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INVESTIGATION INTO THE EXPANSION/CONTRACTION BEHAVIOUR OF COLD RAMMING PASTES DURING BAKING USING A HORIZONTAL DILATOMETER METHOD

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Abstract

The volume stability of the ramming paste used to form the bottom seams and sidewalls of the aluminium reduction cell is critical in the life obtained from the total lining.

The expansion/contraction behaviour during the baking of a range of cold ramming pastes has been examined using a horizontal dilatometer. The influence of anthracite types, whether gas or electrically calcined, the density level of the rammed sample, the binder content and the forming method, whether rammed or pressed, has been examined.

Introduction

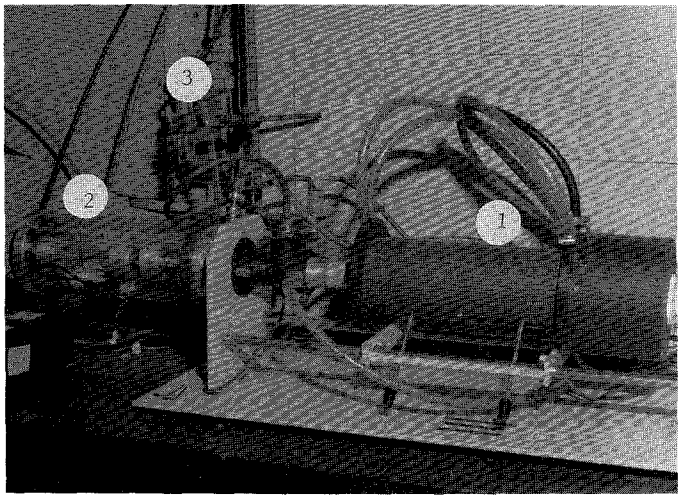
The reduction cell consists of a combination of fired blocks based on anthracite or anthracite/graphite mixtures with the seams between these blocks rammed with a carbon paste. The current work is confined to "cold pastes", that is pastes which require no preheating or mixing prior to use, unless stored at temperatures below 20°C. Installation will be at the normal ambient temperature of the repair bay or cell room which is likely to be 20-40°C depending on the location of the smelter. Whether the ramming paste is installed hot, cold or warm the volume stability as the cell is heated up can be critical to the life of the cell.

The work has consisted of measuring the change in length of samples of different cold ramming pastes when heated under nitrogen in a horizontal dilatometer. The initial measurements were carried out on samples of paste hydraulically pressed and heat treated in a steel mould.

This proved slow to produce a reasonable number of samples, so the method was changed to pressing samples and then heat treating them after extraction from the mould. The pressing method was observed to yield test pieces with a lower green density than the more normal ramming method, so a comparison of the dilatometer behaviour of samples produced by the two different methods was considered. It had also been observed some years ago that the volume change of samples produced by ramming was dependant on the ramming density of the sample and the binder level, so these variations were also introduced into the investigation.

Finally, since three different types of cold ramming paste are produced, two based on electrically calcined anthracite (ECA) and one based on gas calcined anthracite (GCA) the behaviour of these three materials was examined.

Figure 1 General View of Dilatometer



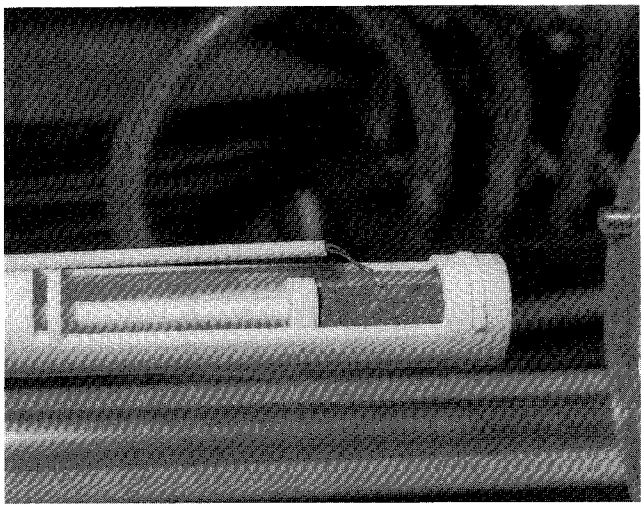
1. Furnace
2. Transducer
3. Gas Train

Equipment

The apparatus is shown in Figure 1 and the sample arrangement in Figure 2. The equipment consists of an alumina tube with an alumina push rod connected to the transducer. A moveable furnace fits over the tube and sample. The furnace has the facility for controlled atmopheres. All the work on ramming pastes has been carried out under nitrogen. The furnace is controlled by an electronic controller which raises the temperatures at 10°C per minute.

The change of length of the specimen is recorded by a data logger onto a disc from which a graph and print out may be obtained.

Figure 2 Sample Arrangement - Dilatometer



Sample Preparation Methods

The samples for the dilatometer were prepared by either ramming or pressing the cold paste.

Ramming Method

Samples were prepared by weighing 180 g of paste into the mould from the American Foundryman's Association (AFA) rammer and giving the specimen 50 blows to each end. The density was calculated and this represented the ultimate bulk density or UBD. Specimens were then produced to 97.5% and 95% of this value by taking a smaller weight and producing test pieces of approximately the same length by giving a reduced number of blows.

Pressing Method

A mould of 70 mm diameter was used. Rammix was placed in the mould and pressed at 12.2 N/mm^2. The total sample was 450 g, but it was found that it was necessary to add this to the mould in by four 112.5 g amounts pressing and scratching the surface with a pointed implement after each addition to avoid lamination.

Heat Treatment

After some experimentation, a procedure of placing the samples, either AFA or pressed in to the cold oven, setting the temperature at 220°C and switching on and leaving to stove overnight for 18 hours.

After cooling, the samples were hard enough to core drill samples 12 mm diameter from which two 25 mm long cores could be obtained. This gave a maximum of six samples from the AFA test pieces and eight from the pressed pieces.

The samples were ground on the ends to ensure they were parallel and perpendicular to the length of the sample. These samples were used for the dilatometer measurements.

Dilatometer Determination

The samples were placed in the dilatometer and the system closed and nitrogen gas passed through the system. The furnaces was then ramped at 10°C per minute to 1100°C.

Experimental Method

Three different materials were used, two based on ECA, referred to A and B and one based on GCA, coded material C.

In each case it was decided to look at four levels of binder content. This is because whilst the materials are made to a consistency considered suitable for ramming, this level of binder is obviously based on a subjective assessment. Thus all three materials were produced to binder levels 1, 2, 3 and 4 - where one was the lowest and four was the highest.

As discussed under sample preparation, from each material and binder level, one sample was prepared by pressing and three by ramming, one at each level of density. In addition, samples were also produced by ramming to measure the volume change on firing to 1000°C in coke, dust and cold crushing strength for comparison with normal quality control results which are carried out by this method.

Results

The graph of length change against temperature produces a characteristic shape shown schematically in figure 3. There is an approximately linear increase with rising temperature to a maximum, normally between 300 and 400°C. This is followed by a shrinkage to a minimum at around 900°C. The values of

Figure 3 Schematic Curve of Dilatometer Results

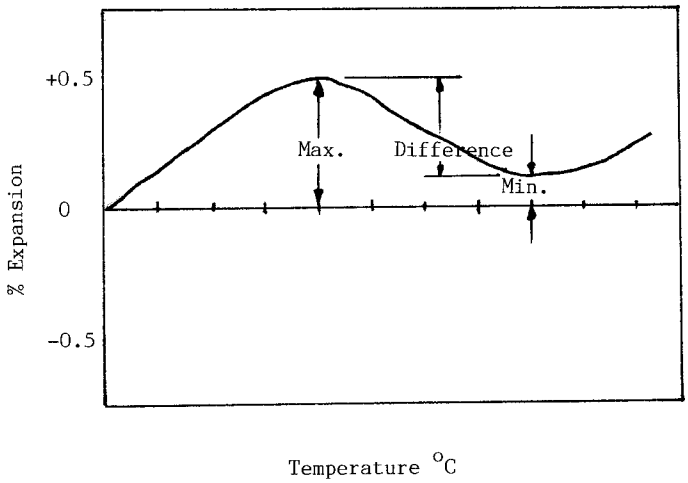


Figure 4 Carbon Rammix Type A
Prepared by Pressing

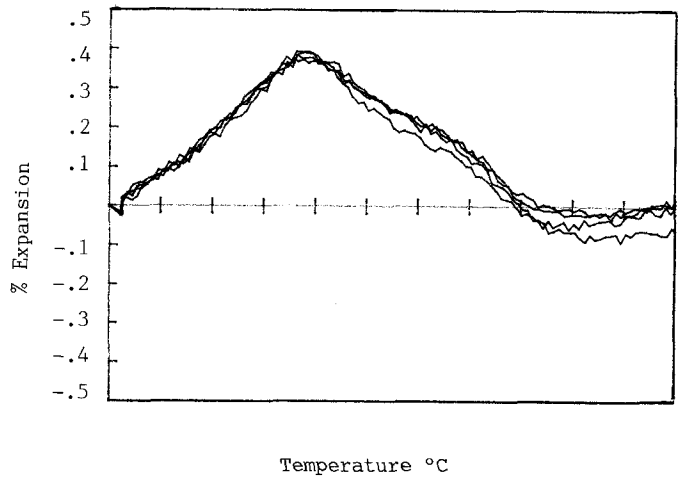


Figure 5 Carbon Rammix Type A
Prepared by Ramming

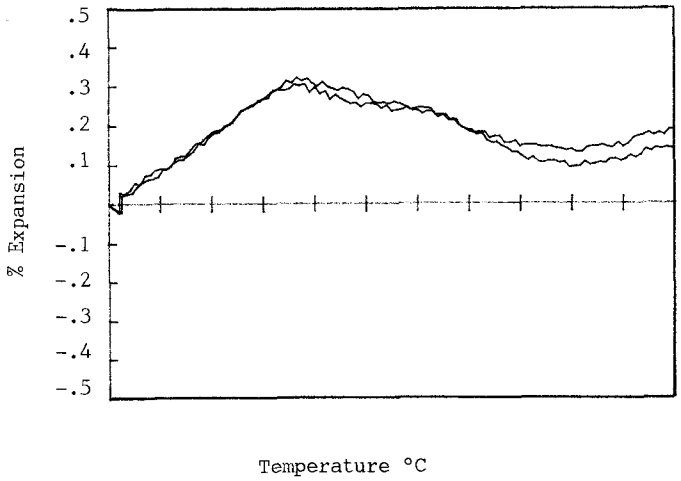


Figure 6 Carbon Rammix Type C
Prepared by Pressing

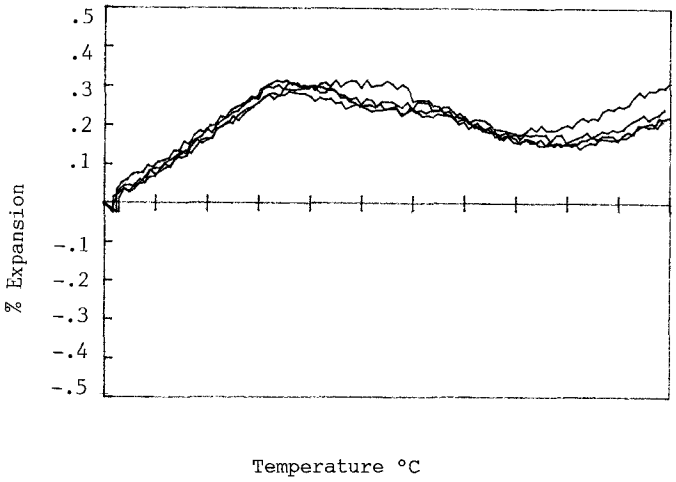
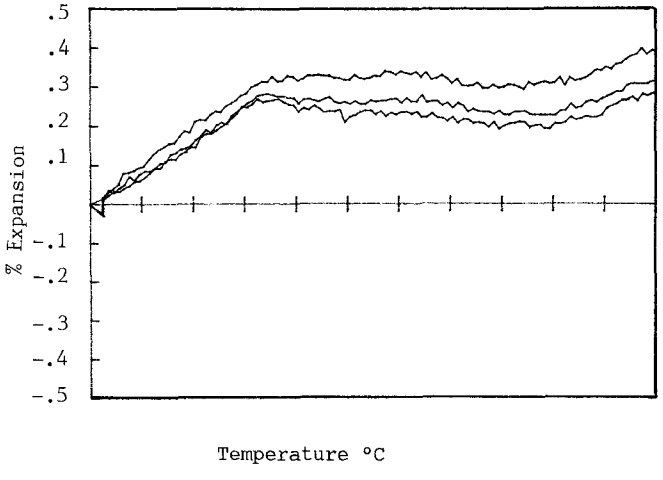


Figure 7 Carbon Rammix Type C
Prepared by Ramming



these maxima and minima have been noted as has the difference between them. This difference parameter is considered important because after approximately 400°C, the ramming paste is rigid and any decrease in length, unless counteracted by the thermal expansion of the other elements of the cell, could conceivably cause cracks to appear in the rammed parts of the lining. This difference parameter therefore is arguably very important in predicting the likely performance of a cold ramming paste in the aluminium cell.

As detailed in the sample preparation section above, multiple determinations of each sample have been carried out; normally a minimum of four cores have been measured and typical examples of the agreement between these duplicates are shown in Figure 4 Rammix A pressed samples, 5 Rammix A rammed samples, 6 Rammix C pressed samples and 7 Rammix C rammed samples.

The maximum and minimum linear expansions and the difference between have been obtained from the data and are shown in Table 1 for Rammix A, Table II for Rammix B and Table III for Rammix C. Also in Tables 1 to III are the green density of all the samples and the fired density for the rammed pieces. On the rammed samples the normal test parameters of volume shrinkage after heating to 1000°C and cold crushing strength were measured and are also presented.

The "difference" parameter has been averaged to compare the three different materials and the influence of the variables used and this average data is presented in Table IV.

Discussion of Results

Rammix A - ECA Based

The difference parameter is greater on samples extracted from pressed test pieces

Table I Results on Test Pieces from ECA Based Rammix A

PROPERTY		BINDER LEVEL	PRESSED SAMPLES	RAMMED SAMPLES		
				100% UBD	97.5% UBD	95% UBD
Green Bulk Density	g/cm^3		1.602	1.640	1.590	1.535
Maximum Expansion	%		0.368	0.344	0.288	0.322
Minimum Expansion	%	1	-0.042	0.068	0.037	0.054
Difference	%		0.410	0.267	0.251	0.268
Volume Change Fired to 1000°C	%			+0.07	-0.75	-1.07
Cold Crushing Strength	MN/m^2			35.5	32.3	25.1
Green Bulk Density	g/cm^3		1.592	1.645	1.605	1.555
Maximum Expansion	%		0.382	0.323	0.314	0.295
Minimum Expansion	%	2	0.075	-0.024	0.112	0.056
Difference	%		0.306	0.347	0.202	0.239
Volume Change Fired to 1000°C	%			-0.13	-0.13	-0.58
Cold Crushing Strength	MN/m^2			31.2	26.1	23.4
Green Bulk Density	g/cm^3		1.593	1.660	1.625	1.570
Maximum Expansion	%		0.386	0.337	0.307	0.338
Minimum Expansion	%	3	-0.051	-0.019	0.043	0.091
Difference	%		0.437	0.356	0.264	0.247
Volume Change Fired to 1000°C	%			+0.53	+0.33	-0.30
Cold Crushing Strength	MN/m^2			28.2	27.6	23.8
Green Bulk Density	g/cm^3		1.601	1.675	1.635	1.580
Maximum Expansion	%		0.385	0.332	0.342	0.333
Minimum Expansion	%	4	-0.023	-0.009	0.062	0.058
Difference	%		0.409	0.340	0.281	0.275
Volume Change Fired to 1000°C	%			+0.89	+0.20	-0.82
Cold Crushing Strength	MN/m^2			29.9	31.4	31.8

Table II Results on Test Pieces from ECA Based Rammix B

PROPERTY		BINDER LEVEL	PRESSED SAMPLES	RAMMED SAMPLES		
				100% UBD	97.5% UBD	95% UBD
Green Bulk Density	g/cm^3		1.590	1.620	1.590	1.540
Maximum Expansion	%		0.408	0.351	0.383	0.369
Minimum Expansion	%	1	-0.057	0.182	0.142	0.247
Difference	%		0.465	0.169	0.227	0.122
Volume Change Fired to 1000°C	%			-0.82	-1.65	-1.24
Cold Crushing Strength	MN/m^2			30.8	31.5	25.7
Green Bulk Density	g/cm^3		1.595	1.625	1.580	1.545
Maximum Expansion	%		0.412	0.349	0.349	0.339
Minimum Expansion	%	2	-0.039	0.073	0.125	0.182
Difference	%		0.452	0.276	0.224	0.157
Volume Change Fired to 1000°C	%			-0.94	-1.55	-1.75
Cold Crushing Strength	MN/m^2			30.2	33.5	25.5
Green Bulk Density	g/cm^3		1.600	1.630	1.595	1.540
Maximum Expansion	%		0.403	0.350	0.368	0.357
Minimum Expansion	%	3	-0.19	0.081	0.084	0.093
Difference	%		0.593	0.269	0.284	0.264
Volume Change Fired to 1000°C	%			-1.12	-1.23	-1.49
Cold Crushing Strength	MN/m^2			34.8	33.2	27.5
Green Bulk Density	g/cm^3		1.605	1.625	1.590	1.545
Maximum Expansion	%		0.395	0.376	0.344	0.353
Minimum Expansion	%	4	-0.161	0.216	0.066	0.237
Difference	%		0.556	0.160	0.278	0.120
Volume Change Fired to 1000°C	%			-1.13	-1.11	-1.20
Cold Crushing Strength	MN/m^2			32.0	30.7	27.8

Table III Results on Test Pieces from GCA Based Rammix C

PROPERTY		BINDER LEVEL	PRESSED SAMPLES	RAMMED SAMPLES		
				100% UBD	97.5% UBD	95% UBD
Green Bulk Density	g/cm^3		1.538	1.635	1.580	1.530
Maximum Expansion	%		0.300	0.280	0.261	0.277
Minimum Expansion	%	1	0.130	0.144	0.167	0.230
Difference	%		0.170	0.135	0.094	0.047
Volume Change Fired to 1000°C	%			-0.22	-0.55	-0.38
Cold Crushing Strength	MN/m^2			68.9	60.8	46.5
Green Bulk Density	g/cm^3		1.552	1.625	1.580	1.535
Maximum Expansion	%		0.288	0.314	0.340	0.283
Minimum Expansion	%	2	0.129	-0.002	0.232	0.229
Difference	%		0.159	0.316	0.108	0.054
Volume Change Fired to 1000°C	%			+0.14	-0.52	-0.16
Cold Crushing Strength	MN/m^2			69.4	63.2	46.8
Green Bulk Density	g/cm^3		1.529	1.580	1.555	1.505
Maximum Expansion	%		0.307	0.297	0.298	
Minimum Expansion	%	3	0.156	0.168	0.239	
Difference	%		0.151	0.129	0.059	
Volume Change Fired to 1000°C	%			-0.87	-1.19	-1.13
Cold Crushing Strength	MN/m^2			59.9	53.5	39.3
Green Bulk Density	g/cm^3		1.541	1.610	1.570	1.520
Maximum Expansion	%		0.271	0.280	0.294	0.288
Minimum Expansion	%	4	0.088	0.083	0.218	0.195
Difference	%		0.182	0.196	0.077	0.093
Volume Change Fired to 1000°C	%			-0.80	-1.67	-1.67
Cold Crushing Strength	MN/m^2			72.6	68.5	50.9

Table IV Summary of "Difference Parameters" with Rammix Type, Sample Preparation Method, Binder Level and Density Level

	RAMMIX		
	A	B	C
Sample Preparation			
Pressed	0.39	0.52	0.16
Rammed	0.28	0.21	0.11
Binder Level (Rammed Samples)			
1	0.26	0.17	0.09
2	0.26	0.22	0.11
3	0.29	0.27	0.09
4	0.30	0.19	0.12
Density Level (Rammed Samples)			
100%	0.33	0.22	0.15
97.5%	0.25	0.25	0.10
95%	0.26	0.17	0.07

than on those from rammed. The average figures being 0.39% as against 0.28%. Looking at the influence of binder content, it may be seen from Table IV that there is an association between the level of binder and the value for the difference parameter, the higher the binder the greater the difference. Likewise, on the rammed samples, the highest density sample also has the largest difference figure.

Rammix B - ECA Based

The results show a similar pattern to Rammix A, the pressed samples show a higher difference figure than the rammed samples. Here the difference is larger than on Rammix A. The association with binder content and density level is less strong on Rammix B. There is an increase in the difference figure up to binder level 3 but at the highest level the figure falls, and there is no association between density level and difference.

Rammix C - GCA Based

The results follow a similar form, but are much lower for the GCA based material. The pressed samples are still exhibiting a higher difference than the rammed samples but the absolute values are about a half of those for the ECA materials. Again there is some association between binder content and rammed density and the values for the differences. The highest binder content showing the highest difference and the highest density likewise the highest difference figures.

General Observations

The method used to prepare the samples is very important in terms of the value found for the difference parameter. In all cases, the pressed samples undergo a higher contraction between the maximum and minimum on the dilatometer curve. This difference is

greatest with Rammix B based on ECA being some two and a half times larger for pressed than rammed samples.

In percentage difference Rammixes A and C are similar, but because of the much lower overall figures for Rammix C this shows the lowest variation with forming method.

Although not present in all cases, there seems to be some general associations between the difference figure and binder content and density level. The higher binder content samples showing the highest differences and the highest density levels also giving the highest difference figures.

It may pay to consider what can be learned from the observed values of the difference parameter. If it is accepted that the decrease in length of the rammix is important in terms of pot performance, what conclusions can be drawn from the data.

The GCA based material has the lowest difference values, but has the disadvantages of being less resistant to sodium attack and much stronger than the ECA based products. The GCA based product could be useful where large amounts of ramming are present. The ECA product has a larger difference figure but will be more resistant to alkali attack and is weaker having a fired crushing strength similar to cathode blocks.

The variations of the difference parameter with sample forming method raises questions about the different installation techniques used for cold ramming pastes. There are two fundamentally different techniques in use, a "rolling" technique in which the rammix is compressed by a wheel and pneumatic ramming, either manual or automatic. Observations carried out on trial ramming experiments in the laboratory suggests that manual pneumatic ramming gives an installed density equivalent to 97½% UBD. It would be interesting to extract samples from rammed and rolled cells to determine the influence of installation method on the dilatometer result.

Conclusion

Whilst there are still some problems in deciding which properties are important in selecting a rammix for a parameter design of cell, the dilatometer offers a means of gaining valuable insights into the behaviour of the materials service conditions.

Acknowledgement

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