DATABASE OF REFRACTORIES FOR EXPLOSIVE- AND FIRE-RESISTANT STEEL CASK FOR PACKAGING AND TRANSPORTATION OF RADIOACTIVE AND HAZARDOUS MATERIALS

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SUMMARY

This paper contains the results of mechanical and thermophysical properties investigations of the dense and porous refractory concretes(silicate(building), chamotte(metallurgical), alumina, zirconia(including ceramics)). Porosities of these materials were 20 - 50 %. Compression strength, thermal conductivity, thermal expansion, heat capacity and operation temperature for this refractories are discussed. The split-Hopkinson bar method was used for investigation of the strain rate about 1000 sec-1.
For damage assessment of the severe events connected with overheating of the metal and oxides contents of cask and terroristical attack by means of the anti-tank weapons to cask we discussed resistance of a zirconia ceramics(concrete) to melted mixture Zr, Fe, UO_2, Fe_2O_3 and Monroe jet.
Our results testify that the porous zirconia ceramics can use in the impact limiter system of casks under mechanical, thermal and chemical attacks.

INTRODUCTION

In PATRAM'95 we suggested to using of the porous refractory concretes for designing casks type the steel concrete CASTOR RBMK cask(Mineev and Romanov 1995). Using of the porous concrete(refractory materials - damper) will decrease the heating of the contents from an external source at an interval time and mitigate the blast transmission from internal explosion to the walls of cask. Damper is part of the impact limiter system.
We publish the results of experiment on investigation of the main properties of the refractory materials for the benchmark designing of a special cask and for creation of Database of the main properties of the refractory materials.

REFRACTORY MATERIALS

Silicate concrete(SC), chamotte concrete(CC), alumina concrete(AC), zirconia concrete(ZHC) and zirconia ceramics(ZC-Y2O3 and ZC-CaO) were investigated. Data about properties of the ultralight corundum concrete(UCC) and ceramics from the corundum globular minim cylinder(CCM) are attracted.

AC is mixture of no less 93 wt% electric-melted Al2O3 with high alumina cement.

ZHC is mixture of 80 wt% ZrO2(stabilized 6 -7 mol % of Y2O3) with special cement(70 wt% ZrO2 + 30 wt% BaO · Al2O3) and water(2.9 wt% above 100%).

ZC-Y2O3 is ZrO2(stabilized 10 mol. % of Y2O3) only.

ZC-CaO is ZrO2(stabilized 10 mol. % of CaO) only.

ZHC, ZC-Y2O3 and ZC-CaO contains of the electric-melted ZrO2 grain size 0.05 - 2.0 mm.

CCM contains the globular minim cylinder with diameter 100 mkm.

Information about properties of zirconia concrete and zirconia ceramics was obtained from publications(Fortov et al. 1993 and Akopov et al. 1997). Information about properties of UCC and CCM was obtained from communication(Ivanov 1996).

Properties of silicate and chamotte concretes were obtained from publication(Ivanov and Bakunov 1982). Properties of ceramics ZC-CaO foam(density 2.0 g/cm3) were obtained from publication(Bakunov et al. 1977).

BASE PROPERTIES

Base properties(density, porosity, compression strength limit(at normal conditions) and operation temperature of investigated refractories are plotted in Table 1.

Table 1

Density, porosity, compression strength limit and operation temperature of investigated refractories.

Refractory	Density, g/cm3		Porosity, %		Compression strength limit, MPa		Operation temperature, K	
	Dense	Porous	Dense	Porous	Dense	Porous	Dense	Porous
Silicate concrete	2.3	1.3	25	60	35	7	1000	800
Chamotte concr.	2.1	1.3	20	47-55	30	4.4	1900	1600
Alumina concr.	2.8	1.5	20	50	60	5	2000	1800
Ultralight corundum concrete	-	1.3	-	61-69	-	≥3.5	-	1850
Corundum globular minim cylinder ceramics	-	0.4	-	90-92	-	≥2.5	-	2100
Zirconia concr.	4.4-4.6	-	15-20	-	30	-	2100-2200	-
Zirconia ceramics ZC- Y2O3	4.7-4.9	-	18-23	-	95	-	2900	-
Zirconia ceramics ZC-CaO	4.57-4.62	2.0	17-18	~65	49.2	37	2900	2900

THERMAL CONDUCTIVITY

Experimental results of the some refractories thermal conductivity data are shown in Table 2.

Table 2.

Thermal conductivity of the some refractories(λ, W/mK)

Refractory	Density, g/cm3	Temperature, K							
		300	400	500	600	700	1000	1500	2100
Silicate concrete	2.3	0.3-0.4	-	-	-	-	-	-	-
Chamotte concr.	2.1	0.2-0.3	-	-	-	-	-	-	-
Alumina concr.	2.8	-	-	2.94	2.64	2.40	2.05	2.21	2.50
Ultralight corundum concrete	1.3	-	-	-	0.58	-	0.58	0.64	-
Corundum globular minim cylinder ceramics	0.4	-	0.38	-	0.36	-	0.40	0.53	-
Zirconia concr.	4.4-4.6	-	2.44	1.75	1.68	-	1.57	1.69	-
Zirconia ceramics ZC-Y2O3	4.7-4.9 2.8	- -	- -	- -	- -	3.2 0.33	1.5 -	2.2 0.37	2.45 -
Zirconia ceramics ZC-CaO	4.57-462 2.0	- -	- -	- -	- -	- 0.5	- -	1.7 -	3 -

THERMAL EXPANSION

Experimental results of the some refractories linear thermal expansion data are shown in Table 3.

Table 3.

Linear thermal expansion coefficient of the some refractories(K^{-1})

Refractory	Density, g/cm3	Linear thermal expansion, $\times 10^{-6}, K^{-1}$	Range of temperature, K
Alumina concr.	2.8	8.47	293 - 1800
Ultralight corund. concr.	1.3	7.6	1100 - 1800
Corund. globular minim cylinder cer.	0.4	7.5 8.8	400 - 1200 1200 - 1900
Zirconia concr.	4.4-4.6	11,1	2070 - 290
Zirconia cer. ZC-Y2O3	4.7-4.9	13.0 - 13.5	1300 - 2600
Zirconia cer. ZC-CaO	4.6	14.5 10	2600 - 1300 1300 - 300

HEAT CAPACITY

Experimental results of the some refractories heat capacity data are shown in Table 4.

Table 4.

Heat capacity of the some refractories(c_p, J/kgK)

Refractory	Density, g/cm3	Range of temperature, 293 - K							
		300	400	500	600	700	1000	1500	2100
Silicate concrete	2.3	481	565	649	733	817	1069	-	-
Ultralight corundum concrete	1.3	850	-	-	-	-	-	-	-
Corundum globular minim cylinder ceramics	0.4	-	-	-	-	1130	-	1300	1370
Zirconia ceramics	4.57-4.62	-	-	-	-	-	510	-	540
ZC-CaO	2.0	-	-	-	-	580	-	620	-

STRESS/STRAIN RELATIONS

The split-Hopkinson pressure bar system was used for investigation stress/strain relation for the silicate concrete, alumina concrete, zirconia concrete, and zirconia ceramics ZC-Y2O3. Results of experiment are presented in Fig. 1. Top curves are stress σ/strain ε relations. Ordinates(left): stress in MPa. Abscissal: strain in %. Low curves are strain rate $\dot{\varepsilon}$ /strain ε relations. Ordinates(right): strain rate $\dot{\varepsilon}$ in sec -1. Real curves in Fig. 1 are disposed with displacement of coordinates start.

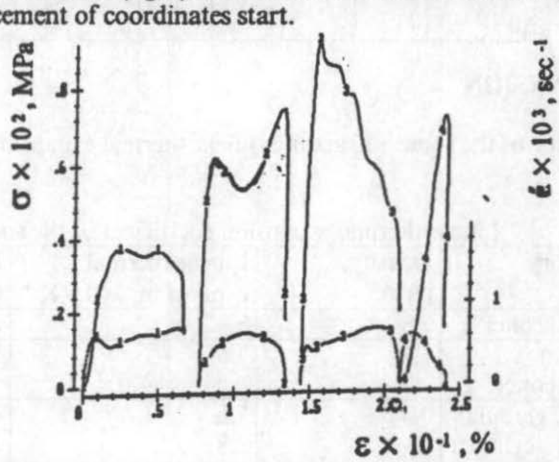

Fig. 1. Stress/strain curves with the same strain rates(without jacket):
1 - building concrete, 2 - zirconia concrete, 3 - alumina concrete, 4 - ZrO2-CaO ceramics.

RESPONSE TO MELTED METALS AND OXIDES

Interaction of the overheating metals and oxides with zirconia concrere, zirconia ceramics ZC-Y_2O_3, and zirconia ceramics ZC-CaO(density 4.57- 4.62 g/cm3) was investigated. Erosion velocities of the concrete and ceramics crucibles were registrated.
Case of ceramics. Composition of core melt(wt%): UO_2 - 57.6, ZrO_2 - 10.9, Zr - 8, stainless steel - 23.5. Time of interaction: 1 - 4 h. Temperature of interaction: 2650 K. Erosion velocity was not observed.
Case of concrete. Composition of core melt(wt%): UO_2 - 50.5 - 60., ZrO_2 - 16 - 25.5, Fe_2O_3 - 15, Cr_2O_3 - 6.4, Ni_2O_3 - 2.6. Time of interaction: 1 - 2 h. Temperature of interaction: 2200 - 2300 K. Erosion velocity was 0.3 - 2.2 mm/min..

RESPONSE TO MONROE JET

Resistant of the dense zirconia ceramics ZC-CaO to cumulative jet was investigated. Results of experiment showed that thickness 65 mm ceramics is equivalent to thickness 28 mm the armour steel. Velocities of the copper jet interacted with the sample ceramics were 4.4(entry) - 2.5(exit) km/sec.

CONCLUSIONS

The above database show the unique properties of the porous zirconia ceramics ZC-CaO: high static and dynamic compression strength limit, high operation temperature, small coefficients of thermal conductivity and heat capacity. Coefficient of the thermal expansion of the ceramics ZC-CaO is equal of the coefficient of the thermal expansion of the ductile cast iron used in the CASTOR RBMK cask.
Ceramics ZC-CaO has not erosion with the overheating metals and oxides of NPP's waste.
Resistant of the ceramics ZC-CaO to Monroe jet is equal resistant of building concrete.
This information make is possible to carry out of the cost-effectiveness essessment for using of the porous ceramics ZC-CaO in the special cask (e.g. CASTOR RBMK cask).

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