A new refractory composite based on calcium aluminate silicate for induction furnaces

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A ductile refractory composite (DURATEC-XP) was developed by Promat International with a designed microstructure to optimize properties required for use in applications where combined resistance to cyclic attack of thermal, electrical and mechanical impact are needed. More specific, the material possesses high bending strength of 45 MPa, impact resistance of 30 kJ/m^2, low thermal expansion coefficient, good electric insulation and good machinability. In this paper, a ductile refractory composite for electric insulation is described with optimized resistance towards crack propagation in a broad temperature range.

Certain applications require high resistance to brittle fracture in conditions where the material is subjected to combined effects of cyclic impact and thermal shock. Typical examples include electric insulations in induction furnaces and arc chute application. For such applications, in the past, traditionally asbestos cement based materials were used. However, since the ban of asbestos due to the health concerns, few alternative products have been developed with satisfactory properties, a reasonable life time and an acceptable cost price. Fibre reinforced ceramics could be a suitable choice, though they are generally considered too expensive for these applications.

Samples of DURATEC-XP boards were made by a lamination process as shown schematically in **Fig. 1**, after which the boards were cured, dried and machined.

The material was characterized by thermal, electrical and mechanical tests as listed in **Table 1**.

The structure of the board before and after arc chutes test was analyzed by SEM and XRD.The flexural behavior of the DURATEC-XP was compared with that of an existing commercial product with similar chemistry targeting the same applications.

Materials and microstructure

The refractory matrix of the composite described in this study is composed of calcium aluminate cement (CAC) and wollastonite. CAC was chosen because of its refractory character and the fact that it has good corrosion resistance against molten metals. In comparison with OPC, alumina-cement has a lower alkalinity and hence better compatibility with E-glass reinforcement.

Wollastonite was employed as functional filler, to reduce the drying shrinkage of the matrix during the cement hydration and to increase the fracture toughness of the composite in the temperature range 20-1200°C. The morphology of the wollastonite crystals was chosen such that an important quantity could be incorporated into the matrix without compromising the flow characteristics required for the formation process. As the wollastonite phase has a high melting point (1540°C), it contributes to a good thermal stability of the composite material.

E-glass fibre webs are employed as reinforcement. The volume fraction of fibres and the fibre/matrix interface were chosen in function of the desired strain hardening effects, characterized by a higher load carrying capacity after multiple cracking of the matrix.

Additives and processing aids are applied to control the setting and rheological properties of the formulation during the production process. Water repellent can be employed in the formulation, should resistance to water absorption be considered necessary.

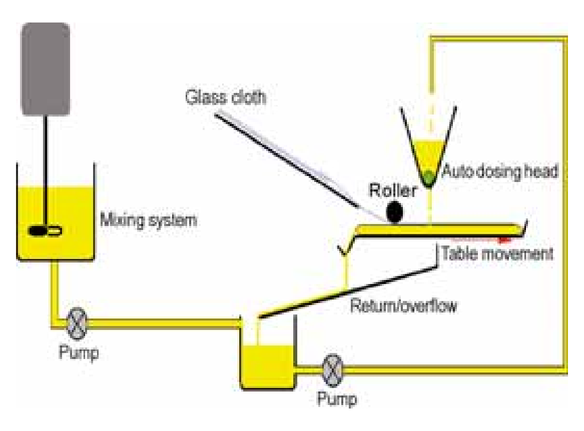

Fig. 1: Production scheme, Kawi BV

Table 1: Test results

Test	Results	Method
Density, kg/cm³	1800	EN 12467
Bending strength , MPa	45.0	EN 12467
Flexural modulus , GPa	5.5	EN 12467
Compressive strength , MPa	180.0	EN 12467
Impact resistance , KJ/m²	31.8	Charpy test
Thermal shrinkage at 1250°C/12hrs, %	0.7	EN1094-6
Thermal conductivity, W/mK 50 °C 200 °C 400 °C	 0.40 0.38 0.35	Hot plate
Volume resistivity, Ωcm	5.2 x10^{12}	DIN IEC
Surface resistivity, Ω	2.4 x10^{13}	60093
Flammability	FH1	EN 60707

Fig. 3: Crack deflection by wollastonite and cleavage of wollastonite crystals

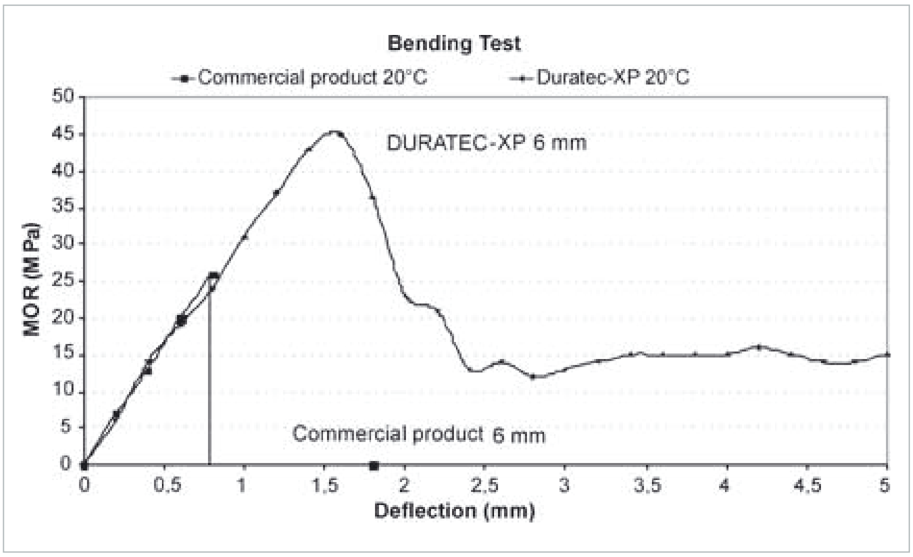

Fig. 2: Strength-deflection curves

Results and discussion

The properties in Table 1 were measured at 20°C, unless otherwise specified.

Bending tests (**Fig. 2**) clearly demonstrate the ductile nature of the DURATEC-XP material with ultimate bending strength of 45 MPa and max. deflection of above 5 mm, in comparison with brittle nature of a commercial product with ultimate strength of 26 MPa and deflection of 0.7 mm, tested with equal sample thickness. The toughening of the DURATEC-XP is in part attributed to the fibre-reinforcement with a frictional bonding between fibre and matrix. In these conditions multiple cracking of the matrix occurs. Straining of the bridged fibres across the matrix cracks and within the matrix blocks gives rise to a composite strain that is substantially higher than the matrix failure strain alone, resulting in strain hardening.

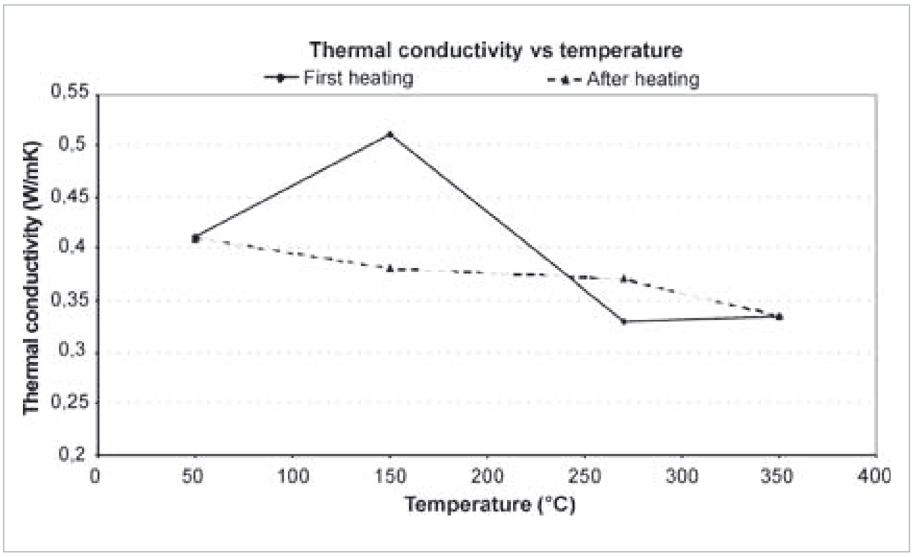

Fig. 4: Strength-deflection curve vs. temperature

The wollastonite-phase leads to additional toughening of the matrix. One toughening mechanism is crack-deflection induced by the wollastonite crystals (**Fig. 3**). The matrix without wollastonite crystals clearly show less branched cracks that penetrate through cement clinker phases as shown in the SEM.

It is also observed that the wollastonite crystals near to the crack tips show more cleavage or microcracking than wollastonite crystals further away. Cleaving of crystals in the vicinity of the crack tip also constitutes a mechanism of energy consumption and toughening. This mechanism is similar to the toughening mechanisms in ceramic composites

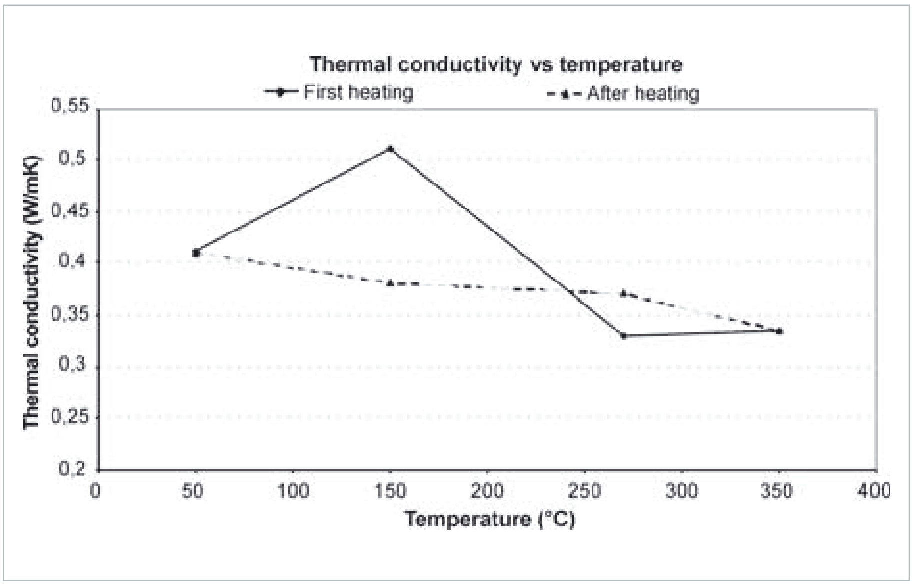

Fig. 5: Lambda-value vs. temperature

based upon some zirconia-types and those with ductile particle reinforcements.

The ductile nature of the DURATEC-XP-material also persists at high temperature after melting of the glass fibre-reinforcement (**Fig. 4**). The toughening in these conditions is attributed to the crack-deflection by wollastonite, wollastonite-cleavage and the presence of round pores left after the melting of the glass fibres, which reduce the tensions associated with crack tips and therefore limit the crack-propagation.

The impact resistance (Charpy test) was measured to be above 30 kJ/m^2 and the surface resistivity was found to be 10^{13} , meaning that the material has the desired impact resistance and good electric insulation, as required for the typical applications.

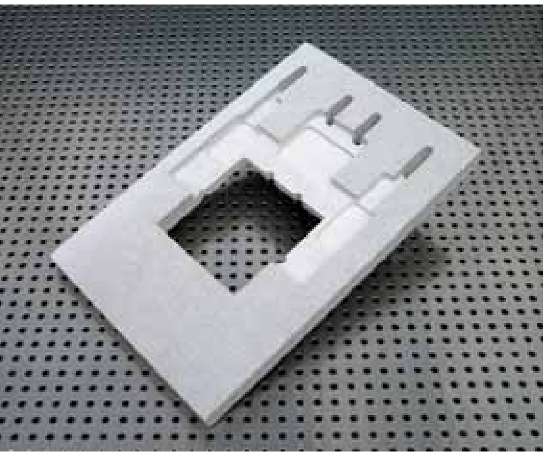

Fig. 6: End Board for Steel Billiet Heater

Thermal characteristics

TMA tests show that DURATEC-XP material has limited dimensional changes until 1200°C and no visible cracks. Material with and without glass fibre reinforcement have been compared. It is clear that the glass fibre enables a reduction of the dimension changes on heating and therefore leads to a material with low linear thermal expansion coefficient of 7.2 m/m°C. The low thermal expansion coefficient and the ductile behavior of the material in the whole temperature range of its applications explain the fact that the material has good thermal shock resistance.

The thermal conductivity of DURATEC-XP was measured by the hot plate

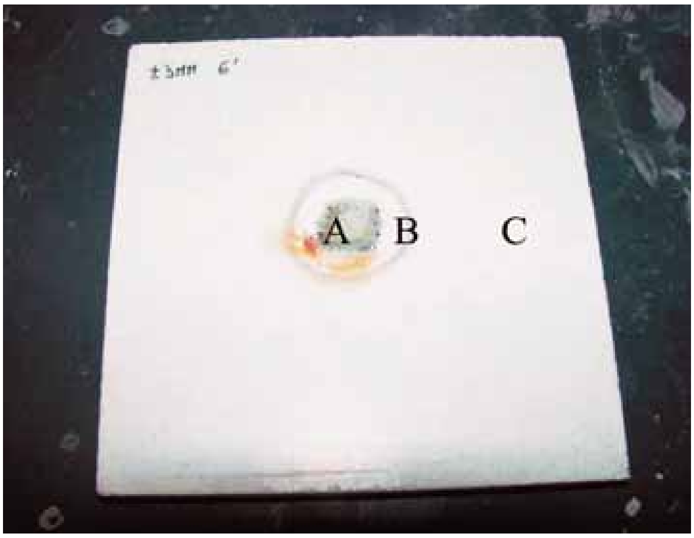

Fig. 7: Results of arc chute test

Fig. 8: Induction crucible furnace featuring DURATEC-XP

method (**Fig. 5**). The values are around 0.35-0.45W/(mK) in the temperature range 20-400°C. The slightly higher value around 150-200°C during the first heating is related to the dehydration of the hydrated cement-phases. The rather low thermal conductivity limits the effects of heat in application such as arc-chutes.

Further applications

The DURATEC-XP board has been in service as end board for a Steel Billiet Heater (Induction furnaces, **Fig. 6**) for more than 10 months, compared to a maximum service life of few weeks of other available commercial products in the market.

Arc chute test with 6 min. exposure at distance of 3 mm, in which peak temperatures of ca 3000°C were reached, show very good stability and material integrity of the material after the arc shock (**Fig. 7**). This is mainly due to the low thermal conductivity of the material and the energy dissipation in the melting-zone. In the highest temperature zone (zone A), melting occurs with crystallization of gehlenite as the main phase by cooling.

In the region of ca 2 mm from the melting zone (zone B), glass fibre is observed, indicating temperatures below 900°C. This shows that there is an important drop of temperature over a short distance because of the low thermal conductivity of the material. The impact of the electric arc leads to multiple tiny cracks, parallel to each other but vertical to fibre web direction. This mechanism absorbs impact energy and avoids formation of major cracks.

Conclusion

A ductile refractory composite has been developed for electric insulation with optimized strain hardening characteristics and thermal shock resistance. Field tests show that it has much better performance and longer service life than similar products available in the market, both for induction furnaces (**Fig. 8**) and arc chute applications. The good performance is attributed to a tailor made material combination, based on a toughened refractory castable and an optimized fibre reinforcement. ■

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