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New Developments of Tabular Alumina and Tabular Alumina Spinel Castables

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Abstract

Es wurde eine neuartige Methode zur Herstellung von monolithischen Feuerfestmaterialien entwickelt. Dieses Verfahren erlaubt trotz Einsatzes der Selbstfließ-Technologie die Verwendung eines hohen Anteils sehr grober Körnungen. So wurden Prüfkörper mit einem Gehalt von ca. 60 % 18-22 mm bzw. 4.5 - 12 mm grober Tabulartonerde bzw. aluminumoxidreichem Spinell hergestellt. Die untersuchten Materialien zeigten eine überraschende Beständigkeit gegenüber Schlackenangriff. Im Laborinduktionsofentest mit basischen Schlacken ($CaO:SiO_2 \approx 6$) mit hohem Fluor-Gehalt (bis zu 5 %) wurde an Prüfkörpern ein sehr gutes Verschleißverhalten gefunden. Das neue Verfahren könnte somit von großem Interesse für die Auskleidung von Stahlpfannen sein, aber auch für andere Feuerfestanwendungen erhebliche Vorteile bieten.

An new method for the production of monolithic refractory materials has been developed. This process allows the use of a high proportion of coarse grains. Despite the use of the self-flowing technology, test specimen with a content of approx. 60 % of 18-22 mm grains resp. 4.5-12 mm from Tabular Alumina and Alumina-rich Spinel have been prepared. When subjected to an induction furnace test the investigated materials demonstrated a surprisingly high resistance against basic slags ($CaO:SiO_2 \approx 6$) containing different amounts of Fluorine ranging up to 5 %. It is expected that the new process will be, in addition to other applications, of specific interest in steel ladle lining applications.

1. Introduction

In recent years considerable progress has been made to decrease the necessary mixing water and open porosity of low cement bonded Tabular Alumina and Tabular Alumina Spinel castables in order to improve their physical properties and resistance against slag attack [1-7]. Self-flowing LC Tabular and Tabular Spinel castables which could be cast with 4.0-4.5 % mixing water, and vibrated with 3.5-3.6 % mixing water, have been developed. These castables showed good slag resistance, excellent cold and hot strengths and very low open porosity. Even after firing at 1 500 °C an apparent porosity of 16-18 % with no open pores larger than 5 µm diameter was obtained. This was achieved by optimized particle morphology, particle size distribution and surface chemistry of the fine castable ingredients: cement, fine Tabular, reactive Aluminas and dispersing Aluminas. This type of high performance castables have been in the meantime successfully used in industrial scale in a variety of different refractory applications, predominantly in steel applications. During industrial applications it became obvious, that a further reduction of porosity, by further optimization of the castable fines leads to even better particle packing and less mixing water requirements. But this would potentially lead to problems in 2 areas: **Drying and raw materials costs**. An even lower open porosity would mean further extended drying times, and in case the dryout process is not controlled carefully, the danger of explosive spalling would increase. The further optimization of Alumina raw materials, making them suitable for self-flowing castables, which would even need less than 4 % mixing water to achieve acceptable self-flow properties is possible [12] but would increase raw material costs. In addition a rather controlled and therefore more costly processing would be needed to prepare and install these high performance castables. This cost increase would be hard to accept from the refractory industry which has in the recent years seen tremendous pressure from the steel industry to reduce the overall refractory costs.

In order to overcome both of these issues, and still further improve slag resistance and reduce mixing water demand, a new technology to produce refractory bodies with simplified processing needs and lower costs of raw materials has been developed [8]. Several different castables, as described in **Tab. 1 a** and **b** with different coarse materials and different chemical compositions, have been produced. In this new method coarse refractory aggregates like Tabular Alumina and Magnesium Alumina Spinel of a grain size between 18-22 mm respectively 4.5-12 mm were used with a content of approximately 60 % [8]. This new method uses for placement the self-flowing technology and avoids the need of any vibration. But the method uses a very different approach to integrate coarse materials when compared to published methods [9-11]. This paper describes selected physical, mechanical and chemical properties of specimen prepared by this new production method. Also the slag resistance against basic slag has been investigated in induction furnace tests.

2. Raw Materials and Castables

All raw materials used are listed in **Tab. 2 a-d**. As coarse materials, 2 principle types with different chemistries and particle shapes have been used:

- ball shaped grains: Tabular Alumina T60 CDS, Spinel AR 90 CDS (18-22 mm)
- irregular shaped grains: T-60 1/2-1/4 inch, AR 90 6-12 mm.

As fine materials (<1mm), the newly developed AFL Alumina was used together with CA-270 cement, Alumina binder Alphabond 300 and the dispersing Aluminas ADS 1, ADS 3 and ADW 1.

3. Physical Properties

Properties of selected testbodies made with the new method are compiled in **Tab. 3 a-b**. They are compared to low cement Alumina and Alumina Spinel castables, which have been prepared with conventional particle size distribution by self-flowing technology. Preparation and testing of specimens followed according to E DIN EN 1402-3, 5 and 6 (**Tab.3c**). When judging the strength test results it has to be considered that the described test specimen sizes (especially for hot properties) are relatively small compared to the aggregate size of >12.5 mm.

3.1 Permanent Linear Change of Dimension (P.L.C.)

The new developed castables with coarse aggregate show, even after firing at 1 650 °C, a permanent linear shrinkage of less than 0.2 %. This can be attributed to the very high portion of coarse

Tab. 1a. Composition of test specimen

# of castable	T-60 CDS 1(7)	T-60 CDS 1(12)	T-60 CDS 2(7)	T-60 1/2-1/4 2(7)	T-60 CDS 15(7)	T-60 CDS 13(7)	T-60 CDS 13(12)	AR 90 CDS 1(7)	AR 90 CDS 1(12)	AR 90 CDS 2(7)	AR 90 6-12 2(7)	AR 90 CDS 15(7)
Type of coarse material	T-60 CDS	T-60 CDS	T-60 CDS	T-60 1/2-1/4	T-60 CDS	T-60 CDS	T-60 CDS	Spinel AR 90 CDS	Spinel AR 90 CDS	Spinel AR 90 CDS	Spinel AR 90 6-12	Spinel AR 90 CDS
Portion of coarse materials [%]	59	59	59	59	59	59	59	59	59	59	59	59
Type of AFL Alumina	AFL 1	AFL 1	AFL 2	AFL 2	AFL 15	AFL 13	AFL 13	AFL 1	AFL 1	AFL 2	AFL 2	AFL 15
Chemical composition of castable [%]												
Al_2O_3	95	94	94	94	93	99	98	89	89	88	88	88
MgO	4	4	5	5	6	–	–	10	10	11	11	12
CaO	0.7	1.3	0.7	0.7	0.7	0.7	1.3	0.7	1.3	0.7	0.7	0.7
SiO_2	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2

Tab. 1b. Conventional castables T 78/90SF and 204 SFL

Castables	204 SFL	T 78/90 SF
Tabular Alumina [%]	78	60
Spinel [%]	–	25
Reactive Al_2O_3 [%]	17	10
Cement [%]	5	5
Mixing Water [%]	4.0	5.8

materials forming a skeleton of dense and high fired aggregates of Tabular Alumina or AR 90 Spinel. Comparable dense castables with usual grain size distribution show, at 1 650 °C, shrinkage of up to 0.6 %.

3.2 Bulk Density, Apparent Porosity, Pore Size Distribution

The apparent porosity of the test castables after pretreatment at 110 °C, 1 500 °C and 1 650 °C, are illustrated in **Fig. 1 a-b**. The new developed coarse aggregate containing castables show very low porosities, some comparable to the proven dense self-leveling castables, some even below. **Fig. 2** shows an example of pore size distribution of a selected fine portion of the castable (1 mm), recalculated to the bulk of the castable (60 % aggregate 12.5 mm, 40 % matrix phase <1 mm). Even after firing at 1 500 °C the pore diameter in the matrix remains under 3μm. The pore size distribution of the coarse grain castable cannot be measured by Hg-intrusion because the used test sample is too small compared to the maximum grain size. The total apparent porosity of the castable is about 3-5 % higher than the part of apparent porosity of the matrix. This is due to the open porosity of the coarse aggreagate

Tab. 2a

	T-60 CDS	AR 90 CDS	T-60 1/2-1/4 inch	AR 9 6-12 mm
Chemical Analysis [%]				
Al_2O_3	≥99.4	≥88.0	≥99.3	≥88.0
MgO	–	9-10	–	9-10
Na_2O	<0.4	<0.2	<0.4	<0.2
Fe_2O_3	<0.05	<0.1	<0.05	<0.1
CaO	0.08	<0.25	<0.08	<0.25
SiO_2	0.06	<0.15	<0.06	<0.15
Mineralogical composition				
α-Alumina	xxx	x	xxx	x
Spinel	–	xxx	–	xxx
Particle size distribution [%]				
12-22 mm	>90	>90	<5	<5
4-12 mm	<10	<10	>95	>95

Tab. 2b. Properties of the newly developed AFL Aluminas

Alumina	AFL 1	AFL 2	AFL 13	AFL 15
Chemical Analysis [%]				
Na_2O	<0.3	<0.3	<0.3	<0.3
Fe_2O_3	<0.05	<0.07	<0.05	0.07
SiO_2	<0.12	<0.12	<0.12	<0.5
MgO	10 - 12	13 - 15	<0.1	14 -16
CaO	<0.3	<0.3	<0.08	<0.3
Mineralogical composition				
Alumina	xxx	xxx	xxx	xxx
Spinel	xxx	xxx	–	xx
Periclase	–	–	–	xx
Grain size distribution [%]				
<0.250 mm	55 - 60	70 - 75	80 - 85	70 - 75
Surface Area acc. BET [m^2/g]	1.2 - 2.0	1.5 - 2.5	1.2 - 2.0	1.2 - 2.0

Tab. 2c. Properties of dispersing Aluminas

	ADS 1	ADS 3	ADW 1
Chemical Analysis [%]			
Al_2O_3	80	78	80
Na_2O	0.15	0.15	0.15
B_2O_3	0.8	2.5 - 3	0.03
CaO	1.6	2.0	1.6
LOI [%] /1050 °C)	17	19	17

Tab. 2d. Properties of used cement and Alumina binder

	Cement CA-270	Alphabond 300
Chemical Analysis [%]		
Al_2O_3	72 - 74	90
CaO	25 - 27	<0.1
Fe_2O_3	0.1	n.d.
MgO	0.09	n.d.
Na_2O	0.16	<0.4
SiO_2	0.14	<0.2
LOI [%] /1050 °C)	<0.3	9

(2 - 4 %) and small amounts of microcracks between the large aggregates and the matrix.

3.3 Cold Modulus of Rupture (M.O.R.) and Cold Crushing Strength (C.C.S.)

The development of M.O.R. and C.C.S. with increasing firing temperature of the prepared castables are shown in **Fig. 3 a-b** and **Fig. 4 a-b**.

The modulus of rupture, which characterizes the bonding between grain and matrix, is generally lower - especially after firing below 1 500 °C - than of comparable dense castables with conventional particle size distribution, but similar to the conventional

Tab. 3a. Properties of new developed castables based on coarse Tabular Alumina aggregates (12,5 mm resp. 4.5-12 mm)

Castable	Pretreatment [°C]	T-60 CDS 1(7)	T-60 CDS 1(12)	T-60 CDS 2(7)	T-60 1/2-1/4 2(7)	T-60 CDS 15(7)	T-60 CDS 13(7)	T-60 CDS 13(12)	204 SFL (conven.)
Cement in castable [%]		3	5	3	3	3	3	5	5
Mixing Water [%]		3.6	3.6	3.8	4.6	3.8	3.4	3.4	4.00
Bulk densitity [g/m^3]	110	3.19	3.11	3.10	3.13	3.14	3.19	3.19	3.23
	1 500	3.06	3.10	3.06	3.04	2.98	3.14	3.14	3.17
	1 650	3.11	3.07	3.10	3.09	3.11	3.17	3.13	3.24
Apparent porosity [%]	110	11.3	12,8	13.1	13.4	12.0	12.2	11.5	17.2
	1 500	16.0	14.8	14.8	17.2	18.2	15.1	14.8	15.9
	1 650	14.1	15.4	15.1	15.4	14.7	14.6	15.4	14
Modulus of rupture (M.O.R.) [N/mm^2]	110	3.6	5.5	4.3	4.2	2.5	4.7	6.7	17.2
	1 000	2.1	2.2	1.4	3.1	2.6	1.0	2.1	13.9
	1 500	14.2	13.4	17.6	22.9	13.1	18.6	10.1	56.1
	1 650	18.1	21.5	17.2	15.5	19.8	24.3	16.1	55
Hot modulus of rupture at (HMoR) 1 500 °C [N/mm^2]	1 500	8.9	7.9	6	9.6	1.2	3.2	8	19.9
Cold crushing strength (C.C.S.) [N/mm^2]	110	70.3	80.9	52.7	60.4	47.0	52.5	75.7	100.9
	1 000	53.1	89.2	50.6	46.4	62.8	53.7	80.6	94.3
	1 500	168.3	188	150.5	152.9	107.5	166.9	182.1	343.4
	1 650	177.1	196.2	123.4	129.6	153.8	154.0	214.7	359.5
Linear permanent change [%]	110	±0	±0	±0	- 0.09	±0	- 0.04	±0	±0
	1 500	±0	-0,08	- 0.09	- 0.09	- 0.09	- 0.04	- 0.26	-0.1
	1 650	-0.15	-0.09	- 0.25	- 0.3	- 0.13	- 0.48	±0	- 0.6

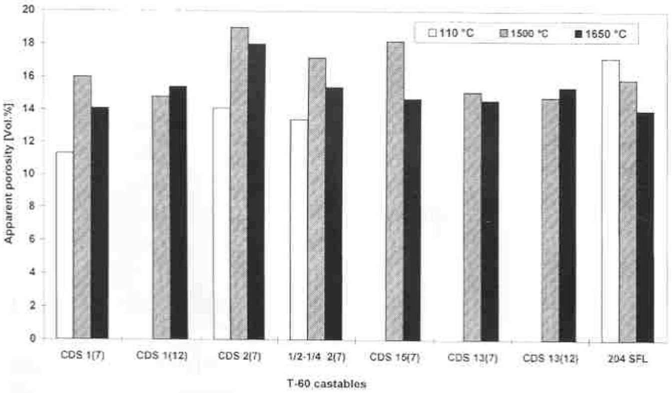

Fig. 1a. Apparent porosity of the test specimen based on coarse Tabular Alumina T-60 after drying and firing at 1 500 °C and 1 650 °C

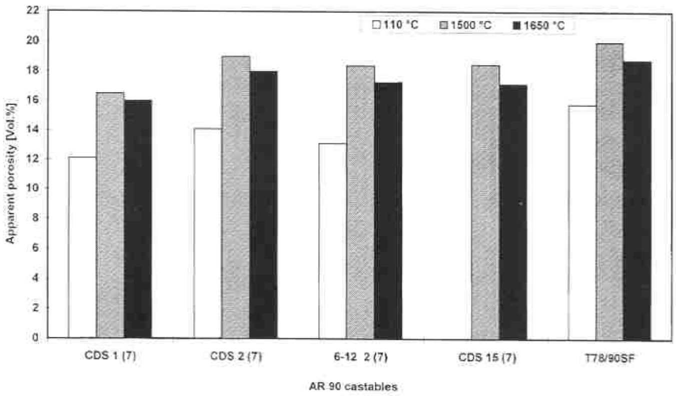

Fig. 1b. Apparent porosity of the test specimen based on coarse Spinel AR 90 after drying and firing at 1 500 °C and 1 650 °C

Tab. 3b. Properties of new developed castables based on coarse AR90 Spinel aggregates (12,5 mm resp. 4.5-12 mm)

Castable	Pretreatment [°C]	AR 90 CDS 1(7)	AR 90 CDS 1(12)	AR 90 CDS 2(7)	AR 90 6-12 2(7)	AR 90 CDS 15(7)	T78/ 90SF
Cement in castable [%]		3	5	3	3	3	5
Mixing Water [%]		3.60	3.60	3.80	4.60	3.80	5.80
Bulk densitity [g/m^3]	110	3.10	3.06	3.02	3.04	3.05	3.03
	1 500	3.07	3.02	2.96	2.96	2.98	2.98
	1 650	3.07	3.04	2.98	3.00	3.01	2.99
Apparent porosity [%]	110	12.1	13.3	14.1	13.1	13.3	15.8
	1 500	16.5	17.5	19.0	18.4	18.5	20.0
	1 650	16.0	16.4	18.0	17.3	17.2	18.8
Modulus of rupture (M.O.R.) [N/mm^2]	110	3.7	2.4	4.3	3.9	1.5	5
	1 000	1.5	2.7	1.4	2.3	2.4	6
	1 500	13.8	13.8	17.6	14.6	12.2	24
	1 650	19.8	21.2	17.2	20.5	12.4	26.5
Hot modulus of rupture at (HMoR) 1 500 °C [N/mm^2]	1 500	6.2	9.9	6	5.8	1.1	15.0
Cold crushing strength (C.C.S.) [N/mm^2]	110	64.9	79.0	52.7	56.8	4.8	35.0
	1 000	55.5	69.0	50.6	48.1	59	40.2
	1 500	169.9	181.7	150.5	145	136	130
	1 650	155.8	188.0	123.4	123.6	136.5	116.5
Linear permanent change [%]	110	-0.04	±0	±0	- 0.04	±0	-0.06
	1 500	0.13	+ 0.3	+ 0.09	±0	+ 0.2	-0.06
	1 650	-0.04	±0	±0	- 0.04	±0	-0.53

Tab. 3c. Test specimen, pre-treatment and test methods.

Test specimen	Pre-treatment	Measured properties	Test method
230 mm x 64 mm x 54 mm	110 °C/24 h 1 000 °C/5 h 1 500 °C/5 h 1 650 °C/5 h	permanent linear change cold modulus of rupture cold crushing strength bulk density, apparent porosity	E DIN EN 1402-5 and -6
115 mm x 64 mm x 54 mm	1 500 °C/5 h	thermal shock resistance air quenching from 950 °C	E DIN ENV 993-11
25 mm x 25 mm x 150 mm	1 500 °C/5h	hot moduls of rupture (cut out of specimen 230 mm x 114 mm x 64 mm)	E DIN EN 993-7
12 segments/test segments: high: 229 mm thick: 38 mm width: 63,5 mm/93 mm	1 000 °C/5 h	corrosion resistance (test 1,3) induction furnace 1 650 °C/3 h 3 x 0.5 kg slag	Internal procedure
8 segments/test segments: high: 270 mm thick: 25 mm width: 75 mm/55 mm	1 000 °C/5 h	Corrosion resistance (test 2) induction furnace 10.000 Hz 1 650 °C/3 h 15 kg steel, 2x 1 kg slag	Internal procedure

castables. Cold crushing strength is high because of the strong coarse grains, which support each other.

3.4 Hot Modulus of Rupture (H.M.O.R.)

The H.M.O.R. at 1 500 °C was measured on test pieces (25 mm x 25 mm x 150 mm) cut out of 1 500 °C prefired brick sized samples (250 mm x 114 mm x 65 mm) (**Fig. 5**). The measured values range between 6 - 8 N/mm^2, and do not reach the values of comparable dense castables. Though there is a disproportion between test piece size and maximal aggregate size the results were found to be reproducible. It is interesting to note that castable T-60 CDS 15(7) and AR 90 CDS 15(7) show only a hot modulus of rupture of about 1 N/mm^2. These in-situ Spinel forming castables contain a small amount of SiO_2 (0.2 %). The finding confirms again the detrimental influence of SiO_2 on the hot strength of low cement bonded Alumina and Alumina spinel castables [2].

3.5 Refractoriness under Load (R.u.L.)

In **Fig. 6 a-b** the refractoriness under load curves are compiled. The test pieces were drilled out from the specimens prefired at 1 000 °C. From two castables also specimens prefired at 1 500 °C were tested.

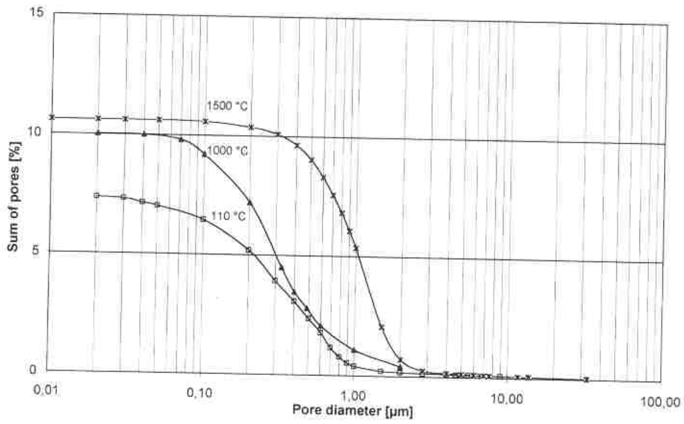

Fig. 2. Example of the pore size distribution of the castable fines portion (<1 mm) after different firing temperatures

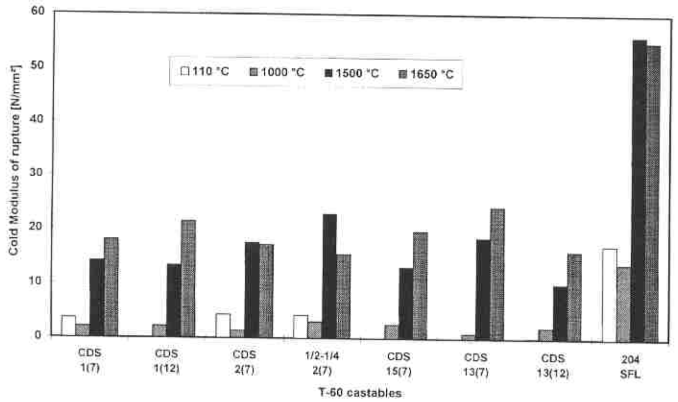

Fig. 3a. Cold modulus of rupture of castables based on coarse Tabular Alumina T-60 after drying and firing

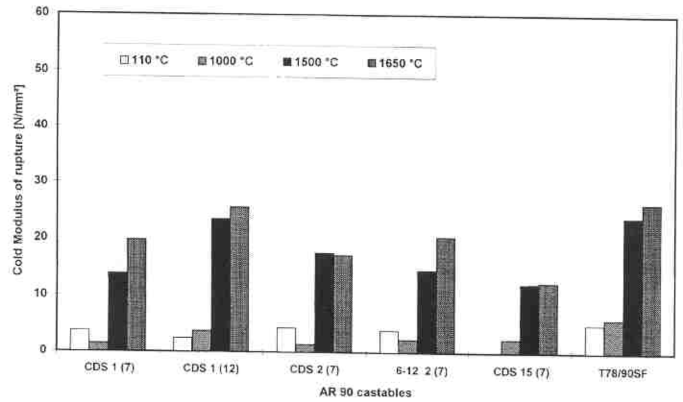

Fig. 3b. Cold modulus of rupture of castables based on coarse Spinel AR 90 after drying and firing

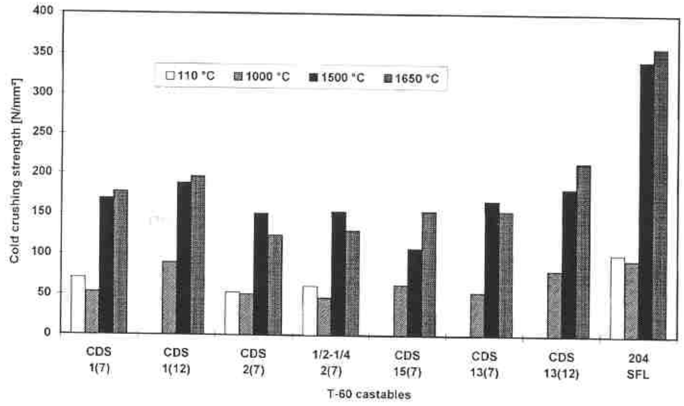

Fig. 4a. Cold crushing strength of the castables based on coarse Tabular Alumina T-60 after drying and firing

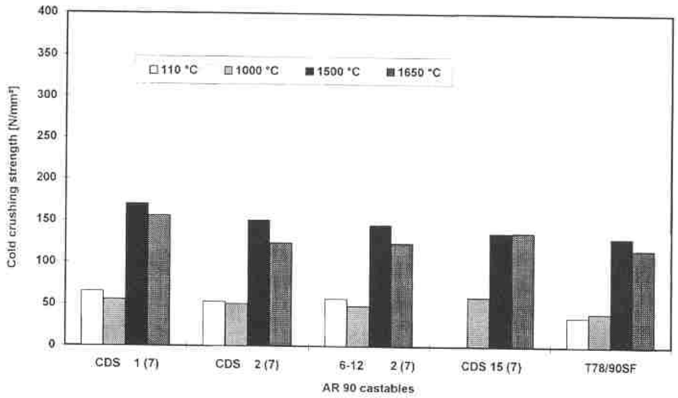

Fig. 4b. Cold crushing strength of the castables based on coarse Spinel AR 90 after drying and firing

The examination of refractoriness under load of test pieces prefired at 1 000 °C gives an indication of changes in the material on first heating to service temperature. The T-60 aggregate start to sinter at about 1 200 °C. After reaching 1 400 °C a more or less secondary expansion takes place which is due to the formation of CA_6. The test castable T-60 CDS 13(12), a Spinel-free mix gives a markably strong secondary expansion. Castable AR 90 CDS 15(7) and T-60 CDS 15(7) containing an in-situ Spinel forming matrix including 0.2 % microsilica develop a pronounced shrinkage at about 1 400 °C.

After prefiring at 1 500 °C both microsilica-free castable types show R.u.L. curves without further reactions. The materials are fully reacted and sintered presenting an excellent refractoriness under load up to 1 700 °C. Especially the castables with AR 90 aggregates show excellent R.u.L. properties.

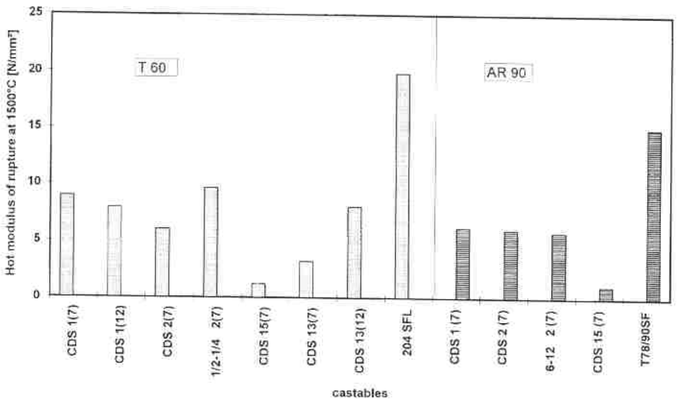

Fig. 5. Hot modulus of rupture at 1 500 °C (prefired at 1 500 °C/5h) of the castables

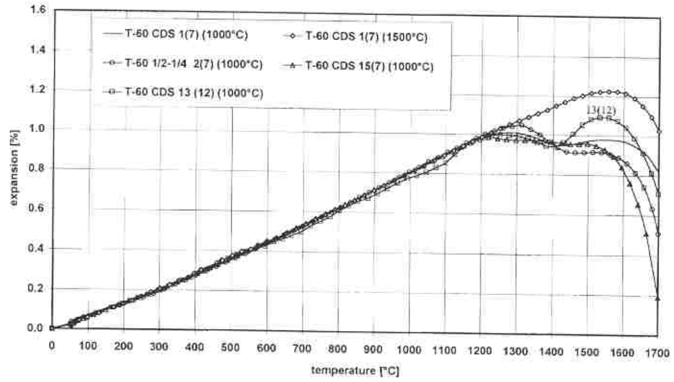

Fig. 6a. Refractoriness under load curves of the coarse Tabular Alumina T-60 based castables ( ):prefiring temperature

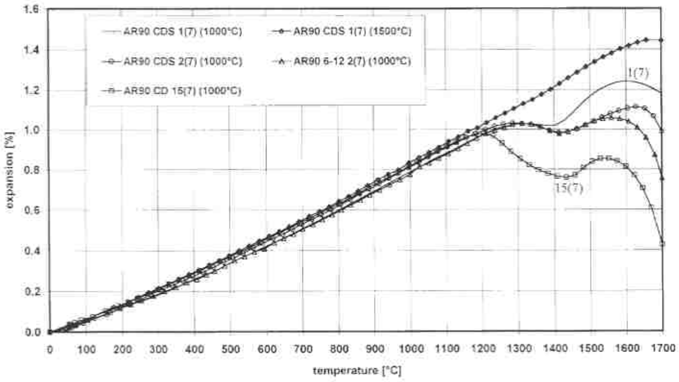

Fig. 6b. Refractoriness under load curves of the coarse Spinel AR 90 based castables ( ):prefiring temperature

3.6 Thermal Shock Resistance

The air quenching method was used to characterize the resistance to thermal shock resistance. The castables were prefired at 1 500 °C for 5 hours to test the behaviour to thermal stresses in the dense sintered stage of the castable. The results shown in **Tab. 4** can only indicate trends in the behaviour of the new castable type against thermal shock. The new concept of a castable composed of a coarse aggregate (> 4.5 mm) and a proper matrix phase (<1mm) obviously enhance resistance to thermal shock. The demand of the refractory user for air quenching cycles >25 can be accomplished. More research is necessary to understand crack propagation and find a better way to characterize the thermal shock behaviour of these castables.

Tab. 4. Thermal shock resistance of selected test specimen according to DIN EN 993-11, air quenching, specimen size 114 mm x 64 mm x 54 mm prefired at 1 500°C/5h

Castable	Cycles
T-60 CDS 1(12) T-60 1/2-1/4 2(7) for comparison: Tabular Alumina castable 204 SFL (conventional)	>25[1] >25[1] 2-4[2]
AR 90 CDS 1(7) AR 90 CDS 2(7) AR 90 6-12 2(7) for comparison: Tabular Alumina Spinel castable 214 SFL conventional	>25[1] >25[1] >25[1] 2-4[2]

[1] crazed appearance

[2] failure by one or two cracks pessing through the specimen

3.7 Corrosion Resistance

Three corrosion tests were run with the different castables in induction furnaces with low iron highly basic slags ($CaO:SiO_2 \approx 6$) at 1 650 °C (Test 1+2:3h, Test 3:2h) (**Tab 5**).
The results of these corrosion tests are as follows:

The first test (**Fig. 7 a** and **b**) demonstrates the outstanding corrosion resistance of different Spinel AR 90 CDS based mixes compared to the conventional self-leveling castable T 78/90SF. Practically no slag infiltration in the aggregate and the matrix phase occurs. Referring to the erosion depth at the slag line the corrosion resistance of the new developed castables is about 2.4 times better than that of the conventional self-flow castable T 78/90SF. The slag used in the test contained 2% CaF_2.

The corrosion test #2 (**Fig. 8**) compares different AR 90 CDS castables (prefired at 1 500 °C) with a MgO-C-brick containing 10 % graphite, used in the slag line of steel ladles. As in test #1, an aggressive high basic slag was used but this time with a high content of CaF_2. The result was that the new castables showed a corrosion resistance close to the tested MgO-C-brick. This result has to be seen in the context that in the recent years a variety of different Tabular Alumina and Spinel castables of conventional

Tab. 5. Corrosion depth (average values) at the slag line after corrosion testing at 1 650 °C

	Corrosion depth [mm]		
Castable resp. brick	test 1 [1]	test 2 [1]	test 3 [2]
AR 90 6-12 mm 2(7)	14	–	–
AR 90 CDS 2(7)	12	–	–
T78/90 SF	34	–	–
AR 90 CDS 1(7)	12	13	9
AR 90 CDS 1(12)	–	16	10
AR 90 CDS 15(7)	–	14	–
MgO-C-brick	–	10	–
AR 90 CDS 13(12)	–	–	18
T-60 CDS 13(12)	–	–	26

[1] 3h/1 650 °C

[2] 2h/1 650 °C

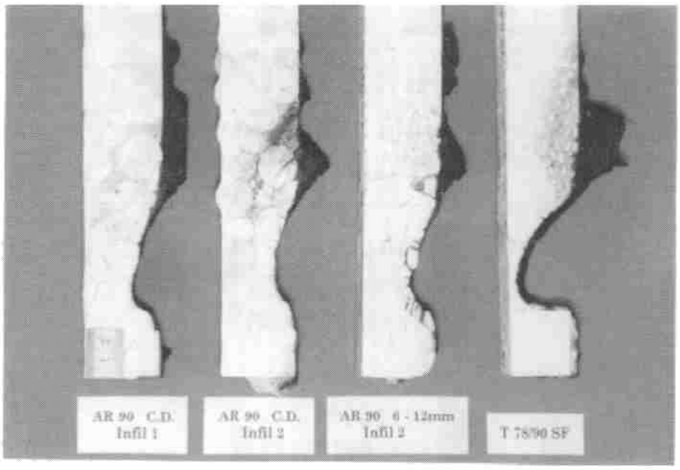

Fig. 7a. Induction furnace corrosion test #1 with a basic slag at 1 650 °C/3h. Different Spinel AR 90 CDS based castables compared to a proved conventional self-leveling Spinel containing castable (T 78/90SF)

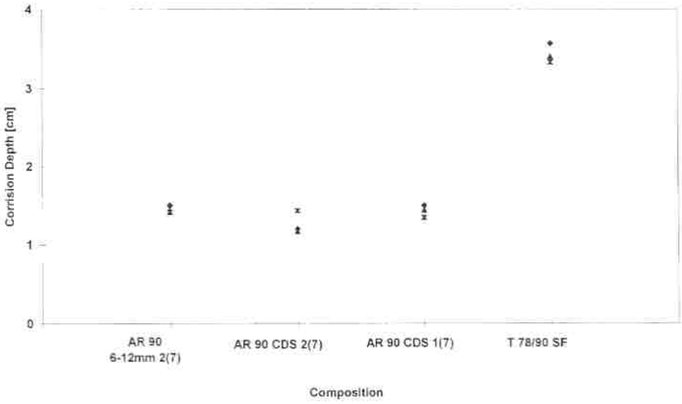

Fig. 7b. Comparison of corrosion depth at the slag line of different Spinel AR 90 CDS castables and the conventional self-leveling Spinel castables T 78/90SF (test#1)

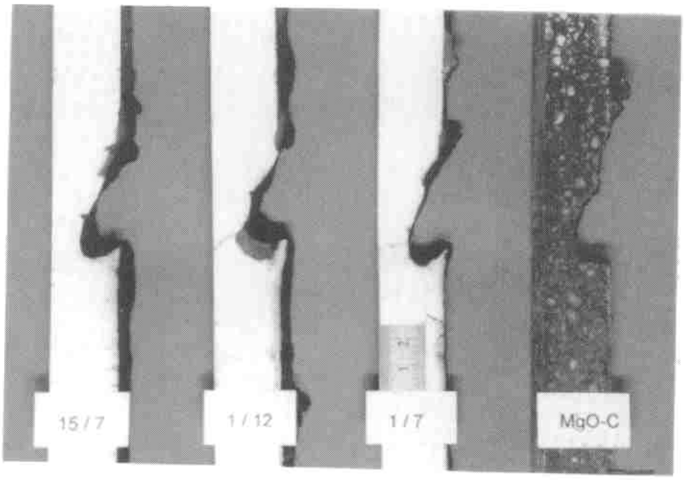

Fig. 8. Induction furnace corrosion test #2 with different Spinel AR 90 CDS castables (prefired at 1 500 °C) and a MgO-C-brick (10 % graphite) with a 10 % CaF_2containing highly basic slag at 1 650 °C/3h.

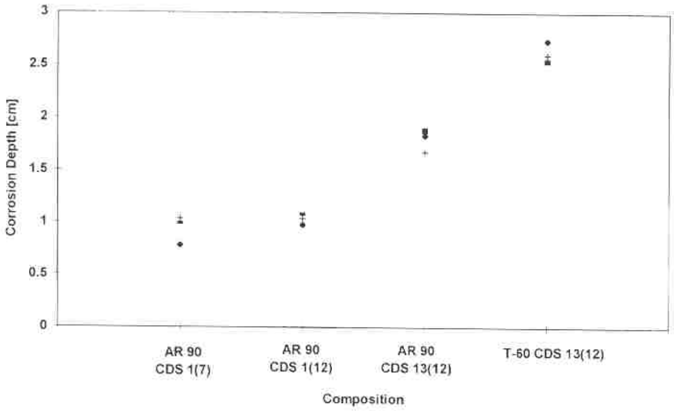

Fig. 9. Induction furnace corrosion test #3 with different new castables (prefired at 1 500 °C) against a CaF_2 free, highly basic slag tested at 1 650 °C/2h

particle sizing with different chemistries and component distributions have been tested against MgO-C-bricks [13]. So far the corrosion performance of these monolithic materials in basic slag environment have not been found close to MgO-C-bricks.

In test #3 (**Fig. 9**) a slag of similar basicity but without CaF_2 was used. The test was run only for 2 h. The castable AR 90 CDS with Spinel in the matrix and in the coarse fraction and with the lowest CaO content showed the lowest corrosion rate (AR 90 CDS 1(7)). A slightly higher corrosion rate (10.3 mm) was seen in the castable with similar coarse and fine fractions but increased CaO content (AR 90 CDS 1(12)). Using Spinel AR 90 only as coarse material and having no Spinel in the fines increases the erosion depth from 10 mm to 18 mm (AR 90 CDS 13(12)). Substitution of Spinel also in the coarse fraction by switching from AR 90 CDS to T-60 CDS, further increases the corrosion rate from 17.9 mm to 26.3 mm (T-60 CDS 13(12)).

Though different induction furnaces and different slags were used, the corrosion results of all 3 slag tests are very consistent (**Tab. 5**). AR 90 as coarse material (>12 mm) with Spinel in the fines and a low CaO content seems to result in the lowest corrosion rate, close to MgO-C-bricks. Increasing the cement content, lowering the size of the coarse Spinel fraction or substituting Spinel by Alumina, clearly increases the corrosion rate. Further corrosion tests with the new castables and MgO-C-bricks and different slags are currently done to certify the outstanding corrosion resistance of the new developed coarse aggregate containing castables.

3.8 Castable dry-out

To investigate the dry-out behaviour of the newly developed coarse grain castables, the following test was carried out: Small cubes (40 mm x 40 mm x 40 mm) were cast with a thermocouple wire ending in the center of the cube. After curing 24 h at room temperature, the cube was suspended in an electrically heated furnace having the end of the wire connected to a balance. The furnace was heated up with 1°C/min. which is normally considered an adequate drying speed for monolithic linings of this thickness. The loss of weight was continuously measured. Samples of the new castables T-60 CDS 15(7) and T-60 CDS 15(7) + 0.5 % aluminum powder were measured in comparison to conventional dense self-flowing castables with a conventional particle sizing. The curves obtained are shown in **Fig. 10**. It can be concluded from these results that the physically bonded water is much easier driven out of the new developed castables containing a high fraction of coarse aggregates. The addition of aluminum powder does further increase the dry-out speed. These results would mean that despite overall similar low open porosity, the new castables can be dried safer, when compared to conventional castables.

4. Conclusion

The results obtained clearly indicate that this new technique for refractory fabrication has several major advantages when compared to conventional castable technologies. In particular improvements in corrosion resistance, thermal shock resistance and speed of drying have been clearly demonstrated. Furthermore the use of lower cost raw materials supports the demand for higher performance Alumina and Alumina Spinel castable refractories at a lower price. This is a direct result of the requirement for lower raw materials processing costs, and a more effective and efficient installation method. The excellent corrosion resistance against basic slags has identified steel ladle linings as an ideal application that can benefit from this new method. Having initiated this promising new technique the challenge now lies with the refractory producer to apply his knowledge and expertise towards the identification and exploitation of potential application opportunities. (F 010)

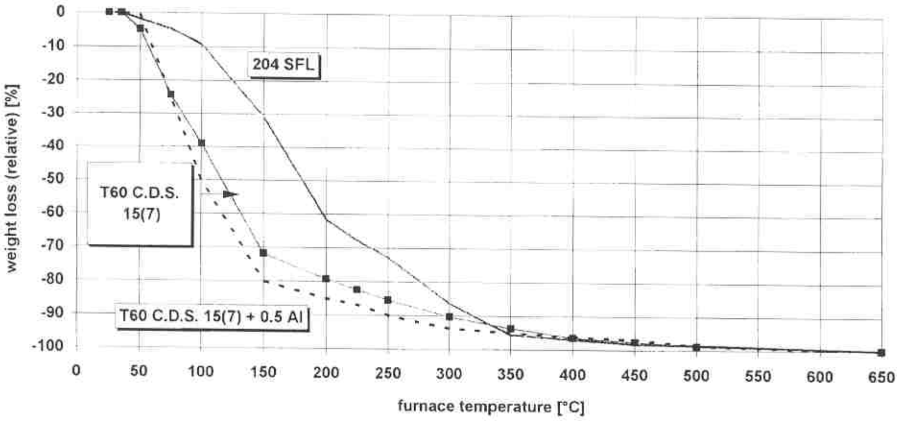

Fig. 10. Dry-out and heating up curves of different castables, heating rate 1°C/min.

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