*Essential Readings in Light Metals: Electrode Technology for Aluminum Production.*
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# IMPROVING ANODE QUALITY BY SEPARATELY OPTIMISING MIXING AND COMPACTING TEMPERATURES

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At the Sabart paste plant (at Tarascon-sur-Ariège, France), the interposition of a paste mixing and cooling unit between the mixer and the compactor makes it possible :

i) to mix at the optimum temperature ensuring good wetting of the dry matter by the pitch and yielding the desired rheology

ii) to compact at the optimum temperature for maximum anode density.

The system affords very considerable latitude as regards grades of raw materials while guaranteeing outstanding anode properties.

## INTRODUCTION

Over the last twenty years, the production of prebaked anodes for the aluminium industry by pressing has been abandoned in favour of vibrocompacting, which enables big anodes to be compacted at lower cost.

This shift to a different forming technique has been accompanied by the abandonment of paste cooling prior to compacting, this because vibrocompacting can be carried out at very close to the mixing temperature. In many paste plants the mixer is in fact sited directly above the vibrocompactor so as to rule out any uncontrolled cooling of the paste. As a result, the mixing temperature is determined by the compacting temperature, which in turn depends on the rheology of the binder.

Aluminium Pechiney successfully employs this type of process to produce high-quality anodes (1)

One of Aluminium Pechiney's objectives is to increase anode density even further with the dual aims of :

i) lengthening the life of the anode in the pot and hence minimising the number of anodes to be manufactured

ii) improving the typical values of the other physical properties such as resistivity, mechanical characteristics and permeability.

A number of possible routes to this end are being investigated at LRF (Laboratoire de Recherche des Fabrications), two of which appear particularly attractive, viz :

i) increasing the cubic contraction of the anode on baking by optimising the paste formulation

ii) increasing the coke yield of the pitch in the anode by using binders having high fixed carbon values.

In the process as currently operated, however, these two approaches are inapplicable because the mixing temperature - dictated by compacting temperature - is not high enough. This being so, it appeared essential, if progress was to be made, to modify the process by interposing a paste cooler between the mixer and the vibrocompactor, thereby enabling mixing and compacting to be optimised separately.

The technique employed is to spray water onto the paste in motion in a mixer (2). This ensures uniform and controlled cooling. A cooler of this type has been installed in the paste plant at Tarascon-sur-Ariège in France (3). The plant has a production capacity of 10 metric tons per hour (tph) and has been operating a cooler since the end of 1986. All the results obtained under industrial operating conditions and quoted in what follows refer to anodes made in this paste plant, incorporating 20 % of recycled baked scrap and no green scrap, and then employed on the potlines at the Auzat smelter.

## OPTIMISING THE FORMULATION OF THE MIX

The approach adopted consists of optimising the particle size distribution (PSD) of the dry matter and then optimising the proportion of binder accordingly.

### Adjusting binder content to grain size

The optimum proportion of binder will vary with, and hence has to be adjusted to, the porosity of the bed of dry matter. The factors influencing the porosity of the bed are in turn determined by the characteristics of the aggregate (i.e. intergranular porosity and shape of the grains) and by the degree of compaction achieved. For an aggregate of given characteristics, therefore, the optimum content of binder is directly related to the compaction of the coke bed as measured by green dry density "GDD", where :

$$GDD = GAD\ (1 - P) \qquad (1)$$

and P denotes pitch content
GAD denotes green apparent density.

Aluminium Pechiney's method of optimising binder content is to maximise green dry density (4)

This procedure also has the effect of optimising the other physicochemical of the baked anode, as illustrated by Figure 1.

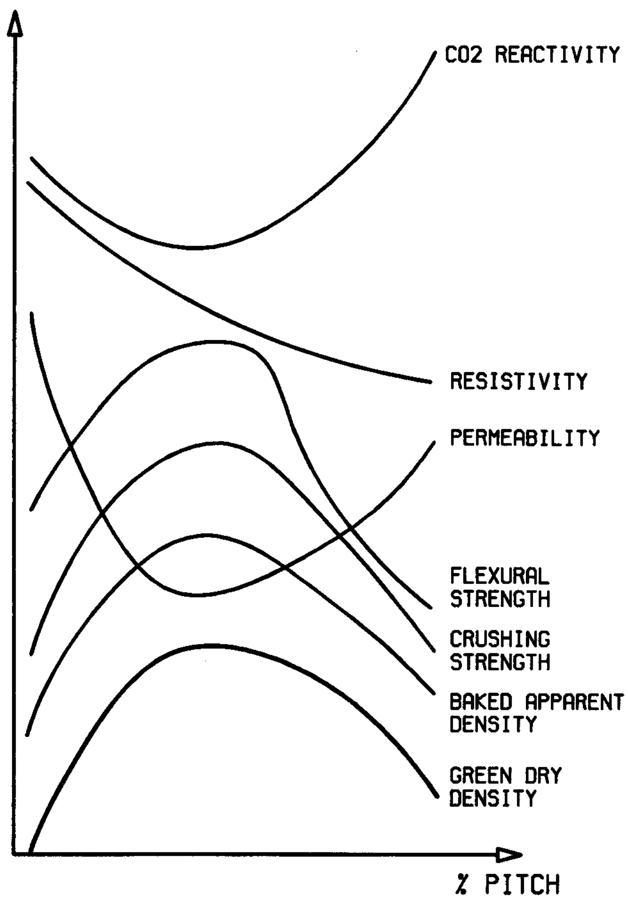



Figure 1 - Effect of pitch content on green dry density and on physicochemical properties of baked anodes.

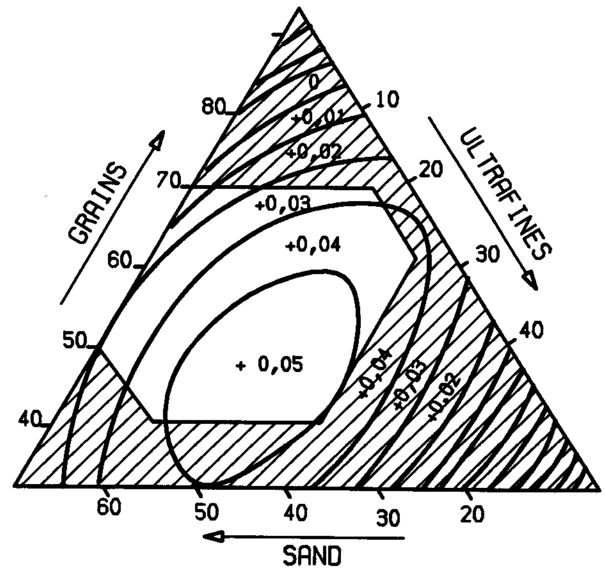
Pitch content is now adjusted continuously by an automated process based on the method just outlined (5). This task is fulfilled by the process control of the paste plant.

Optimising the grain size of the aggregate

The PSD of the aggregate entering into the composition of the prebaked anode has a considerable impact on the characteristics of the final product. In what follows, it is to be taken that pitch content has in every case been optimised as already described.

An earlier study using bench-scale experimental electrodes 90 mm in diameter successfully identified the grain sizes required to optimise the various physical properties of the anode (1).

As regards baked apparent density (BAD), it was concluded from the study that for the pitch content corresponding to saturation of the bed of coke and at pressure of 450 bars, maximum BAD is obtained with contents of ultrafines, grains and sand of ca. 20, 44 and 36 % respectively (cf. Figure 2). This is to be explained in the main by a substantial contraction in the volume of the anode on baking.




Grains : dia > 300 µm
Sand : 30 < dia < 300 µm
Ultrafines : dia < 30 µm

Figure 2 - Optimisation of BAD for varying contents of grains, sand and ultrafines.

The practical application on the plant of the conclusions drawn from the study has consisted mainly of increasing the percentage content of ultrafines in the direction of the optimum composition. The extent to which this is possible is however limited, in the process as currently operated, by the rheology of the paste, as fairly accurately reflected by the viscosity of a mix consisting solely of the pitch and the ultrafines. Under the conditions investigated, and at the optimised pitch content, the percentage of ultrafines in the mix of pitch and ultrafines corresponding to the percentage in the full formulation needs, to achieve the optimum composition, to be ca. 5 % higher than it would be in the standard PSD, the effect of which is considerably to increase viscosity (cf. Figure 3)

Therefore, in order to mix in the usual region of viscosity, we have to operate at higher temperature. The optimum compacting temperature, however, being essentially determined by the rheology of the pitch, increases with ultrafines content to an extent which is much less pronounced than for the mixing temperature.

Consequently, the standard operating procedure, under which the mixing and compacting temperatures are inseparable, cannot take full advantage of this sort of formulation since there is no scope for optimising both the mixing temperature and the compacting temperature.

Using a paste cooler, on the other hand, means that the finer-grained formulations can be mixed at the optimum temperature and then cooled uniformly under controlled conditions to bring the mix to the optimum temperature for compacting.

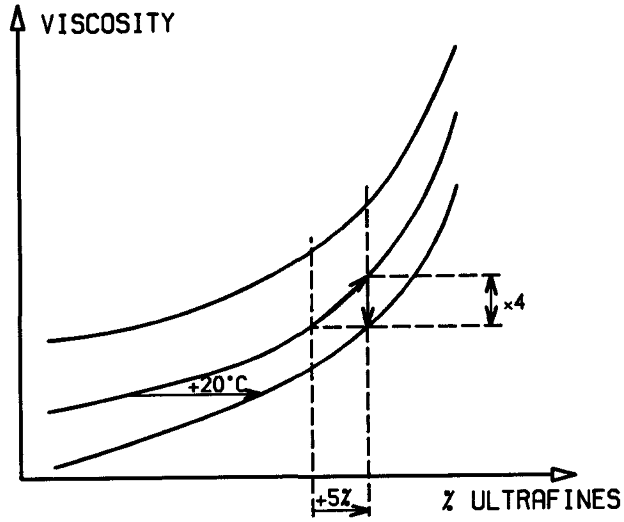



Figure 3 - Variation in viscosity of pitch/ultrafines mix with ultrafines content and mix temperature

A number of batches of anodes were produced under normal industrial operating conditions, using differing PSD's and differing contents of binder. Mixing was carried out at high temperature and constant power input (1,4) and followed by compacting at the temperature imposed by the rheology of the pitch. Figure 4 shows the increases in density obtained, under the optimum mixing and compacting conditions for the plant, on modifying the formulation of the paste. The curves on the left correspond to a standard PSD, those on the right to a high-ultrafines formulation approaching the optimum indicated by the laboratory study.

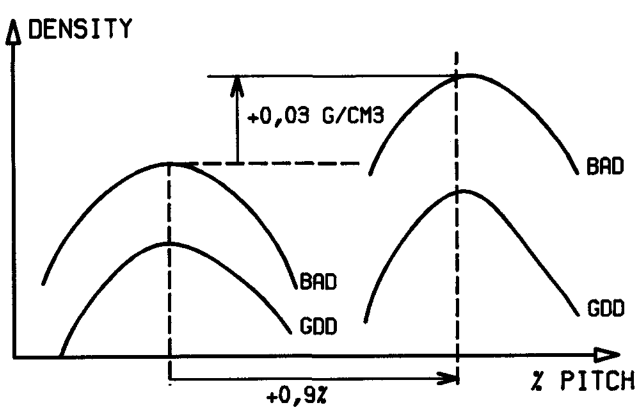



Figure 4 - Increases in density obtained with a high-ultrafines PSD

As regards the green stage, formulation with a PSD high in ultrafines results in an increase in anode GDD and a displacement of the optimum of ca. 1 % in the direction of higher pitch contents. On baking (105 hours), the effect of this modification in grain size is a pronounced contraction in anode volume to yield a high-density baked product.

To conclude this chapter, the findings of the laboratory study appear to be borne out in actual industrial practice. Also, an effective method of adjustement of pitch content, in association with a technique enabling an aggregate of optimised PSD to be mixed under the most effective operating conditions, yields substantial improvements in baked anode density and other characteristics (cf. Table 1) as compared to the standard process.

Table 1 - Improvements in baked anode properties resulting from formulation with high ultrafines content.

| | | |
|---|---|---|
| Baked apparent density | $g/cm^3$ | + 0.03 |
| Permeability | nPerm | - 1.5 |
| Resistivity | $\mu\Omega$ cm | - 200 |
| Flexural strength | $N/mm^2$ | + 1.2 |
| Crushing strength | $N/mm^2$ | + 4.5 |

BINDERS WITH HIGH FIXED CARBON VALUES

The first route to improving anode properties, as already discussed, is to optimise the formulation of the green mix. The second route consists of maximising the coke yield of the pitch in the anode.

The three physicochemical properties of pitch of particular importance to the process of production of prebaked anodes are :

i) viscosity, which must be such that the various stages in the anode production process can be operated over a reasonably achievable region of temperature

ii) wetting power, which governs the wetting of the aggregate by the pitch at the mixing stage. Wetting ability can be measured by a method developed by Pechiney (6) and subsequently elaborated upon and confirmed by other investigators (7.8), consisting of monitoring the effect of temperature on the ability of a drop of pitch to penetrate a bed of coke

iii) the fixed carbon value, which is a measure of the coke yield of the pitch under certain standardised conditions.

To increase the coke yield of the pitch in the anode not only necessitates the use of a pitch of higher fixed carbon value but also an intensification of the interactions between the pitch and the dry matter, as measured by wetting ability. Simply increasing pitch fixed carbon is not enough to improve anode characteristics : this is illustrated by Table II, which outlines the changes in pitch quality in recent years and their effects in terms of the standard process.

Table II - Standard process - Changes in pitch specification and impact on anode properties

| Pitch | Source Tar | Heat Treatment | Fixed Carbon | Wetting Power (7) | Anode Properties |
|---|---|---|---|---|---|
| A | Heavy * | Moderate | >55 % | P1=P2 < 145°C | High |
| B | Light ** | Severe | >55 % | P1<145°C P2>160°C | Low |
| C | Light ** | Moderate | <52 % | P1=P2 < 145°C | Medium |

* Heavy = high QI content ** Light = low QI content

The most important properties of pitches A, B and C are set out in Table III.

The data in Table II show that a compromise can be found as between the fixed carbon value and the wetting power of the pitch. Within certain limits, a light pitch possessing good wetting ability (C), despite its low fixed carbon value, yields better results than a pitch (B) with high fixed carbon but poor wetting ability. In every case, however, the light pitch will yield anodes with properties inferior to those obtained with the pitch (A) featuring high fixed carbon and good wetting ability. This is illustrated by the plots in Figure 5 based on results obtained under actual industrial operating conditions.

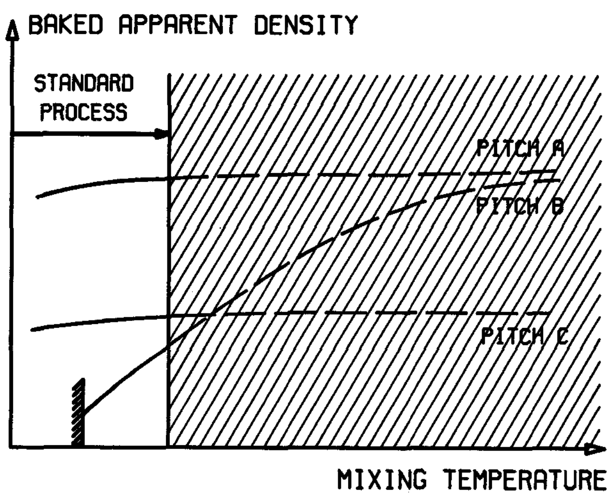



Figure 5 - Standard process - Comparison of baked anode densities obtained using three categories of pitch (A, B and C)

The characteristics of light pitch derive from the optimisation of operating parameters in its production from light coaltars with a view to use in the standard process of anode manufacture. In this application, it does resolve the problem of wetting power but has the demerit of low fixed carbon and is therefore unable to yield anodes with outstanding characteristics.

To enhance these characteristics, we have to use a pitch with very high fixed carbon. However, the very great majority of the pitches on the market able to meet this requirement have only poor wetting ability (Type D pitch - characteristics in Table III).

The production of anodes possessing outstanding properties from these pitches therefore calls for mixing at a temperature such that they are able spontaneously to wet the dry aggregate. This is made possible by the latitude with regard to mixing temperature afforded by the modified process described.

Trials under industrial operating conditions were run on a 360 tons lot of Pitch D, the principal characteristics of which are given in Table II. In parallel, pitches A, B and C were mixed at higher temperature. For each pitch and each mixing temperature, various proportions of binder were investigated. All formulations were mixed at constant power input. Results are represented in Figure 6.

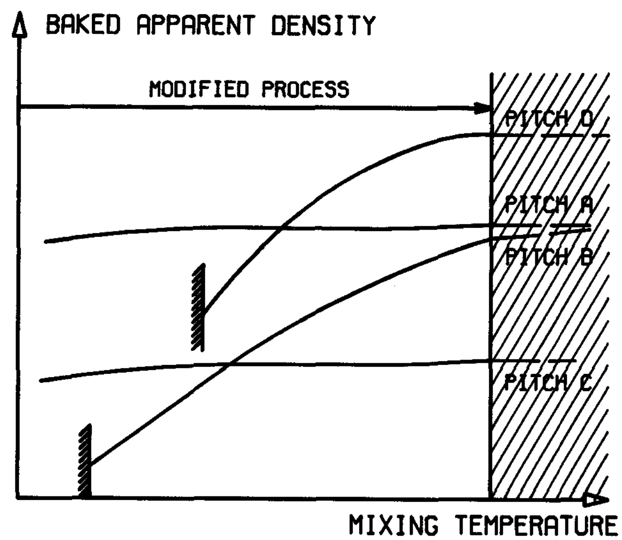



Figure 6 - Modified process - Comparison of baked anode densities using four types of pitch (A, B, C and D)

Figure 6 shows that, for each pitch, a mixing temperature exists above which the pitch wets the coke. In the case of pitches A and C, this wetting temperature is situated at the lower end of the range of mixing temperatures employed in the standard process. Mixing at higher temperatures yields no significant improvement in properties. In the case of pitches B and D, the threshold temperature is high and is achievable only in the modified process. At temperatures below the threshold, interaction between the pitch and dry matter is weak, so that, despite the high fixed carbon value, the coke yield is poor. In fact, if Pitch D is employed in the standard process, not only are the anode characteristics very badly affected, the percentage of rejects also becomes substantial. Increasing the mixing temperature up to the threshold improves the characteristics of the green anode and, to a much more pronounced extent, those of the baked anode by virtue of the higher coke yield (cf. Figure 7).

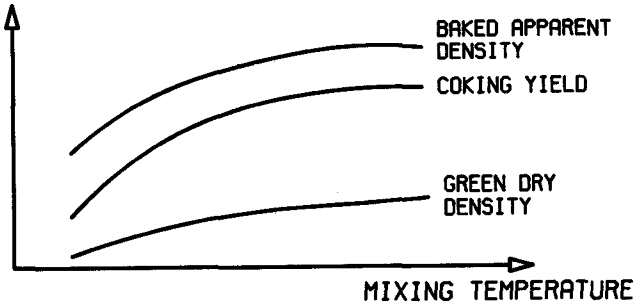



Figure 7 - Effects of mixing temperature on green dry density, baked apparent density and coke yield of pitch (B) in the anode.

Consequently, once wetting has been achieved (by optimising the mixing temperature), the difference in characteristics of anodes made with the two pitches B and D respectively (Figure 6) is determined solely by the difference in fixed carbon values.

To conclude this chapter, there exists a threshold temperature for each pitch above which it is able spontaneously to wet the aggregate. In order to maximise interaction between the pitch and the aggregate, and hence the coke yield of the pitch in the anode, mixing has to be effected at a temperature above this wetting threshold.

Where the standard type of process is being operated, this considerably restricts the range of pitches that can be used. The modified process on the other hand, by virtue of the latitude it affords as concerns the choice of the mixing temperature, makes it possible to optimise the utilization of the usual range of binders and even to widen the range of binders suitable for use.

Table III - Principal physicochemical properties of the various pitches referred to.

| | | A | B | C | D |
|---|---|---|---|---|---|
| METTLER softening point | °C | 104.1 | 104.4 | 104.8 | 121.6 |
| Wettability | | | | | |
| P1 | °C | 139 | 139 | 142 | 164 |
| P2 | °C | 139 | 192 | 142 | >230 |
| SERS fixed carbon | % | 54.8 | 54.0 | 48.2 | 57.2 |
| QI | % | 10.4 | 12.6 | 4.6 | 12.9 |
| TI | % | 33.1 | 36.2 | 27.8 | 38.7 |
| Viscosity | cP | | | | |
| 140° C | | 4350 | 5400 | 7520 | 24800 |
| 160° C | | 920 | 1100 | 1350 | 3940 |
| 180° C | | 300 | 340 | 380 | 1010 |
| 200° C | | 130 | 140 | 150 | 360 |

## PROCESS PERFORMANCE

### Anode properties

The combination of the two approaches described enables anodes of very high quality to be produced commercially (cf. Table IV).

Table IV - Anode properties

| 940 anodes in the lot | | 108 anodes sampled |
|---|---|---|
| Baked apparent density | g/cm³ | 1.62 |
| Permeability | nPerm | 0.3 |
| Resistivity | μ Ω cm | 5100 |
| Flexural strength | N/mm² | 13.2 |
| Crushing strength | N/mm² | 48.5 |
| Real density | g/cm³ | 2.088 |
| $CO_2$ reactivity | mg/hg | 19.6 |
| $O_2$ reactivity | mg/hg | 20.1 |

### Productivity

Since the system of regulation of the cooling stage can be fully integrated into the automated paste plant management system and the capacity utilization factor is the same, the productivity of the paste plant is unaffected by the inclusion of this additional processing step.

Again, the consequences of the higher density obtained are, as concerns the Sabart and Auzat plants :

i) a reduction of more than 4 % in the number of anodes to be baked, and hence an increase in baking furnace production capacity

ii) a 32 hour extension in anode life in the pot, thereby boosting potroom productivity by virtue of the smaller number of anodes to be changed and handled

Where a new plant is to be built, the increase in baked anode density means a significant reduction in capital cost.

## CONCLUSION

Aluminium Pechiney's modified process for the production of prebaked anodes makes it possible to optimise mixing and compacting temperatures, hitherto inseparably interlinked.

Mixing at high temperature, followed by controlled uniform cooling of the paste to the optimum temperature for compacting, has two advantages :

i) fine-grained formulations can be processed, the objective being to maximise the contraction of the anode on baking

ii) the degree of interaction between pitch and aggregate is intensified, thereby maximising the coke yield of the pitch in the anode.

It is thus possible, over a very wide range of raw materials, to guarantee optimum anode properties.

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