Fast Acting Vacuum Device – Guaranteed Quality for Pressed Refractories

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Abstract:
Lamination and cracks as defects in pressed bricks frequently result from inadequate de-airing during hydraulic pressing. Even after completion of de-airing strokes, in conventional moulding excess air pressure in the brick leads to lamination, arising during the relief phase after pressing. If the green strength of the newly pressed matrix is inferior to the air pressure arising in the brick, it is damaged when the entrapped air expands.

Use of de-airing strokes has limitations, in particular when due to its grain structure and the binding agents applied the brick reaches very high densities. Lamination frequency occurs when the density of the brick reaches levels higher than 90% of the theoretical density.

Evacuation of the mould ahead of compaction prevents air compression in the body and is effective in preventing lamination, while ensuring a homogeneous distribution of density.

In recent years, Alpha Ceramics and Loisi Bucher have developed a new fast acting vacuum device directly on the mould which minimizes the space to be evacuated compared to traditional methods in such a way that evacuation can be completed in minimum time. By cutting out the de-airing strokes, the cycles are kept constant or can even be shortened in comparison to conventional moulding. Application of the new vacuum device thus enhances product quality while maintaining output performance at a comparable level.

Inhaltsangabe: Eine schnelle Vakuumeinrichtung - garantierte Qualität für gepresste Feuerfestwerstoffe


Wird die Pressform vor dem Verdichtungsvorgang evakuiert, wird ein Druckaufbau der Luft im Pressling unterbunden und die Lagenbildung wirksam vermieden, wobei die Dichteversetzung homogen ist.

Alpha Ceramics and Loisi Bucher have in the last years in a new developed Vakuumeinrichtung den zu evakuierenden Raum so weit minimiert, dass die Evakuierung der Form in kürzester Zeit erfolgen kann. Durch das Einsparen von Entlüftungshöhen bleiben die Zeiten gegenüber der herkömmlichen Pressformgebung gleich oder können sogar verkürzt werden. Der Einsatz der neuen Vakuumeinrichtung führt damit zu einer verbesserten Produktqualität bei minimalem gleichbleibender Produktionsleistung.

Keywords: hydraulic pressing, defects, lamination, cracks, vacuum device, product quality

1 Introduction

Over the past 5 years, Alpha Ceramics has been conducting investigations into the moulding of powders and granulated materials for a very wide range of raw material mixes. Despite multiple de-airing strokes, conventional pressing has repeatedly produced both laminations and cracking.

Fig. 1 shows an example of this kind of cracking, occurring with a conventionally pressed, resin-bonded MgO-C brick.

This kind of experience has prompted Alpha Ceramics and Loisi Bucher to set up the vacuum technique in a range of different moulds, optimizing them in terms of costs and cycle times.

The following article describes the experience with a new fast acting vacuum device. Detailed information is provided about the following aspects:

- Which physical phenomena are at the root of lamination?
- How can lamination be avoided by applying a vacuum pressing technique?
- What potential is there for the vacuum technique to achieve high densities in the pressed brick?

2 Current Technology

A problem inherent to pressing mixes of raw materials from the batch is the air entrapped in the material. When not previously evacuated from the batch, this air becomes compressed during compaction. Over-high compression of the air is normally countered by completing de-airing strokes of the plungers. The process of compression takes place in stages, thus allowing the compressed air to escape from the body being pressed in the mould.

Fig. 1
Cracking in an MgO-C pressed brick; the matrix is cracked due to internal air pressure following removal from the mould.
However, lamination still occurs when

- the air is prevented from escaping by extremely fine-grain components contained in the body
- the travel of the plunger in the mould is not great enough
- extremely high densities occur in the brick (>90% of the theoretical density of the body)
- high-volume bodies are pressed.

These factors directly lead on to the special problems involved in pressing refractory bricks, for which extremely high densities need to be achieved (because the mixes consist of a number of different fractions and also because binding agents, such as pitch and synthetic resin, are used).

Even though the vacuum technique has been identified as a solution to this problem in principle, the high costs involved so far have prevented it from being widely used.

3 The Task

Even when a conventional pressing process is correctly executed by applying adequately adjusted de-airing strokes, and a brick with no visible signs of cracking is produced, the manufacturer cannot really be sure whether the distribution of density is sufficient and that the brick contains no hidden laminations.

Notwithstanding ISO 9002, these hidden quality defects are often accepted, even though application of the vacuum pressing technique might lead to their effective removal.

4 Theoretical Principles

4.1 Derivation of the Compression Factor

As the air in the pressed piece becomes compressed, the air trapped inside increases in pressure hyperbolically as the compaction of the body increases. The compression of the air depends basically on only three typical dimensions of the process:

\[ \varepsilon_0 = \text{bulk density of the material composition} \]
\[ \varepsilon_D = \text{density of the shaped product (pressed density)} \]
\[ \varepsilon_{th} = \text{theoretical density of the mix or "maximum possible product density".} \]

These dimensions, easily determinable in any compacting task, enable calculation of the compression factor for the air inside the pressed product (Fig. 2)

\[
\text{Compression of air} = \left[ 1 - \left( \varepsilon_0 / \varepsilon_{th} \right) \right] / \left[ 1 - \left( \varepsilon_D / \varepsilon_{th} \right) \right] \times \left( \varepsilon_D / \varepsilon_0 \right)
\]

[Important: "theoretical density" is calculated for any mixture by dividing the bulk material components of the individual components by the density of the individual components, and the "pure volume" of the mix is the summation of these single values].

The theoretical considerations outlined here show the volumes available for the air both before and after pressing. The compression factor of the entrapped air or C (for compression), is obtained via quotient formation. This compression factor assumes that no air can escape. Despite the fact that this does not apply in conventional pressing, this approach constitutes a valid approach to the conditions in the pressed piece.

It should be especially remembered that the denominator tends to zero the closer actual density in the pressed piece approaches the theoretical density.

Fig. 3 clearly shows the hyperbolic increase in air pressure versus the density reached in the pressed product. The three curves show how pressure evolves for three bulk materials of different compaction ratios.

The problem in connection with the hyperbolic increase at pressed product densities >90% is clearly highlighted in this figure. With hyperbolic air pressure increase, there is a compression for any mixture at which internal air pressure exceeds the strength achieved in the pressed piece.

4.2 Typical Lamination Scenarios

When bulk materials are compacted in a non-evacuated mould, three things can happen:

- Air can escape along the plungers (as far as compaction of the body at the edges of the brick allows this).
- Because of the pressure gradient, the air can accumulate in areas which are the last to be compacted.
- The air remains in the pressed piece and causes laminations if the air pressure arising is greater than the strength of the newly pressed piece.

The alternative scenarios outlined above result both in an accumulation of air in the middle plane of the pressed
have shown that while vacuum pressing can achieve higher densities, the degree of this increase falls short of what is generally expected.

In the final analysis, the increase in density with vacuum pressing can only be ascertained for a given body, compacting pressure and cycle via the reduction in expansion of the brick following removal from the mould. Experience shows that this expansion, which is approx. 0.5% linear in conventional moulding, is reduced to approx. 0.4% linear. This effect produces an increase in density of approx. 0.3% in vacuum pressing.

However, this only slight increase in density under vacuum does not mean that vacuum does not still remain an absolute requirement in achieving higher brick densities, since the problem of lamination due to entrapped air always occurs with conventional presses after a given (high) density.

The grain structure of the body together with properties of the binding agents (resins, pitch, sulphide waste, etc.) are factors of crucial importance in achieving maximum product density, as are the compacting pressure and pressing cycle.

To obtain maximum density on a hydraulic press with a given body, brick size and maximum compacting pressure, pressing should be carried out in cycles at high pressure, i.e. compaction in steps with intermediate relief. This kind of pressing in cycles at high pressure leads to changes in the relative positions of the grains, resulting in a higher packing density.

With resin-bonded refractory bricks a higher temperature of the mix (e.g. 60 °C) also results in higher densities because resin is less viscous when warm and thus has a greater "lubricating effect" between grains. This option is often not made use of because experience in traditional production has shown that a hot pressed body tends to form laminations. It is generally not appreciated that lamination only arises because of increasing brick density. At the same time, with vacuum, new horizons are opening up for density optimization without the risk of laminations.

5 The Solution

Since in many areas of the refractory brick manufacturing industry the crucial goal is to achieve as high a density as possible in the brick via optimization of the grain structure and diverse pressing agents, the approach outlined above results in the desirability of removing as far as possible the air in the body ahead of compaction:

- The smaller the volume of air to be evacuated, the shorter the time needed for evacuation.
- The level of evacuation required can be calculated for any body from the equation shown above.

5.1 Potential for the Vacuum Technique to Achieve Higher Densities

The interesting question for refractory brick manufacturers is whether vacuum pressing always results in higher densities in the brick. The investigations carried out...
5.2 The Fast Acting Vacuum Device

Whereas in the conventional vacuum system approx. 2–3 m² of air had to be evacuated ahead of each cycle (each lasting approx. 10–15 s), the new system limits itself to evacuation of the space inside the mould, making a reduction in evacuation time of approx. 1–2 s a possibility (Fig. 5).

The advantages of the new Loesis Bucher fast acting vacuum device:
- Air is removed from the mould cavity prior to compaction.
- The space to be evacuated is reduced to a minimum (short time before final vacuum is reached).
- Pre-evacuation container cuts evacuation time.
- Evacuation is possible via upper and lower plunger or only via the upper plunger.
- Degree of evacuation can be limited due to calculation of gas compression factor.

The investment outlay for the new plant is approximately one third of the traditional vacuum technique, and it is often possible to install the new system for existing presses and moulds.

Table 1 provides an overview of the advantages of the new vacuum system compared with the previous de-airing stroke technique and the conventional vacuum system.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Comparison of different de-airing systems</th>
</tr>
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<tr>
<td>Topics</td>
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<td>difficult</td>
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<tr>
<td>Installation time</td>
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<td>Place required / m²/m³</td>
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6 Experimental Experience

Alpha Ceramics has conducted a wide range of investigative tests with this fast acting vacuum device in cooperation with refractory manufacturers.

Evacuating the mould down to a residual pressure of 20 mbar in under 4 s on the refractory press (Type HPP 630) enabled the company to manufacture bricks entirely free of laminations and cracks from a wide range of different bodies. The range of materials used ranged from chrome corundum, spinel, clay-bonded SiC, SSIC, and resin-bonded MgO-C to technical ceramic, aluminum oxide and zirconium oxide.

Investigations proved that, depending on the mix and the brick density obtained, there was no absolute necessity to evacuate the body down to a residual pressure of 50 mbar. As theoretically derived above, the evacuation level required depends exclusively on the density reached when pressing. If only 90 % of the theoretical density is reached, an evacuation of 200 mbar is sufficient. However, if a value of approx. 98 % of the theoretical density is obtained during compaction, evacuation really needs to continue until a residual pressure of 50 mbar is reached (so that lamination is prevented).

Practical application has confirmed that evacuation should only continue up to the level necessary. This is because:
- over-evacuation wastes time
- overlong evacuation may lead to evaporation of the solvents in the synthetic resin or water (leading in inferior compaction due to the diminished plasticity of the mix)
- during overlong evacuation, the brick may become "stuck" to one of the plungers (upper or lower). After ejection, the underpressure in the brick then results in it being pressed onto the plunger by the external pressure of the air.

6.1 Case History 1

For a refractory brick manufacturer, chrome corundum bricks were pressed. With prior evacuation to 60 mbar, it proved possible to press the bricks to much higher densities than had been possible in the client’s production facility (Fig. 6).

At the same time, in comparative studies using conventional de-airing strokes it proved impossible to achieve the target, lamination-free density of 3.2 kg/l. The test results prompted the customer to invest in a fast acting vacuum device for his production press.

6.2 Case History 2

The next example is from the field of technical ceramics, in this instance, wear protection plates made of aluminum oxide (Fig. 7). On the left, the typical picture after compaction with 10 KN/cm² pressure, with no de-airing stroke, with laminations clearly visible. On the right, the same compacting cycle is shown, but under vacuum: perfect fracture image, homogenous matrix.

Justification of the installation costs for the fast acting vacuum device is provided immediately in the form of enhancement in quality and production safety.
6.3 Case History 3

It is extremely difficult to press resin or graphite-bonded refractory products without laminations. Pressing using conventional de-airing strokes requires very frequent ventilation, which in turn lengthens the cycle. However, laminations still appear repeatedly, sometimes only after extended storage of the bricks or after tempering.

The example shows pressed pieces made of pure graphite. Despite multiple de-airing strokes, there are clear signs of lamination on the left-hand, conventionally pressed cylinder. The right-hand, vacuum-pressed cylinder shows a perfect test result.

In this case, the fast acting vacuum device does not result in the complete exclusion of laminations, but considerably shortens the cycle as compared to the conventional technique.

6.4 Case History 4

A client in the sector of high-refractor functional ceramics asked to produce crack-proof plates of large dimension from a fine-grade SiC powder body (Fig. 9). The high purity demanded from the product excluded the use of additives or binding agents in the body. First, conventional de-airing strokes were used to compact the plates. The Figure 9a shows one of six extremely negative results, where pressing involved ten de-airing strokes. The use of a fast acting vacuum device resulted in a perfect brick in the first try, see Figure 9b. This example shows the high potential of the fast acting vacuum device for pressing extremely fine-grained powders.

6.5 Case History 5

Undisputable evidence that the high densities desired were only achievable with no lamination when pressing took place with a fast acting vacuum device was provided by a series of investigations with resin-bonded MgO-C and alumina zirconium carbon bricks. The figures 10, 11 and 12 compare the test results with and without vacuum.

7 Conclusion

Laminations and cracks as defects in pressed bricks resulting from inadequate de-airing during hydraulic pressing can be avoided by a new fast acting vacuum device recently developed by Alpha Ceramics and Læsis Bucher.

This new fast acting vacuum device works directly on the mould and avoids the pressure build up inside the pressed piece that would normally lead to the formation of defects. By directly evacuating the mould the space to be evacuated is considerably reduced compared to traditional vacuum systems.
thus rendering this fast acting vacuum device highly cost effective. Investment costs are only one third compared to traditional vacuum systems; at the same time the cycle time is comparable to conventional pressing.

A further advantage is the possibility to install this new device on existing presses and moulds.

This fast acting vacuum device therefore offers the full benefit of the vacuum technique with improved, repeatable quality and avoidance of hidden defects in refractory products, all achieved without increasing the cycle time of the hydraulic press used.

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Fig. 10  
Resin bonded MgO-C brick: 250 mm x 100 mm x 140 mm, pressed with 3 de-airing steps; density 2.96 kg/l; obvious laminations

Fig. 11  
Resin bonded MgO-C brick: 250 mm x 100 mm x 140 mm, pressed with 90 % vacuum, no de-airing steps; density 3.00 kg/l; no laminations; perfect matrix

Fig. 12  
Fraction area of a conventionally pressed alumina-zirconium-carbon brick (left, obvious laminations) and a vacuum pressed brick (right, perfect matrix)

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FAST ACTING VACUUM DEVICE: GUARANTEED QUALITY FOR PRESSED REFRACTORIES

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