Recycling refractories

While providing a more sustainable fuel source for kiln firing in cement plants, the use of alternative fuels places extra demands on refractories. Therefore, refractory suppliers have developed improved refractory bricks and brick recycling technologies.

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For decades the cement industry has been reducing the environmental impact of operations by using industrial waste and alternative fuels,[1] while the building industry has been recycling concrete to reduce volumes being sent to landfill and the consumption of natural resources. Complete combustion of flammable wastes (such as plastics, tyres and meat and bone meal) removes toxins and their ash components are used as cement raw materials. Therefore, cement kilns are widely recognised as important waste management facilities.

However, excessive consumption of industrial waste accelerates the wear of the refractory brick lining, shortens brick service life and increases the risk of sudden stoppages due to unexpectedly large areas of wear. Therefore, to achieve stable kiln operations, cement plants have implemented several brick improvement projects.

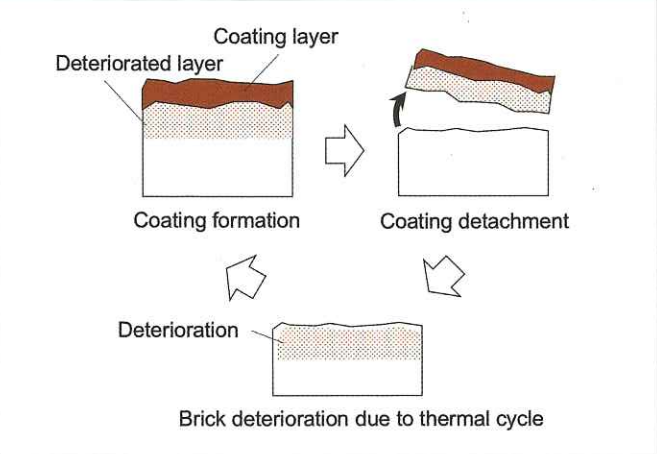
In terms of safe operation, good refractory management requires that residual thickness thicker than the critical value at the end of an operational campaign is maintained. As a result, a certain amount of used brick will become industrial waste. While this type of waste can also be used as a raw material in cement production, the establishment of a brick recycling system is crucial since brick raw materials are produced through an energy intensive process.

This article describes the successful results of brick improvement projects in kilns where waste and/or alternative fuels are used, followed by the introduction of a brick recycling project.

Brick wear and improvements

In Japan, as in many countries, kilns are divided into four zones (from the inlet onward): calcining, transition, burning and cooling. Different brick materials are applied in each of these zone, depending on the operational environment. Among these zones, brick wear in the burning and transition zones is a dominant factor limiting service life.

Figure 1: schematic of brick peeling repetition in burning zone



Burning zone

The burning zone is the highest temperature zone in which clinker contains the largest amount of liquid phase. Thanks to the appropriate liquid phase formation, the boundary between clinker and brick surface is connected tightly by capillary force to form a coating layer. However, fluctuations in combustion due to large alternative fuel rates induce local brick corrosion[2] as well as coating instability that causes brick surface peeling.

Figure 1 shows a schematic illustration of brick peeling accompanying coating detachment in the burning zone. Since brick peeling occurs from the deteriorated layer, minimising deterioration thickness is essential. The deterioration layer is formed by localised small thermal shocks induced by the thermal cycle and slight mismatching in thermal expansion of refractory grains. Therefore, it can be suppressed by carefully controlling the microstructure to absorb the thermal expansion incompatibility.

Transition zone

In the transition zone, gas species such as sulphur, chlorine, and alkalines, derived from industrial wastes and alternative fuels, not only alter the bricks but also the steel shell. The reaction of gas with impurities contained in the bricks promotes brick deterioration.[2] The reactivity between brick and gas can be minimised by achieving a microstructure in which the amount, size and position of unavoidable impurities such as CaO is carefully engineered.

Kiln shell alteration promotes shell deformation, which is unfavourable for the brick lining, particularly in the transition zone, as a kiln tyre is installed in this zone. Rotation of the shell creates complex stress distribution in the brick lining, and shell deformation enhances the stress intensity and stress distribution complexity. Shear stress resulting from torsion promotes inner cracking in the brick and therefore, discontinuous peeling. To improve brick performance, it is effective to enhance the brick's stress relaxation capability. From a microscopic point of view, stress relaxation occurs as a result of rearrangement of micro particles. This is achievable through optimising micro particle mobility by forming an adequate amount of liquid phase in the brick matrix as well as controlling micro-cracking initiation and propagation by adjusting the coarse grain size and fraction.

Burning zone brick improvement project

At Kiln A in Japan, an increase in burning zone brick wear had been an issue.

Figure 2: permanent linear change after 30 times cyclic heating of burning zone bricks

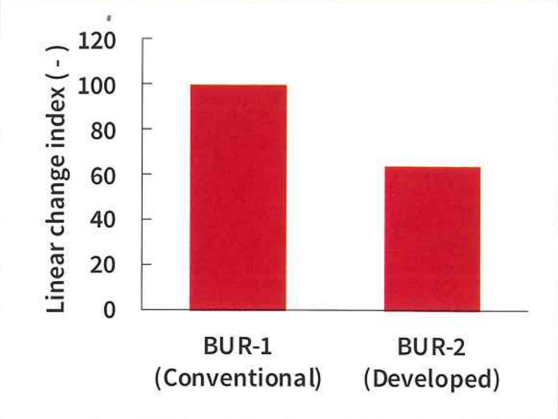


Table 1: typical properties of bricks for the burning zone

Parameter	BUR-1 (conventional)	BUR-2 (developed)
Apparent porosity (%)	14.5	16.5
Bulk density (kg/m^3)	3040	2950
Cold crushing strength (MPa)	56	60
Chemical composition (mass %)		
MgO	84.6	84.7
Al_2O_3	12.1	11.8

Following observations during a kiln shutdown, refractory damage due to peeling was recognised. An effective countermeasure was thought to be the minimisation of structural deterioration as caused by the kiln's thermal cycle. Therefore, the cement plant carried out an adjustment of the chemical composition and texture of the refractory bricks to achieve improved resistance to the thermal cycle deterioration.

Since thermal cycle deterioration is a phenomenon in which the microstructure loosens, an increase in brick length according to the thermal cycle would be observed if no mechanical restraint is imposed. Thus, thermal cycle deterioration was evaluated by permanent linear change after repetition of heating-cooling cycles. For the evaluation, two vertically-connected electric furnaces were used. Temperatures of the upper and lower furnaces were controlled at 1400 and 700 °C, respectively, and a furnace hearth on which brick samples were set shuttled between them every 10 minutes. After 30 cycles of heating-cooling repetitions, permanent linear expansions were measured. In this article, the permanent linear change after 30 cycles is adopted as thermal cycle deterioration indicator and shown by the index normalised by the value of BUR-1. The permanent linear change index after 30 cycles is compared in Figure 2. An approximately 40 per cent reduction in linear change was achieved for the improved material and therefore, a commercial trial would follow. Table 1 summarises the typical properties of bricks for the burning zone.

Figures 3 and 4 show the results of the first trial. A significant improvement was clearly observed for the developed

Figure 3: brick surface appearance after use in the burning zone of kiln A

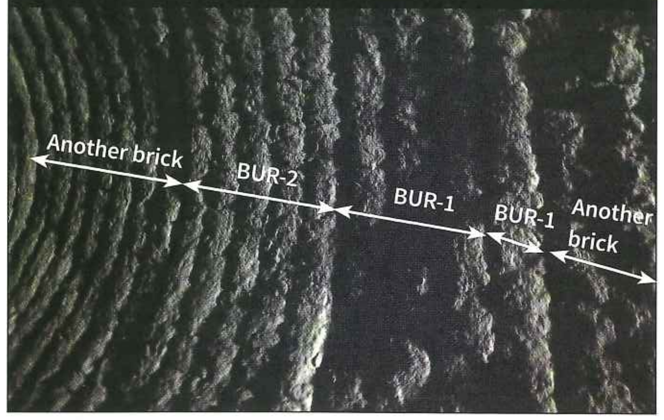


Figure 4: comparison of brick wear rate in the burning zone of kiln A

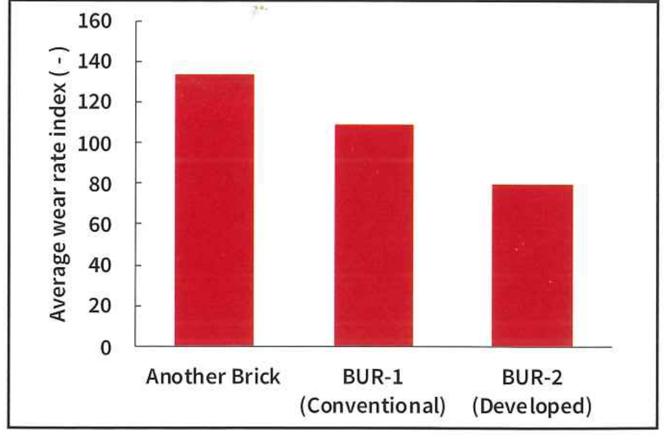


Figure 5: torque relaxation behaviour of transition zone bricks

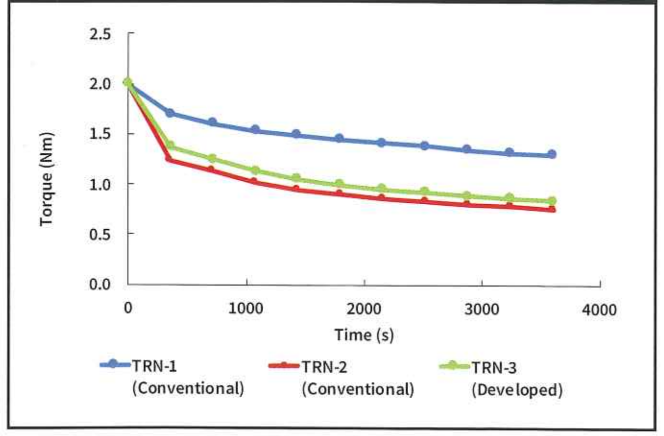


Figure 6: permanent linear change after 30 times cyclic heating of transition zone bricks

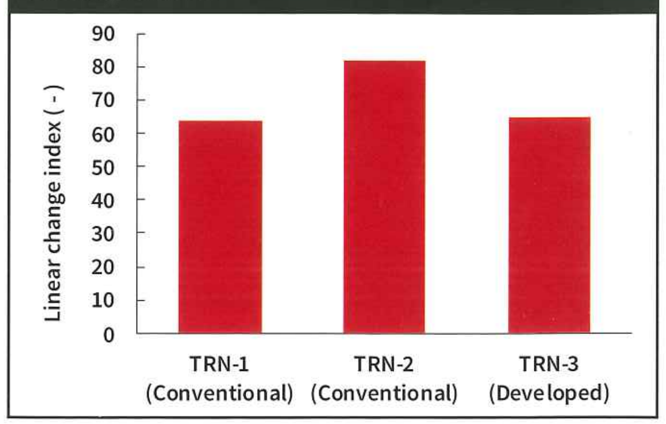
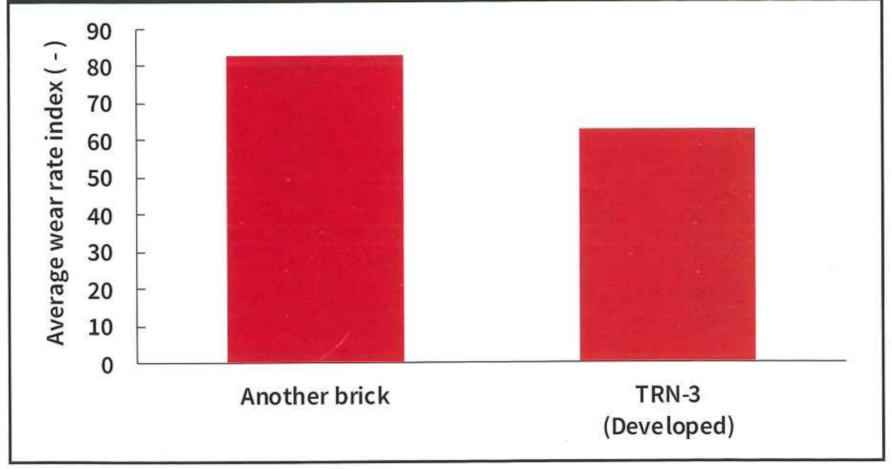


Table 2: typical properties of bricks for the transition zone

Parameter	TRN-1 (conventional)	TRN-2 (conventional)	TRN-3 (developed)
Apparent porosity (%)	15.5	15.1	15.5
Bulk density (kg/m^3)	2950	3000	2950
Cold crushing strength (MPa)	48	50	45
Chemical composition (mass %)			
MgO	81.0	81.0	80.1
Al_2O_3	17.1	17.6	17.2

Figure 7: brick surface appearance after use in the transition zone of kiln B

Figure 8: comparison of the brick wear rate in the transition zone of kiln B



material and currently, the application range in this kiln has been extended.

Transition zone brick improvement project

At kiln B in Japan, a reduction of transition zone brick wear was required. An investigation found that the dominant wear factor was frequential peeling due to cracking caused by internal stress. Therefore, improvement of stress relaxation capability was attempted. While there was a brick possessing sufficient stress relaxation capability, it showed poor thermal cycle deterioration resistance. Taking the operational conditions of kiln B into account, using this brick was deemed risky. Therefore, improvement of stress relaxation capability with equivalent thermal cycle deterioration resistance was targeted.

In this project, stress relaxation behaviour was evaluated with a torsion test. One end of a rectangular specimen, heated at 1250°C by an electric heater, was twisted to the angle of which 2Nm in torque was imposed and fixed, followed by continuous torque measurement. Thermal cycle deterioration resistance was evaluated under the same conditions as described in the previous section.

Figures 5 and 6 show a torque decrease in torsion test and permanent linear change index after 30 heating cycles. Improved material satisfied both targets and no problems were found in relation to the typical properties shown in Table 2. To be able to evaluate the wear rate in detail in the commercial trial, a planned temporary stoppage after short-term operation was carried out. As shown in Figures 7 and 8, a marked improvement in the wear rate was seen.

Overall brick consumption improvement project

In North America a brick consumption reduction project was started for kiln C. In this kiln a stable coating protects the burning zone bricks effectively and the maximum wear rate of the transition zone is at an acceptable level. However, wear of the upper part of the transition zone could be improved. Previous investigations indicated that structural spalling induced by foreign components contained in the industrial waste and/or alternative fuel is the main cause of brick wear. Therefore, TR-1 conventional brick, as shown in Table 2, with well-controlled reactive impurities was selected.

Figure 9 compares the wear rate distribution of the trial campaign with the average of several former conventional brick campaigns. The trial brick showed less than half the wear rate at the upper part of the transition zone. This enables the repair frequency of the corresponding area to be reduced by half, resulting in a significant reduction of overall brick consumption.

Recycling project

Basic research has enabled the establishment of brick recycling technology.[3] In this process, recycled brick is used as an alternative dense coarse grain with an inevitable increase in porosity. Therefore, it is recommended to carefully consider to what extent this brick can be used in kilns where intensive chemical corrosion takes place. However, in many cases, peeling according to the thermal cycle and/or internal stress is a dominant factor of brick wear as discussed above. Hence, maintaining thermal cycle stability was prioritised to determine maximum recycled material content.

Figure 9: wear rate index of the transition zone of kiln C

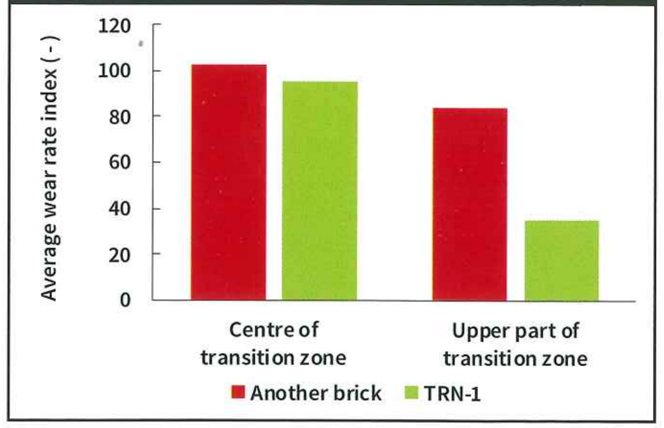
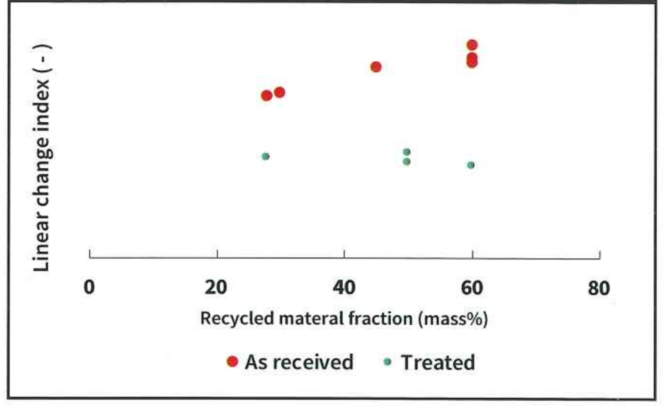


Figure 10: influence of recycled material treatment on linear change index variation



To maximise the recycled material fraction, a treatment process was developed. Figure 10 shows the permanent linear change index after 30 heating cycles as a function of recycled material fraction. Thanks to the material treatment process, containing a large amount of recycled material became possible.

A brick recycling project has been launched through cooperation with a cement manufacturer. Since it reduces industrial waste as well as GHG emissions when refractory raw material is manufactured, a successful outcome is expected.

Conclusion

Three recent brick improvement projects have been described in this article. Since the operational conditions of kilns and the improvement targets of projects vary, suitable technologies were developed for each kiln. Additionally, a brick recycling project has been launched. These innovative developments will contribute to improving kiln operations from an environmental point of view. ■

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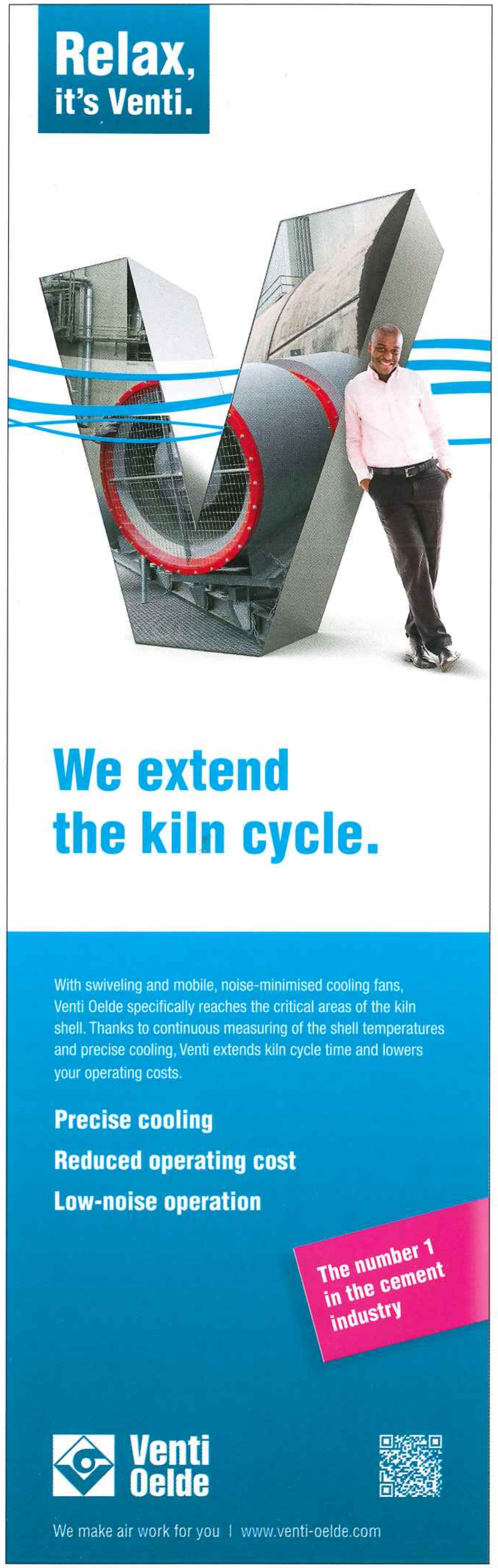

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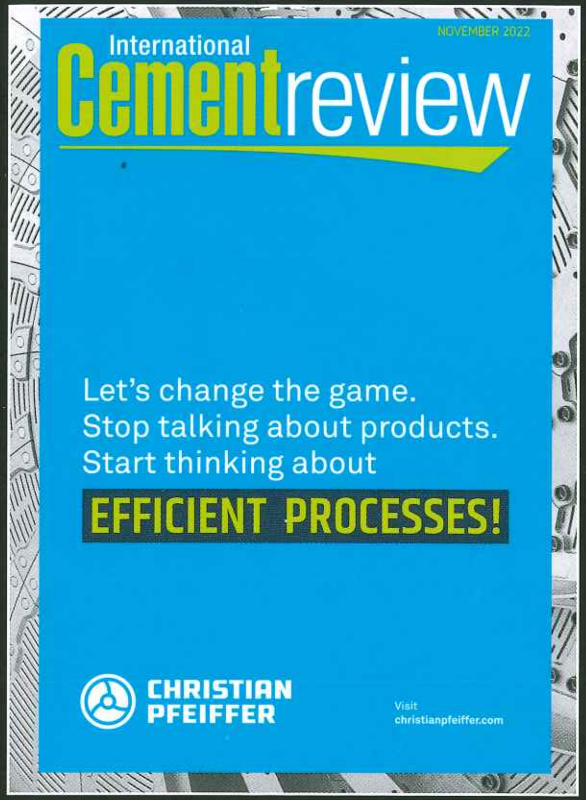

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