

ALUMINUM

New Methods for Testing Raw Materials for Anode Carbon Paste

O. BOWITZ, T. EFTESTOL, and R. A. SELVIK

Elektrokemisk A/S, Kristiansand, Norway

Abstract

Two methods are described for selecting raw materials that will impart to the Soderberg anode paste favorable flow properties as well as low dusting tendency. The correlation between these methods and more scientific methods is discussed, with emphasis on the importance of the interaction of binder and dry aggregate in the anode.

INTRODUCTION

Judging from the many test methods used to characterize raw materials for Soderberg anode paste and binders, no method has been provided so far which effectively characterizes the desired properties of binder or aggregate coke.

Generally, the binder or dry aggregate coke are tested separately. However, in the mixer and in the cell line, the binder and the dry aggregate coke form a typical two-component system. There is strong evidence for mutual interaction between the two components. Therefore, a property of the binder when tested separately may be different from that of the mixture of binder with coke.

The carbon industry still lacks an adequate knowledge of the physical nature of the binder. Very few, if any, correlations exist between scientific methods and the behavior of the paste in the cell. Therefore, test methods should be applied to actual mixtures of binder and dry aggregate coke. These test methods should also be relevant to the requirements of the Soderberg anode paste.

Of the two types of Soderberg anode systems now in use in the aluminum industry, the vertical-contact spike (V.S.) anode and the horizontal-contact spike (H.S.) anode, the former is no doubt the most affected by the quality of the raw materials. It should also be noted that larger anodes generally are more affected than small ones.

The requirements for Soderberg V.S. anode paste may be summarized as follows.^{1,2}

1. The flowability should ensure an even distribution of the paste on the anode top. The flowability should be temperature insensitive, i.e., it should be as closely as possible the same around the spikes and at the anode casing. A temperature-sensitive paste may freeze to the cold parts of the casing, and eventually form a carbonized layer, fixed to the anode casing, preventing the paste from descending smoothly into the cell. This may cause serious horizontal cracks, or holes, to form in the anode. Serious outflow of paste through the spike holes, or underneath the casing, may occur if the flowability of the paste is too temperature sensitive.

2. During baking in the anode, little shrinkage of the paste should occur. Much shrinkage will seriously increase the formation of vertical cracks around the spikes.

3. The paste should result in a dense, baked anode carbon with a low reactivity. It is preferred that the difference in specific reactivity between the binder coke and the dry aggregate coke should be as small as possible. The larger the difference, the larger the tendency of the anode to dust.

4. The anode should have (a) a low electrical resistivity, to reduce the voltage drop, and (b) a low ash content, to reduce the reactivity of the paste and the contamination of the metal.

In the following section, new methods relevant to these requirements are suggested, and the correlation with scientific and technological methods is discussed.

FLOW PROPERTIES OF BINDERS AND MIXTURES OF BINDERS AND MILLED COKE PRODUCT (FINES COMPONENT OF AGGREGATE)

Rheological Considerations

Binders

The rheological properties of coal-tar pitch binders themselves are Newtonian. The temperature susceptibility of the viscosity is defined by the logarithmic temperature coefficient,

$$n = \frac{\log \eta_2 - \log \eta_1}{\log T_1 - \log T_2}$$

where η_2 and η_1 are the viscosities (in poises) at the temperatures T_2 and T_1 (in °C) respectively. The temperature susceptibility increases

ANODE CARBON

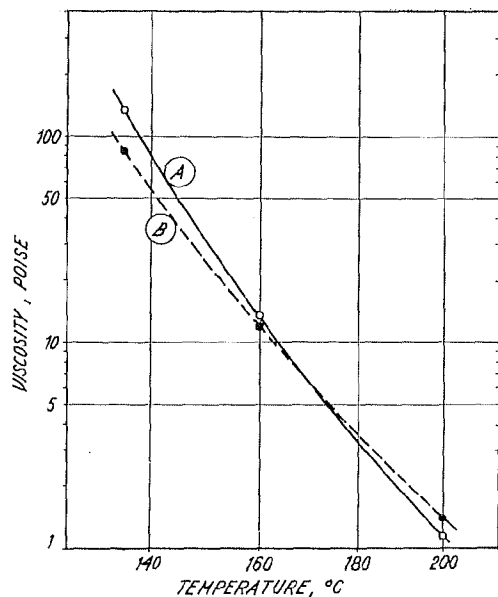


Fig. 1. Viscosity/temperature curves for coal-tar pitch binders A and B.

with increasing softening point, but for all normal tar pitches falls within a narrow band.³

In Figure 1 the viscosity/temperature curves are given for two selected binders, A and B. The corresponding logarithmic temperature coefficients are 12.3 for binder A and 10.7 for binder B in the 140–180°C temperature region. These two temperatures are chosen partly because the temperature in the mixer and the upper anode layer may vary within these limits, and partly due to experimental convenience during the measurements.

The two binders, both used industrially, behave very differently in the anode. With binder A, the flowability of the paste is very temperature sensitive; the paste appears to be stiff on the anode top and freezes to the anode casing. At higher temperatures it becomes very liquid, and may cause serious explosions when running through the cracks and holes into the bath. With binder B, the flowability is nearly constant over a wide temperature interval. No flow problems in the cell line have ever resulted from use of this binder. In view of this large difference in flow behavior in the cell, the rather small difference in flow behavior in the viscometer is astonishing.

ALUMINUM

Mixtures of Binders and Milled Coke Product

In the paste, over 85% of the available surface of the dry aggregate coke is concentrated in the milled product fraction. The properties of binder/milled product system therefore to a large extent dominate the behavior of the whole paste. In the paste, the volume concentration of

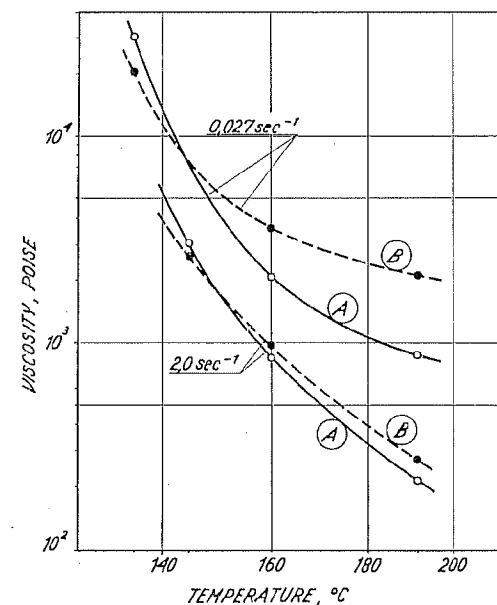


Fig. 2. Viscosity/temperature curves at different rates of shear for binder/milled product mixtures with binders A and B.

the dry aggregate coke is about 55%. A large part of this is coarse and medium fractions, and it may be estimated that a mixture of binder and milled product of about 40% by volume milled product or a 50/50 by weight binder/milled product ratio reasonably represents the conditions in an actual paste.

The flow behavior of this mixture depends on the shearing rate and on the mutual interaction between the binder and milled product. Generally, the binder/milled product mixtures are thixotropic. At temperatures of about 140°C, they are plastic, with a small, but significant, yield value. At higher temperatures, depending on the melting point of the binder, they are pseudoplastic.

ANODE CARBON

Effect of Shearing Rate. Being thixotropic mixtures, the viscosities are shear dependent. This also holds for the viscosity/temperature curves. In Figure 2 the viscosity/temperature curves for 50/50 by weight mixtures with the binders A and B are given at 0.027 and 2 sec⁻¹ rates of shear, respectively. Table I gives the corresponding logarithmic temperature coefficients in the 140–180°C temperature interval, at 0.027, 0.1, and 2 sec⁻¹ rates of shear, respectively.

As indicated by the curves and the table, the logarithmic temperature coefficient increases with increasing rate of shear, the increase however is more pronounced in the mixture with binder B than with binder A.

TABLE I
Logarithmic Temperature Coefficients for Two 50/50 by Weight Binder/Milled Product Mixtures at Different Rates of Shear

	Shear rate, sec ⁻¹		
	0.027	0.1	2
Binder A in mixture	10.5	11.2	11.2
Binder B in mixture	5.9	7.9	9.5

Yield Value. The yield values given in Table II are measured by giving the bob in the viscometer successively higher momenta, and observing if the system starts to flow. The highest value observed without flow is then taken as the yield value. These values correspond very well to the values obtained by extrapolating the consistency curves to zero rate of shear.

TABLE II
Yield Values in dyne/cm² for Binder/Milled Product Mixtures

	135°C	160°C	200°C
Binder A in mixture	715	7	0
Binder B in mixture	119	10	0

As indicated in Table II, the yield value decreases with increasing temperature, and it is considerably higher in the mixture with binder A than with binder B at 135°C. As already shown, this mixture also has the highest logarithmic temperature coefficient.

Effect of Binder. Table III gives the routine analyses for the two binders A and B.

ALUMINUM

TABLE III
Analyses of Binders A and B

	A	B
Softening point, °C, R and B	100	90
Coking value, % ^a	63	60
Toluene insoluble, %	27	35
Quinoline insoluble, %	6	10
Density, g/cm ³	1.300	1.315

^a Revised Elektrokemisk method.

As already shown in Figure 1, these two binders, when measured separately, revealed only slight differences in rheological behavior. When measured in a binder/milled product mixture at low rate of shear, the flow behavior corresponded very well to the flow behavior in the cell line.

No attempt has been made to correlate the properties of these two, or other industrially used binders, with the rheological behavior of the mixtures. A correlation between the aromaticity of the binder and the temperature susceptibility of the viscosity may, however, be very

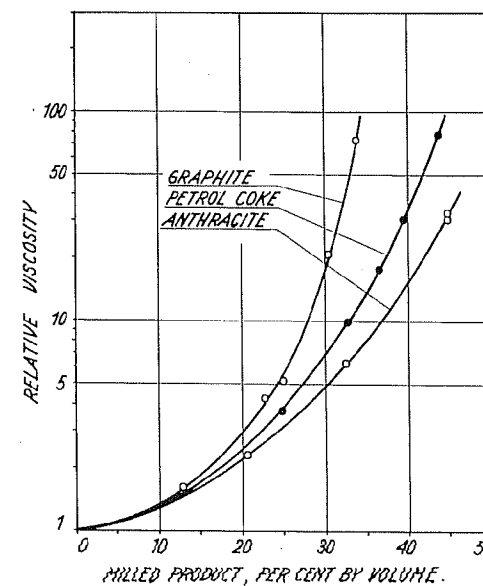


Fig. 3. Relative viscosity of binder/milled product mixtures with graphite, petroleum coke, and anthracite as a function of volume concentration of the milled product.

ANODE CARBON

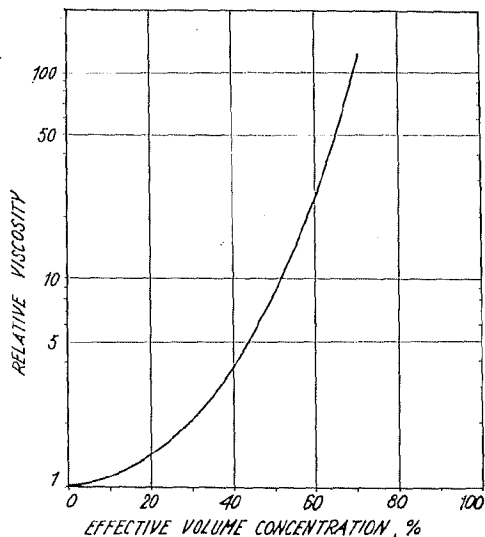


Fig. 4. Relative viscosity of binder/milled product mixtures with graphite, petroleum coke, and anthracite as a function of effective volume concentration of the milled product.

reasonable. The per cent quinoline insoluble, acting as a filler, may also affect the flow behavior of the mixture.

Effect of Dry Aggregate Coke. The effect of different dry aggregate cokes on the rheological behavior of the mixtures is revealed in Figure 3 where the relative viscosity $\eta_{rel} = \eta_{mixture}/\eta_{binder}$ for mixtures with graphite, anthracite, and petroleum coke is plotted as a function of the per cent volume concentration of the dry aggregate coke. In Figure 4 η_{rel} is plotted as a function of the per cent effective volume concentration of the milled product.⁴ The effective volume concentration of the milled product is defined as the ratio of the actual volume concentration of the milled product to the volume concentration at maximum density of the mixture, i.e., where the binder amount is just sufficient to fill all pores and voids in the milled product.

The fact that the mixtures with graphite, anthracite, and petroleum coke have different relative viscosities at the same per cent volume concentration, but the same relative viscosity at the same effective volume concentration strongly indicates that the viscosity of the mixture is influenced by the porosity or shape and the degree of packing of particles in the mixture.

ALUMINUM

Interaction of Binder and Milled Product. The mutual interaction between binder and milled product at the two different rates of shear may be visualized in Figure 5 where the $\eta_{rel} = \eta_{mixture}/\eta_{binder}$ is plotted as a function of temperature.

In the mixtures, the following effects most likely take place during the rheological measurements:⁴ (1) orientation of the anisodimensional particles under the shearing, (2) disorientation due to the Brownian

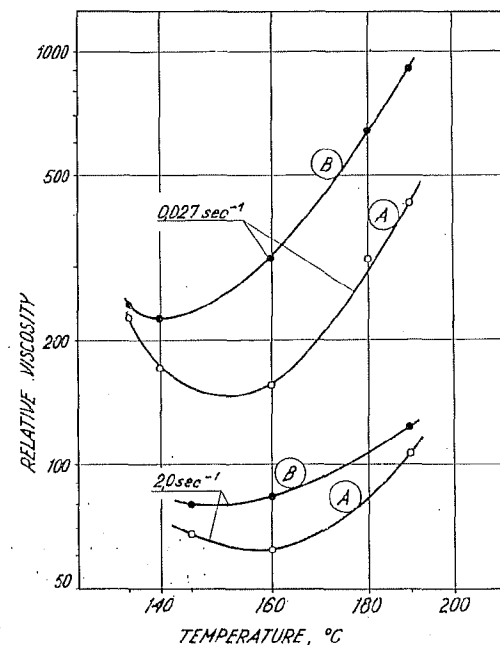


Fig. 5. Relative viscosity/temperature curves of binder/milled product mixtures at different rates of shear.

movement, and (3) breaking up and reforming of an ordered type of structure.

At the lowest rate of shear, the change in η_{rel} is most likely due to a mechanism involving a dynamic equilibrium between the orientation of the particles under the shearing in the viscometer and the disorientation by the Brownian movement; above 150°C the effect of raising the temperature would be to shift the equilibrium further toward the disoriented state, and thus increase the particle interference and hence η_{rel} . At higher rates of shear, the orientation effect is strong and more in equilib-

ANODE CARBON

rium with the disorientation effect by the Brownian movement, and the η_{rel} is consequently more independent of the temperature.

The hysteresis curves (thixotropy) indicate further that the ordered structure which is broken down by the shearing (at a given temperature) cannot reform immediately. The existence of a yield value also points to a definite structure, having a sufficient rigidity to withstand flow below some critical stress. According to Green,⁶ a yield value is strongly connected with flocculation or poor wetting of the dry material by the liquid.

Experimental

The rheological measurements concerning the temperature susceptibility of the mixtures have been carried out in a Roto-Visco, a rotational viscometer from Gebrüder Haake, Berlin. In the viscosity calculations of the pseudoplastic materials, the total stress, not the excess stress over the yield value, has been used. In the actual paste, or binder/milled product mixture, the flowability is a function of a yield value term and a viscosity term. By using the total stress these two terms are combined to a single value which is most effectively correlated with the flow behavior of the mixtures.

The effect of the different dry aggregate cokes on the rheological behavior of the system has been investigated in a modified Stormer viscometer.

Flowability of Binder/Milled Product Mixtures

As indicated by the rheological measurements, the differences between the binders are primarily revealed in the mixtures at the lowest rates of shear. This calls for very expensive apparatus and trained rheologists.

When testing the temperature susceptibility of a binder to be used in the paste plant, instead of making a paste with full granulometric composition of the dry aggregate, the easiest and most reproducible method is to make a binder/milled product mixture and make an elongation or flowability test on this mixture.

Description of the Flowability Test

The liquid binder is mixed in a 50/50 by weight ratio with calcined petroleum coke milled to a standard fineness, say 80% -200 mesh U.S. sieve series at 160°C for 20 min, molded directly from the mixer into test cylinders (9 mm diam, 35 mm long) and placed on a sloping

ALUMINUM

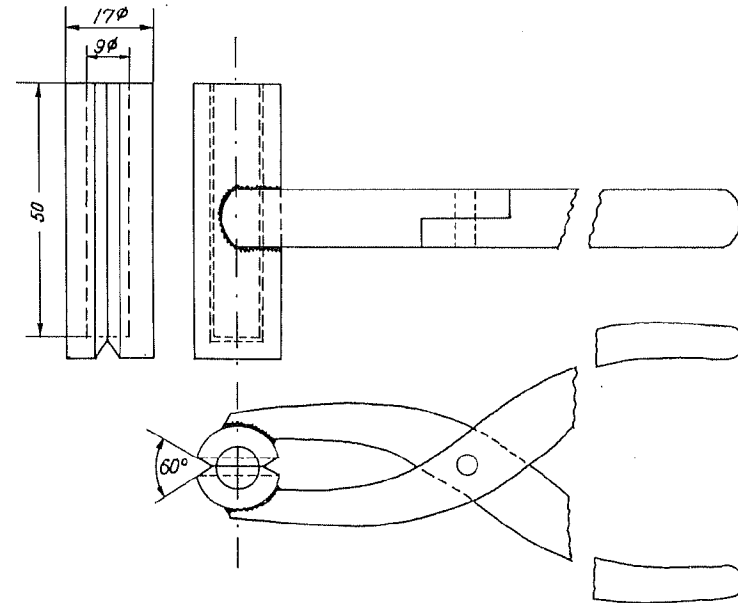


Fig. 6. Molding device for test cylinders for flowability test.

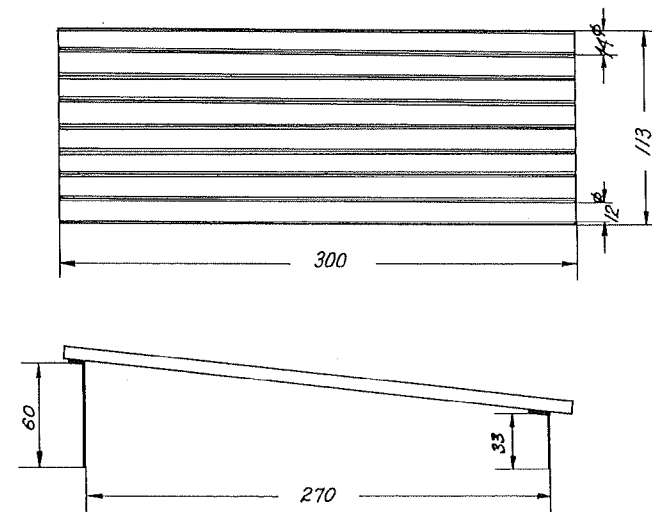


Fig. 7. Sloping board for flowability test.

ANODE CARBON

board provided with grooves for the test cylinders. After inserting the sloping board in a thermostat-regulated oven at the appropriate temperatures (140 and 180°C, respectively) for 60 min, the flowability of the test cylinder is reported as the per cent increase in elongation over the original length of the cylinder.

Figures 6 and 7 are drawings of the molding device and the sloping board.

Flowability and Viscosity

The flowability/temperature curves for binder/milled product mixtures with the binders *A* and *B* are given in Figure 8. The mixtures are identical with those already tested in the viscometer. The logarithmic temperature coefficients of the flowability in the 140–180°C interval are given in Table IV.

During these measurements the mixtures are subjected to very low rates of shear. The results agree very well with the results from the

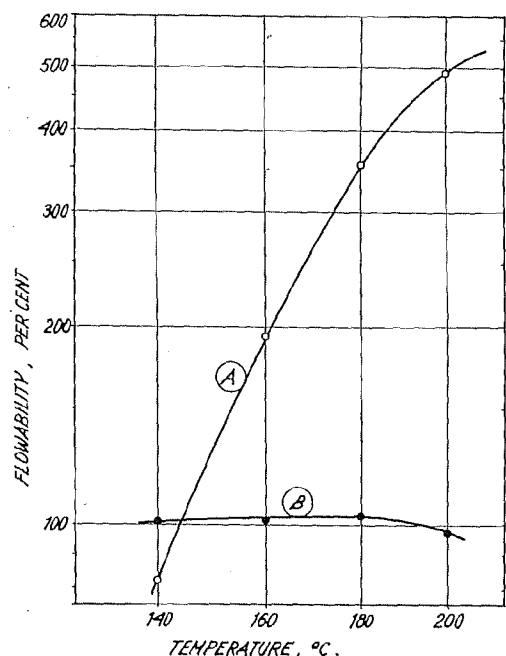


Fig. 8. Flowability/temperature curves for binder/milled product mixtures with binders *A* and *B*.

ALUMINUM

TABLE IV
Logarithmic Temperature Coefficients of Flowability

	Log temp. coeff.
Binder <i>A</i> in mixture	5.8
Binder <i>B</i> in mixture	0.1
Binder <i>A</i> separately	4.3
Binder <i>B</i> separately	3.9

rheological measurements carried out at the lowest rates of shear. In full accordance with the rheological measurements, the flowability test also revealed no significant difference between the two binders when tested separately without the addition of milled product.

Flowability and Binder Properties

Generally, the logarithmic temperature coefficient of flowability of the mixture decreases with increasing amounts of quinoline or anthracene insolubles, and increases with increasing softening point of the binder. It also decreases with increasing aromaticity of the binder, as measured by the ratio of the aromatic and aliphatic stretching vibrations at 3046 and 2925 cm^{-1} , respectively. With the same amount of quinoline insolubles and same softening point, petroleum pitches, usually low in aromaticity, have higher logarithmic temperature coefficients than coal-tar pitches.

Thus both the nature of the crude tar and the distillation process seem to influence the flow behavior of the binder.

Properties of the Paste in the Baking Zone

The shrinkage of the paste in the baking zone should be low to prevent crack formation around the spikes. This shrinkage is caused (a) by the unavoidable volume reduction of the binder coke during the baking and (b) in cases where the aggregate coke is calcined at lower than normal temperatures, also by the additional calcination and volume reduction of the dry aggregate coke in temperature zones above its original calcination temperature. The dry aggregate coke should have a sufficient degree of calcination to prevent additional shrinkage. It should also have a granulometric composition which reduces the effect of the unavoidable shrinkage of the binder coke. With a density above 1.980 g/cm^3 for petroleum coke and somewhat lower for pitch coke, and with a reasonable amount of binder; the shrinkage of the paste is primarily determined by granulometric composition of the dry aggregate coke.

ANODE CARBON

A detailed description of the shrinkage test and its applications is given elsewhere.⁹

PROPERTIES OF THE BAKED BINDER/MILLED PRODUCT MIXTURE

The extremely different properties of a binder calcined separately, and in a mixture with precalcined aggregate coke, have been demonstrated earlier.⁷⁻⁹ Briefly, it may be summarized that the specific surface of the binder coke in the baked mixture is larger than the specific surface of the binder calcined separately, and also larger than the specific surface of the aggregate coke. It has further been demonstrated that this difference in specific surface between the binder coke and the dry aggregate coke in the anode paste is a dominating cause of the selective oxidation of the binder coke when oxidized with O₂ or CO₂. The selective oxidation of the binder coke results in a surface disintegration of the baked mixture. Much evidence indicates that carbon dust formation in the cell is primarily caused by a similar selective oxidation. It is concluded that for the study of carbonized pastes, also, a method should be adopted that takes into consideration the interaction of the two paste components.

As in the fluid zone, the binder/milled product system dominates to a very large degree the properties of the baked anode. The investigation of the properties of baked carbons has been carried out in binder/milled product mixtures, since these are less complicated systems than a paste with a number of different dry aggregate fractions.

Specific Surface of Binder/Milled Product Mixture

The microcrack formation set up in the system when baking a binder/milled product mixture is well demonstrated by measurements of the specific surface by the B.E.T. method, using krypton as the absorbing gas. Table V gives the specific surfaces of (1) fused silica, (2) binder baked separately, (3) a baked 27/73 by weight binder/fused silica mixture.

TABLE V
Specific Surface of Test Specimens

	Specific surface, m ² /g
Fused silica	0.01
Binder <i>C</i> baked separately	0.82
Binder <i>C</i> in mixture	1.61

ALUMINUM

Whereas the specific surface of the baked binder is distributed more or less uniformly throughout the whole specimen, the specific surface of the baked mixture must be concentrated in the outer binder coke layer. Assuming a binder coking value in the mixture of about 60%, and a real density of binder coke and fused silica of 2 and 2.26 g/cm³, respectively, the ratio of binder coke/dry aggregate of the baked mixture should be about 18/82 by weight. The specific surface area in the binder coke should then be about 9 m²/g or about 11 times higher than in the binder baked separately.

During the mixing and subsequent baking of a binder/dry aggregate coke fines mixture, the binder will penetrate and carbonize in the available pores in the coke particles. The measured specific surface of these mixtures is thus concentrated in the binder coke structure to a large degree also.

Table VI gives the specific surface values of two 35/65 by weight mixtures, one with a good quality binder *D*, and one with a poor quality binder *E* (as characterized by their dusting tendency in the cell line).

TABLE VI
Specific Surface of Binder/Milled Product Mixtures

	Specific surface, m ² /g
Binder <i>D</i> in mixture	4.10
Binder <i>E</i> in mixture	9.55

Assuming as before a 60% binder coking value in the mixture, and a real density of the binder coke and dry aggregate coke of 2 g/cm³, the specific surface of the binder coke *D* and *E* in the two mixtures may be estimated as 16.9 and 39.2 m²/g, respectively. Even allowing for an appreciable part of the pores to be distributed in the dry aggregate coke, the values are on a completely different level than the specific surface of 0.8 m²/g for the binder *C* baked separately.

Microporosity of Binder/Milled Product Mixtures

The B.E.T. method is time consuming and the equipment is rather expensive. An indirect method for the determination of specific surface of baked mixtures is provided by the microporosity method.

Description of the Microporosity Test

By submerging the test specimen in liquids with different wetting or penetration abilities, i.e., mercury and kerosene, the difference in

ANODE CARBON

apparent density of the test specimen in the liquids may be used to calculate the porosity.

We have accordingly:

$$\text{microporosity, \%} = \frac{(V_{Hg} - V_k) 100}{V_{Hg}} = \frac{(d_k - d_{Hg}) 100}{d_k}$$

where V_{Hg} , V_k and d_{Hg} and d_k represent the volume and apparent density of the specimen when submerged in mercury and kerosene, respectively.

The liquid binder and the dry aggregate coke, milled to a standard fineness, say, 80% -200 mesh U.S. sieve series, are mixed in a 35/65 by weight ratio at 160°C for 20 min and transferred to an iron casing, (height: 120 mm, diam: 65 mm) provided with iron stoppers at both ends. The mixture is baked from room temperature to 950°C in 20 hr and kept at that temperature for 1 hr. During the baking, the mixture is subjected to a pressure of 0.5 kg/cm² applied to the iron stopper. After baking, the mixture is crushed and screened into the fractions -50 + 100 mesh and 100% -200 mesh U.S. sieve series for the determination of apparent density using mercury and kerosene, respectively.

Mercury is applied to the coarser fraction due to its extremely poor wetting abilities. If a too-fine fraction were used the mercury would be unable to disperse the particles, and the voids between the particles might also be registered as pores, thus giving deceptively high microporosity values.

Apart from the nature of the binder itself and the coke quality, the microporosity of the binder coke depends on the rate of heating and the pressure applied to the mixture during the baking.²

Briefly, it may be stated that the smaller the heating rate and the higher the pressure, the higher is the binder coke microporosity.

Microporosity of Binder Coke

When using the microporosity test on the samples from Table V, values are obtained as given in Table VII.

TABLE VII
Microporosity of Test Specimens

	Microporosity, %
Fused silica	1
Binder C baked separately	5
Binder C in mixture	12

ALUMINUM

In complete accordance with the specific surface measurements, the microporosity of the binder baked separately is distributed throughout the whole particle, whereas in the baked mixture the microporosity is concentrated mainly in the binder coke layer. Assuming a binder coking value of 60% in the 27/73 by weight mixture of binder and fused silica and a density of 2 g/cm³ for the binder coke and 2.26 g/cm³ for the fused silica, the microporosity in the binder coke will be about 41%, or about 8 times that of the binder baked separately. As already mentioned, the specific surface of the binder coke, measured by the B.E.T. method, was about 11 times the specific surface of the binder baked separately.

Effect of the Dry Aggregate Coke

The porosity and the thermal expansion of the dry aggregate coke affect the microporosity to a very large degree. Logically, the thicker the layer of binder surrounding each coke particle during the baking, the less is the tendency of this binder coke to crack. It should be noted, however, that this layer is the surplus binder, after the filling of all pits and pores in the particles. To obtain the same binder layer surrounding the particles, a high-porous petroleum coke requires a greater amount of binder in the mixture than does a pitch coke of low porosity. It should be noted, however, that pitch coke generally gives lower microporosity values than does petroleum coke even when allowing for this difference in porosity.

TABLE VIII
Microporosity of Test Specimens

	Microporosity, %
Binder F baked separately	6.2
Binder F in mixture with uncalcined coke	5.9
Binder F in mixture with calcined coke	20.5

The microporosity, caused by the difference in thermal shrinkage between the dry aggregate coke and the binder coke, is of course reduced by reducing the thermal expansion of the former, viz., by using coke calcined at a relatively low temperature as milled product. In Table VIII microporosity values are given for a binder F baked separately, and in 35/65 by weight mixtures with uncalcined and calcined dry aggregate coke respectively.

ANODE CARBON

Effect of Binder Quality

When measuring the microporosity values of the two binders *D* and *E* from Table VI, values are obtained as given in Table IX.

TABLE IX
Microporosity of Baked Binder/Milled Product Mixtures

	Microporosity, %
Mixture with binder <i>D</i>	13.1
Mixture with binder <i>E</i>	19.7

Making the same assumptions as before, it may be estimated that the microporosities are 38% and 50%, respectively, for the binder coke *E* and *D* in the two mixtures.

As already stated, binder *D* gave a hard, dense working surface, with little dust formation and a low anode carbon consumption, whereas binder *E* performed very badly.

When comparing the microporosity value and the performance in the cell line of a number of industrially used binders, the dusting tendency and also the anode carbon consumption figures seem to correlate very well with the microporosity values of the binder/milled product mixture.

Based on experience, the following quality range has been adopted for microporosity of binder/milled product mixtures with coal-tar pitch binders and petroleum coke: >18.5, poor quality; 18.5–16.5, below average quality; 16.5–14.5, above average quality; and <14.5, excellent quality.

Microporosity and Binder Properties

Aromatic/Aliphatic Carbon Ratio. A high aromatic/aliphatic carbon ratio, as measured by the optical densities of the adsorption bands from the aromatic and aliphatic stretching vibrations at 3046 and 2925 cm^{-1} , is generally associated with good binder quality. This aromatic/aliphatic carbon ratio seems to be a very constant, insensitive property, and heating or distillation seems to influence it only very little. Increasing the softening point of binder *F* from 85 to 152°C R and B by distillation increased the value only from 1.5 to 1.8, whereas the microporosity decreased from 20.5 to 12.5%. Generally, an increase in softening point has a beneficial effect on the paste, presumably for two reasons: (1) the higher the softening point, the higher the coking value and the percentage of the green paste which will carbonize into a useful anode, (2) the

ALUMINUM

thicker the binder coke layer surrounding each particle, the less microcracks are formed during baking.

The reduction in dusting tendency which is clearly reflected by the microporosity method, is indicated only to a very small degree in the aromatic/aliphatic carbon ratio.

Unlike the beneficial effect on the dusting tendency, an increase in softening point very often has an unfavorable effect on the temperature susceptibility of the flowability of the paste.

When comparing binders with not-too-different softening points, there seems to be a good correlation between the microporosity and aromatic/aliphatic carbon ratio. It is felt, however, that in some cases the aromatic/aliphatic carbon ratio of the binder has given values that were not consistent with subsequent performance in the plant.

Coking Value. The binder coking value seems to be an important property of the binder for reasons already stated. The correlation between coking value and microporosity is very good.

Density. The density is a property closely associated with the aromaticity of the binder. The correlation between microporosity and density is good.

Reactivity. The reactivity of a baked binder/milled coke mixture is strongly connected with the impurities in raw materials, acting as catalysts for the Boudouard reaction, and also with the reacting surface of the carbon.

At the same level of identical impurities, the reactivity is intimately related to the microporosity of binder cokes.⁹ In comparing binders with very different impurities, this relationship between microporosity and reactivity is missing.

CONCLUSIONS

Good cell operation and low anode consumption are realized when the paste properties in the fluid and in the baked zones meet a number of different requirements.

A flowability method is proposed for the characterization of the flow behavior of paste with a given binder. A microporosity method is proposed for characterizing the dusting tendency of the paste. These methods, combined with the method for determining paste shrinkage and with the usual routine analyses (i.e., ash analysis and electrical resistivity), provide a good indication of the prospective properties of the paste long before it is charged on the anode top.

ANODE CARBON

The authors wish to express their thanks to Mr. Ove Sandberg, Manager of the research department at Elektrokemisk A/S, Kristiansand S, for valuable discussions and suggestions during the course of this investigation. They are also indebted to Mr. Gunnar Eia and Mr. Ole B. Dale of Sentralinstitutt for Industriell Forskning, Oslo, for carrying out the B.E.T. measurements and part of the rheological measurements.

References

1. Thomas, B. E. A., *Gas World*, 151, No. 56, 51 (1960).
2. Bowitz, O., and O. Sandberg, *Trans. AIME*, to be published.
3. McNeil, D., and L. J. Wood, *Ind. Carbon Graphite. Papers Conf. London, 1957, 1958*, 162.
4. Rigden, P. J., "The Rheology of Non-aqueous Suspensions," Road Research Tech. Paper No. 28, London, 1954.
5. Green, H., *Industrial Rheology and Rheological Structures*, Wiley, New York, 1949.
6. Sandberg O., L. Olsen, and T. Eftestøl, *Trans. AIME*, 209, 261 (1957).
7. Mrozowski, S., *Proceedings of the First and Second Conference on Carbon*, Pergamon, New York, 1956, p. 31.
8. Mrozowski, S., *Ind. Carbon Graphite. Papers Conf. London, 1957, 1958*, 7.
9. Bowitz, O., O. Chr. Bøckman, J. Jahr, and O. Sandberg, *Ind. Carbon Graphite. Papers Conf. London, 1957, 1958*, 373.

Discussion

J. Waddington (*British Aluminium Co., Scotland*): Is it your recommendation to use a coke with a low specific gravity so that microporosity is a minimum?

O. Bowitz: As far as dusting is concerned, yes. But a coke with too low density will induce heavy shrinkage and crack formation in the anode baking zone, and it will also give the anode a high electrical resistivity. With petroleum coke, any real improvement in dusting is obtained only below a real density of 1.98 g/cm³. At this low degree of calcination, shrinkage and crack formation may start to cause troubles, especially if the calcination is uneven, with part of the coke being below, say, 1.94 g/cm³. Taking this into account, we would rather utilize the improvements in electrical resistivity obtained by using a highly calcined petroleum coke.

J. A. Branscomb (*Reynolds Metals Co., Sheffield, Ala.*): Do you disregard other routine control tests?

O. Bowitz: It is necessary to differentiate between routine tests and quality tests. A routine test controls and checks the variations or homogeneity of different shipments. A quality test such as the microporosity or flowability test gives specific information about the behavior of the raw materials in the anode.

E. A. Hollingshead (*Aluminium Labs, Arvida, Quebec*): How was the fluidity of the "binder separately" determined for Table IV?

O. Bowitz: The flowability of the binder without fines was measured on the same sloping board as for the mixtures, but with a smaller angle and for a shorter time. The logarithmic temperature coefficient is a measure of a relative difference in flowability at two selected temperatures, and it should not be influenced by the angle of the sloping board or the duration of the test.