous Quick Mixing & Repairing Technology (QMS), does not require the gunning mix to be transported through hoses and therefore, the amount of water can be decreased. As a result the installed body, obtained by means of the QMS method, has a more excellent quality when compared to the wet-gunning method. Furthermore the cleaning job after the gunning repair is as easy and simple as that after dry-gunning. This paper describes the development of QMS and the improved durability of the gunned material.

1 PREFACE

The conventional gunning application of refractory materials has been performed in various ladles and furnaces and classified as dry-gunning and wet-gunning. The former is easier and simpler from the point of view of application, but a much greater amount of water is required in the gunning mix, which often results in poor durability of the gunned material body. The latter is effective to obtain a relatively dense gunned body, but gunning work is not simple due to the preliminary mixing and to the cleaning of equipment after work. Continuous Quick Mixing & Repairing Technology (QMS as the abbreviation of Quick Mixing Shot) is introduced in this paper. It provides both a simpler and easier gunning method equivalent to that in conventional dry-gunning and a more excellent quality of the gunned body which results in better durability than that obtained in conventional wet-gunning.

2 FEATURES OF THE GUNNING EQUIPMENT

2-1 Conventional gunning methods

Fig. 1 shows the typical conventional gunning methods: dry-gunning and wet-gunning. In dry-gunning dry refractory material is conveyed by air flow and gunning water is added at the tip of the nozzle to produce slurry which is subsequently applied.
In wet-gunning the material is mixed first with water to produce slurry which is pressurized and conveyed through hoses and mixed with binder at the tip of the nozzle in order to solidify the gunned body.

2) The Continuous Quick Mixing device

Fig. 3 shows the vertical section of the Continuous Quick Mixing device. In the fixed outer casing the inner rotor is installed and rotates with 800 rpm. The upper half of the rotor has many dispersion blades on its cylindrical surface, while the lower half is conical and has many kneading pins on its conical surface. The blades and pins are positioned along the spiral line on the rotor surface. The outer rotor, which covers the conical surface of the inner rotor, rotates with 150 rpm. Dry material is sprayed with water\(^1\) and fed horizontally close to the top of the outer casing. After having been mixed by the dispersion blades in the upper half of the inner rotor, the mix descends to the lower half and forms there the relatively dense retention layer due to the centrifugal force generated by the rotation of the outer rotor. As shown in Fig. 4, the retention layer is scratched by many kneading pins on the inner rotor. When scratched, the retention layer of the mix is subjected to shearing, compression and tensile forces and deformed and kneaded sufficiently. The scratching does not occur at the same height but on the different levels of each kneading pin, due to the spiral positioning of the kneading pins. The kneaded mix is gradually pushed downward along the inner
surface of the outer rotor to the projection disk.

![Mechanical structure of the continuous quick mixing device](image)

Fig. 3. Mechanical structure of the continuous quick mixing device

![Principle of kneading](image)

Fig. 4. Principle of kneading

3) Principle and mechanical structure of the gunning device

The kneaded mix is conveyed and gunned to the targeted repair spot not by means of conventional compressed air but by centrifugal flinging force. As shown in Fig. 5, the gunning device consists of 1) the projection disk positioned at the lower exit of the outer rotor, 2) the belt wound around the disk (with one opening area) to drive it and 3) the reflector to direct and rectify the mix flow toward the spot of application. The adhesion of the kneaded mix on the targeted repair spot can be optimized by adjusting appropriately both the velocity of the mix flow and the thickness of the gunned material body.

![Plane view of the gunning device and isometric view of the projection disc](image)

Fig. 5. Plane view of the gunning device and isometric view of the projection disc

3 EVALUATION OF THE MIXING EFFECT

To evaluate the mixing effect, the QMS was compared with a common desk-top mixer in mixing for three minutes. After adding a specified amount of water, the material was mixed for three minutes with the continuous quick mixer and also with the desk-top mixer and the viscosity of the mixed material was measured in each case. The kneading ratio is defined as the value determined by dividing the viscosity of the material mixed by the QMS device with that mixed by the desk-top mixer. As shown in Fig. 6, the QMS device showed 89% of kneading ratio under the mixing condition of a 15 mm gap between the kneading pins and the outer rotor. In general, the faster rotation of the inner rotor results in a better kneading ratio because it is guessed that both the shearing and the compressing force applied on the material increase as the rotation of the inner
rotor becomes faster. With the smaller gap of 10 mm, the kneading ratio of 93 % was obtained because of a similar reason. Fig. 7 shows the distance of the gap between the kneading pins and the outer rotor.

![Figure 6](image)

**Fig. 6.** Influence of the gap between the kneading pins and the outer rotor and the rotation of the inner rotor on the kneading ratio

![Figure 7](image)

**Fig. 7.** Gap between the kneading pin and the outer rotor

4 FEATURES OF THE REFRACTORY MATERIALS FOR QMS

To obtain excellent durability of the applied material in hot service, the refractory materials for QMS have been developed pursuing the targets:

1) the application of a small amount of water and

2) a tight adhesion on the targeted spot.

Fig. 8 shows the quality map of the materials applied with the QMS method among various application methods of monolithic refractories. Table. I shows typical properties of the material for the QMS in comparison with the material for conventional wet-gunning.

![Figure 8](image)

**Fig. 8.** The quality map in the obtained apparent porosity comparing various application methods of monolithic refractory materials

<table>
<thead>
<tr>
<th>Installation method</th>
<th>QMS</th>
<th>Wet-gunning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical composition/%</td>
<td>Al$_2$O$_3$</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>MgO</td>
<td>12</td>
</tr>
<tr>
<td>Apparent porosity/%</td>
<td>110°C×24h</td>
<td>21.4</td>
</tr>
<tr>
<td></td>
<td>1500°C×3h</td>
<td>26.0</td>
</tr>
<tr>
<td>Bulk density/g/cm$^3$</td>
<td>110°C×24h</td>
<td>2.93</td>
</tr>
<tr>
<td></td>
<td>1500°C×3h</td>
<td>2.74</td>
</tr>
<tr>
<td>Modulus of rupture/MPa</td>
<td>110°C×24h</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>1500°C×3h</td>
<td>25.0</td>
</tr>
<tr>
<td>Permanent linear change/%</td>
<td>1500°C×3h</td>
<td>+1.36</td>
</tr>
<tr>
<td></td>
<td>1500°C×12h</td>
<td>+1.38</td>
</tr>
<tr>
<td>Amount of water/mass/%</td>
<td>7.7</td>
<td>8.8</td>
</tr>
</tbody>
</table>

There is generally a tight connection between the amount of water applied and the density of the gunned material. During application,