Doctoral Thesis

Cracking behaviour of prebaked carbon anodes used for the aluminium production

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Cracking Behaviour of Prebaked Carbon Anodes
Used for the Aluminium Production

DISSERTATION

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Summary

Aluminium is produced by the electrolytic reduction of alumina (Al₂O₃) dissolved in a bath of molten cryolite (Na₃AlF₆). This process requires carbon anodes which are consumed during the operation. When the new anode is inserted into the electrolysis cell, it is subjected to a thermal shock: a heat wave starts to penetrate into the bulk of the anode which generates considerable stresses. If these thermal stresses exceed the bearable limit of the anode, a crack is formed which can cause carbon chunks to fall into the pot.

Cracked anodes need to be rejected and recycled. The resulting gross carbon consumption is thus increased, which leads to higher aluminium production cost. If the cracked anodes disturb the conditions in the electrolysis cell, the carbon net consumption increases too, with an even greater financial impact on the aluminium production cost.

This study has been carried out to evaluate the various types of mechanical failure of the carbon anodes and to propose countermeasures that are feasible in practice.

The cracking behaviour is equally influenced by the following three stages of the anode production and consumption:

- **Quality of the raw material**
  A high cracking resistance is obtained with an anisotropic, needle-like coke with a low coefficient of thermal expansion and a low modulus of elasticity.

- **Quality and consistency of the anode manufacturing process**
  A high cracking resistance is obtained with a coarse recipe, a moderate amount of pitch, intensive mixing and a slow baking temperature gradient. All processing steps need to be as consistent as possible.

- **Severity of the thermal shock in the electrolysis cells**
  A mild thermal shock is obtained with low superheat, little metal and bath movement (i.e. no horizontal current components due to uneven side ledges), small immersion depth and a small anode size.
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The cracking phenomenon was found to be mainly a statistical problem. In order to avoid anode cracking, first the variation and then the average anode quality needs to be improved.

A thermal shock resistance indicator (TSR) has been developed which enables to estimate the potential risk of anode failure. It could be verified that the validity of the TSR is very high in practice.

The analysis of the worldwide aluminium production and anode raw material supply shows a growing trend of thermal shock problems. The severity of the thermal shock is expected to increase while the raw material quality is about to deteriorate. New electrolysis cell designs will require larger anodes. The increasing demand for more efficient cell operations and less anode handling dictates higher anode densities which leads to brittle material behaviour. This unfavourable development can only be compensated by a superior anode manufacturing process that is well under control.

Cracked carbon anode due to the thermal shock in the electrolysis cell
Zusammenfassung

Die Produktion von Aluminium erfolgt durch die elektrolytische Reduktion von Tonerde (Al₂O₃), die in geschmolzenem Kryolith (Na₃AlF₆) gelöst ist. Für diesen Prozess werden Kohlenstoff Anoden benötigt, die fortlaufend konsumiert werden. Wenn eine neue Anode in die Elektrolysezelle eingesetzt wird, ist diese einem Thermoschock ausgesetzt: eine Hitzewelle beginnt in das Innere der Anode einzudringen, was zu erheblichen Spannungen führen kann. Wenn diese Wärmespannungen eine kritische, durch die Anode gegebene Grenze überschreiten, bildet sich ein Riss in der Anode. Dabei können Bruchstücke der Anode in das Elektrolysebad fallen.

Beschädigte Anoden müssen ersetzt und recikliert werden. Infolgedessen wird der Brutto Kohlenstoffverbrauch erhöht, was die Aluminiumproduktion verfeuert. Die rissbehafteten Anoden können das thermische Gleichgewicht der Elektrolysezelle stören, was zu einer Erhöhung des Kohlenstoff Nettoverbrauches führt. In diesem Fall sind die Auswirkungen auf die Aluminiumproduktionskosten höchst gravierend.

In dieser Arbeit werden die verschiedenen mechanischen Versagensarten der Anode untersucht. Darauf basierend werden Gegenmassnahmen vorgeschlagen, die sich in der Praxis realisieren lassen.

Das Rissverhalten wird gleichermassen von drei Faktoren während der Herstellung und des Einsatzes der Anode beeinflusst:

- **Qualität des Rohmaterials**
  Eine hohe Beständigkeit gegen Rissausbreitung wird erreicht mit einem anisotropen Nadelkoks, der einen tiefen Wärmeausdehnungskoeffizienten und einen tiefen Elastizitätsmodul aufweist.

- **Qualität und Gleichmässigkeit des Anodenherstellungsprozesses**
  Eine hohe Rissbeständigkeit wird erreicht mit einer grobkörnigen Rezeptlinie, einer mässigen Pechzugabe, einer intensiven Durchmischung der Masse und einer langsamen Aufheizrate des Brennofens.