Determination of the Pitch Level in Green Anode Using Image Analysis

Yao Ahoutou[1], Duygu Kocaefe[2], Dipankar Bhattacharyay[3], Yasar Kocaefe[4] and Jules Côté[5]
1. Master student
2. Professor, Chair CHIMI
3. Professor
4. Professor
UQAC Research Chair on Industrial Materials (CHIMI), Chicoutimi, Québec, Canada,
University Research Centre on Aluminium (CURAL), Chicoutimi, Québec, Canada,
Aluminium Research Centre (REGAL), Québec, Canada,
University of Quebec at Chicoutimi, Chicoutimi, Québec, Canada
5. Vice President Engineering and Plant Processes
Aluminerie Alouette, Sept-Îles, Québec, Canada
3. Professor
Presently working at Centurion University of Technology and Management, India
Corresponding author: duygu_kocaefe@uqac.ca

Abstract

The anode quality plays an important role in aluminum production. Utilization of good quality anodes decreases the carbon and power consumptions as well the greenhouse gas (GHG) emissions, and increases the production. One of the important factors affecting the anode quality is the percentage of pitch used and its distribution in the anode. The under-pitched or over-pitched anodes decrease the anode quality, hence cause problems during the production. Currently, the quality of anodes is evaluated either visually or by characterizing a small core taken from the top of the anode, which does not represent the whole anode. In addition, core characterization is done only for 1.5 to 2 % of the anodes produced. The objective of this study was to determine the distribution of pitch on the surface of green anodes by image analysis in order to detect if the pitch distribution is uniform and if they are under or over-pitched. An image analysis software was developed for this end using Visual Basic. To test the software, ten laboratory anodes with different percentages of pitch, particle size distribution, and vibro-compaction conditions were produced in the carbon laboratory of the Research chair on industrial materials (CHIMI) of the University of Quebec at Chicoutimi (UQAC). Their images were analyzed with the software developed. A validation of the software, based on chemical analysis, was also carried out. This involved the spectrophotometric analysis of the pitch content of samples taken from different parts of the anodes, which were identified as over-pitched or under-pitched by the image analysis software. The results were in agreement with the predictions obtained with the software showing that it can be used as a tool to determine the pitch level (over or underpitched) on anode surfaces.

Keywords: Aluminum production, Under-pitched anode, Over-pitched anode, Image analysis, Spectrophotometric pitch analysis.

1. Introduction

The prebaked carbon anodes act not only as a source of carbon, but also as an electrical conductor during the aluminum electrolysis. They represent around 15-20 % of the cost of producing aluminum. They are composed of petroleum coke, butts, recycled green and baked anodes (dry aggregate) and coal tar pitch (binder) [1]. The quality of the raw material and the parameters of the manufacturing process such as chemical composition, electrical conductivity, thermal shock resistance, homogeneity, and air and CO_2 reactivities have a significant impact on the anode properties. Therefore, the quality of raw materials affects the energy and carbon consumption, production cost, and greenhouse gas (GHG) emissions.

It is also well-known that the quantity and the distribution of pitch in an anode are two of the important parameters affecting the anode properties [2-3]. The over-pitching significantly increases the quantity of volatiles, thus the greenhouse gas (GHG) emissions. This also leads to an overload in the volatile burning systems, hence greatly increases the fire risk. The release of large quantities of volatiles also result in crack formation in anodes. On the other hand, under-pitched anodes are more porous (less dense). They have high electrical resistivity. Utilization of such anodes increases the energy and carbon consumption. The uneven distribution of the pitch leads to the generation of cracks in the anode during baking and causes variations in the consumption of anode during electrolysis. However, there is no technology that can be used in the plant for quickly estimating the pitch percentage and its distribution in the anodes. The quality control concerning the pitch level is based on a visual inspection (color and surface finish) by the operators. The aim of this study is to develop a method based on image analysis to determine the distribution and the level of pitch on the green anode surfaces.

Image analysis is a well-known technique used in various fields such as analysis of medical x-ray images [4], extraction of character chains from overlapping images of text and its background [5], correlation of variations in chemical analysis, process parameters and mechanical properties of microstructures in steel industry [6], characterization of porous structures of copper [7].

The image analysis is vastly used in the field of aluminum. Solymar et al. [8] studied the microstructure of bauxite by digital image analysis using a scanning electron microscope and a micro analyzer electron probe. Martinent-Catalot et al. [9] have developed a new method of analysis of digital color images to characterize and identify different types of alumina used by aluminum smelters. Swillo and Perzyk [10] analyzed the surface of primary aluminum after casting to detect the surface defects.

Image analysis is also used for anodes and its raw materials mostly using the optical or scanning electron microscopes. Rorvik et al. [11] characterized the components of a green anode and the porosity of coke particles using optical microscopy and digital image analysis. Tessier et al. [12] used image analysis to determine the composition of the anode cover material. Bowers et al. [13] developed an imaging technique to determine the porosity, shape, and size of the calcined coke. Adams et al. [14] conducted an image analysis study for pitch in anodes. The aim of this study was to determine whether semi-automatic image analysis could give the appropriate amount of pitch for a defined size distribution of coke particles. However, their method was only applicable to large particles. Saravanan and Society [15] have proposed a new algorithm to preserve contrasts, sharpness, shadow, and image structure. Bhattacharyay et al. [2] focused on the development of a technique that can be used to analyze the distribution and amount of pitch, coke, pores and cracks on the surface of a green anode. These studies were mostly carried out in the laboratory. To our knowledge, there is no reported study to investigate the entire surface of an anode. The present study focuses on image analysis technique to identify pitch distribution on the surface of a green anode in real time. To do this, an image analysis software using the Canny algorithm and the distribution of primary colors, red, green, and blue (RGB), was developed. In addition, the Gauss filter is used to cancel the noise generated by the Canny algorithm. The software can determine if the surface of the anode is over-pitched or under-pitched. It can also determine if the pitch distribution on the anode surface is homogeneous or not.

The laboratory anodes with properties similar to those of the industrial anodes can be produced in the laboratory of Chair CHIMI at UQAC. Therefore, the method was first tested and validated in this laboratory. Then, it is tested in the plant with industrial anodes. This article presents the results obtained with the laboratory pilot anodes.

A method based on chemical analysis was used to validate the results of the image analysis software developed. This involved the spectrophotometric analysis of samples taken from different parts of the anodes that were identified as over-pitched and under-pitched by the image analysis software. Afterward, the chemical analysis and the image analysis results were compared to validate the software.

2. Methodology

2.1 Production of Laboratory Anodes

All of the raw materials, pitch and dry aggregate, used in the production of laboratory anodes were obtained from the industrial partner. These are the same materials which are used in the production of industrial anodes.

First, the dry aggregate is sieved to have the desired particle size distribution. Then, it is mixed with pitch in an intensive mixer to prepare the anode paste. After, green anodes are formed with vibro-compactor, which are then baked to produce baked anodes. The anode production conditions were similar to those used in the industry.

It is difficult to change the anode production parameters at the plant. Therefore, two groups of anodes with known defects and pitch distributions were produced in the laboratory. The first group of anodes (Table 1) are manufactured under standard conditions with different pitch percentages. The second group of anodes (Table 2) are special anodes manufactured under different conditions and with different specifications in order to test if the software will be able to detect these particularities. The anodes in the second group all had the same pitch percentage (15 %) as anode 3. This pitch percentage gave anodes the best properties in the laboratory (optimum percentage).

Table 1. Laboratory anodes manufactured under standard conditions with different pitch percentages.

Anode no	**Pitch (%)**	Density g/cm^3)
1	11	1.44
2	13	1.52
3	15	1.59
4	19	1.63

2.2 Experimental Image Capture System

The experimental setup consists essentially of a light source for the uniform illumination of the anode surface and a digital camera to capture images as shown in Figure 1.

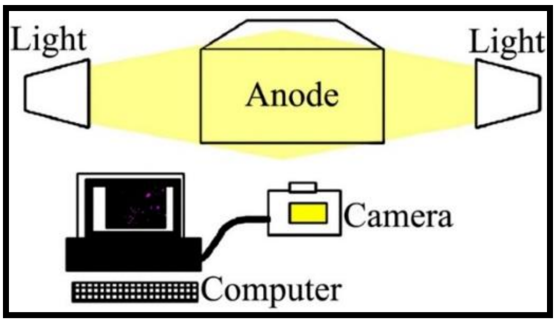
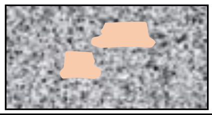
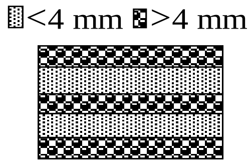
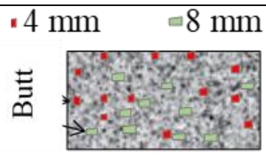


Figure 1. Image analysis setup.

Table 2. Specifications for the second group of laboratory anodes.

Anode no	Pitch (%)	Density (g/cm^3)	Specificity of the anode	Schematic of view of anode
5	15	1.44	Cold mold	
	15.2	1.56	Creation of pitch rich spots on the anode surface with addition of pitch	
7	15	1.56	With oil spots on the anode surface	
8	15	1.55	Anode surface exposed to water jet	
9	13	1.43	Two types of paste used: One with particle size > 4 mm and the other with particle size < 4 mm. The position of different pastes is visible on the anode surface.	
10	15	1.61	Anode produced using large butt particles (particle size of 50% of butts is 4 mm and the other 50% of butt particles are 8 mm).	

2.3 Image Analysis Software

This software uses two approaches, as shown in Figure 2. The first approach is based on the distributions of red, green, and blue colors in the images. The second method is based on the surface structure of the anode. It is important that the images are taken under the same lighting conditions.

In the first method, at the beginning, the background illumination of the coke is measured and subtracted from the image of the anode. Several types of cokes are used for the anode production. The different colors of these cokes influence the color of the anode. This step eliminates the effect of coke color. After, the distribution of green, red, and blue colors from the corrected anode image are determined and their histograms are plotted. The over-pitch threshold for these different components are taken as the average value for each color. Then, the over-pitched regions are marked with pink. Then, the final image is constructed from the pink regions common in the images of three colors. If the calculated percentage is bigger than the predetermined threshold, the anode is over-pitched and has an uneven pitch distribution. Thus, it may not be acceptable. Otherwise, anode has a uniform pitch distribution and might be acceptable. For the final decision, the size distribution of the pink regions is plotted for the anodes identified as over-pitched. If the size of some of the pink regions is large, the over-pitched regions are concentrated in specific regions on the anode surface. The anode is not acceptable. If all the spots are small; then, the over-pitched regions are not concentrated in particular regions. The anode may be acceptable.

As mentioned previously, the second method is based on the surface finish of the anodes. A granular surface indicates a lack of pitch, while a very smooth surface indicates an over-pitched anode. First, the distribution of particle boundaries is identified and marked in white. The percentage of white color is determined and tested if this value is within a predetermined range, thus the anode is acceptable. The presence of a large amount of white color points out the presence of a large number of particles, hence a granular surface (under-pitched). Small amount of white color indicates a smooth surface (over-pitched surface). These anodes are not acceptable.

2.4 Chemical Analysis

The sections of the anode shown in Figure 3 were crushed to have fine powder. This powder was immersed in a solvent to extract pitch. The solution containing pitch was analyzed with a visible spectrometer. Also, the same solvent was doped with different quantity of pitch and analyzed with the spectrometer to obtain a calibration curve. This made the determination of the quantity of pitch present in each section possible. These results are compared with those obtained with the image analysis software developed during this study.

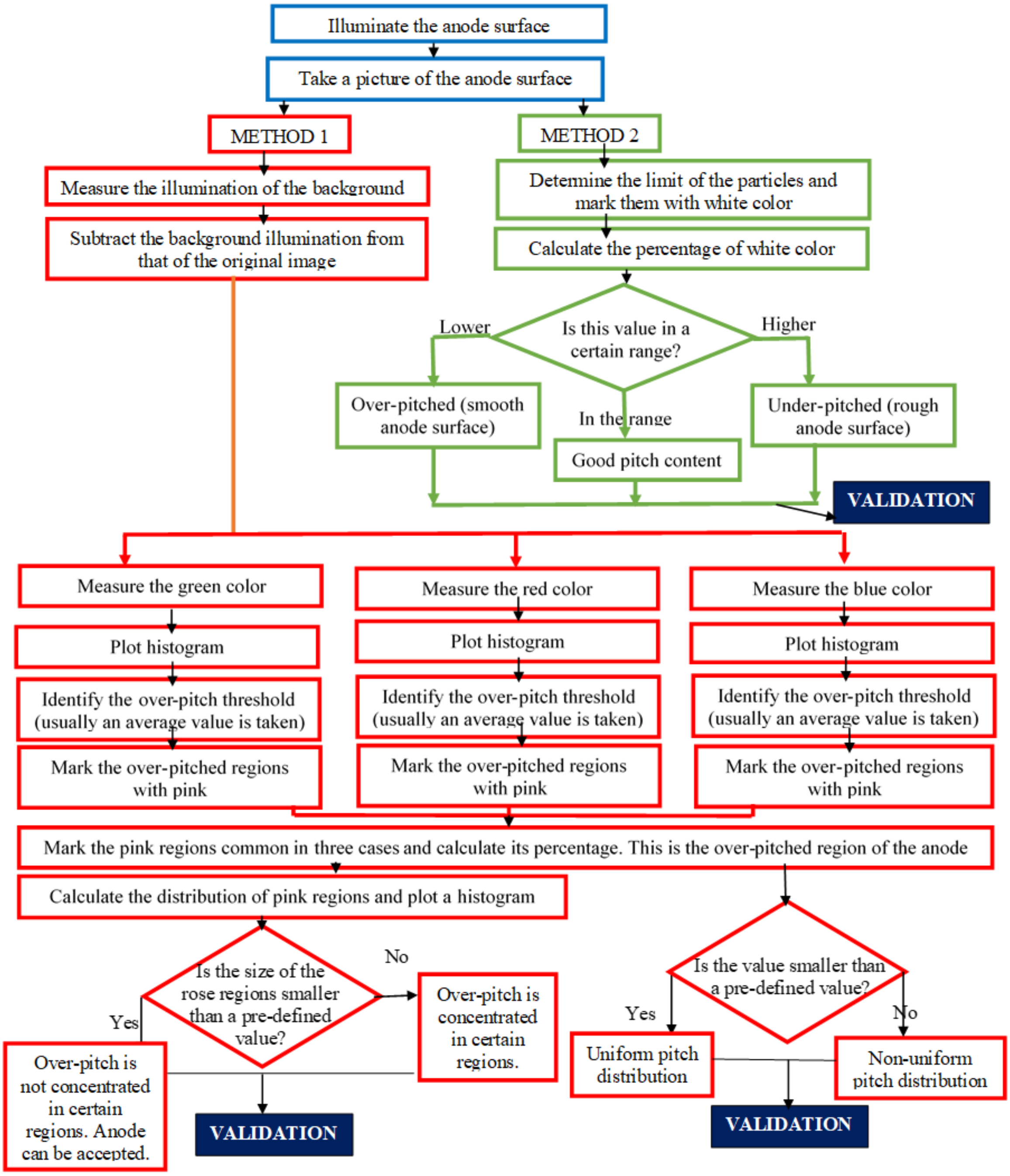


Figure 2. Flowchart of the image analysis software.

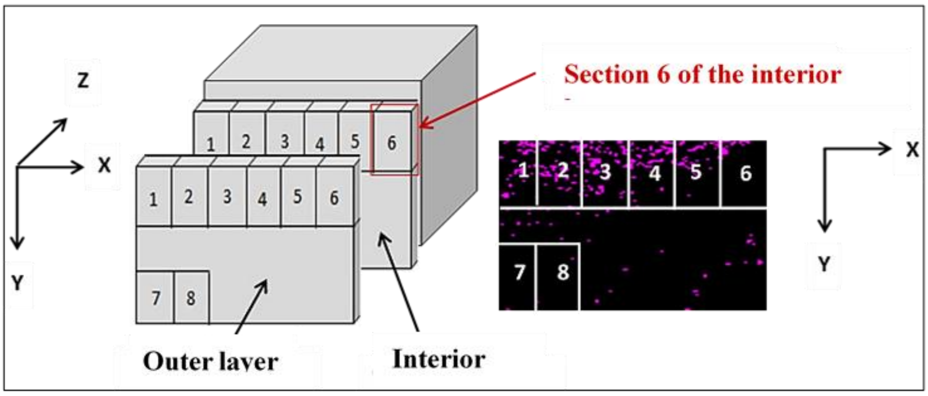


Figure 3. Sections of the anode used for the chemical analysis.

3. Results and Discussion

3.1 Image Analysis

It is important to note that this software is developed for consistent evaluation of anode surfaces instead of the visual quality control carried out by the operators. It does not predict the actual state of the anode. However, it predicts what the operator will see. It is difficult to obtain the overall quality of the anode only from its surfaces. There are technologies developed to predict the anode quality in 3D such as SERMA [16] and MIREA [17].

3.1.1 Effect of Pitch Percentage

The images of four standard green laboratory anodes (1 to 4) produced with different pitch percentages (Table 1) are analyzed with the image analysis software. Similar results are available for all the cases, but they are not all presented due to the lack of space. The results from this analysis are presented in Figure 4 for the same small side-surface of the anodes. In this figure, the first row shows the images of the anode surface as taken with the camera under the same illumination. The second row displays the particle boundaries (Method 2), and the third row presents the over-pitched regions in pink (Method 1). The fifth row presents the histograms which show the size of the over-pitched regions. The broad lines on the right of the histograms show large over-pitched regions whereas the small lines on the right show the small over-pitched regions. The density of the anodes increases with the increasing pitch content (Table 1).

Figure 5 presents the percentages of white particle boundaries and the percentages of pink over-pitch regions as a function of the pitch percentage of the anodes. As can be seen from this figure, the percent of white decreases while the percentage of over-pitched regions increases with increasing pitch percentage. When the pitch percentage is high, liquid pitch flows towards the surface during compaction, therefore, there are more pink regions and less white (smooth surface) on the surface of the anodes which have high pitch content.

The results show that there are more over-pitched regions on the upper part of all four anodes. This may be due to non-uniform temperature distribution in the mold of the vibro-compactor. The higher temperature of the top of the mold gives a greater fluidity for pitch. The relatively cooler bottom temperature of the mold prevents the flow of the pitch to the surface.

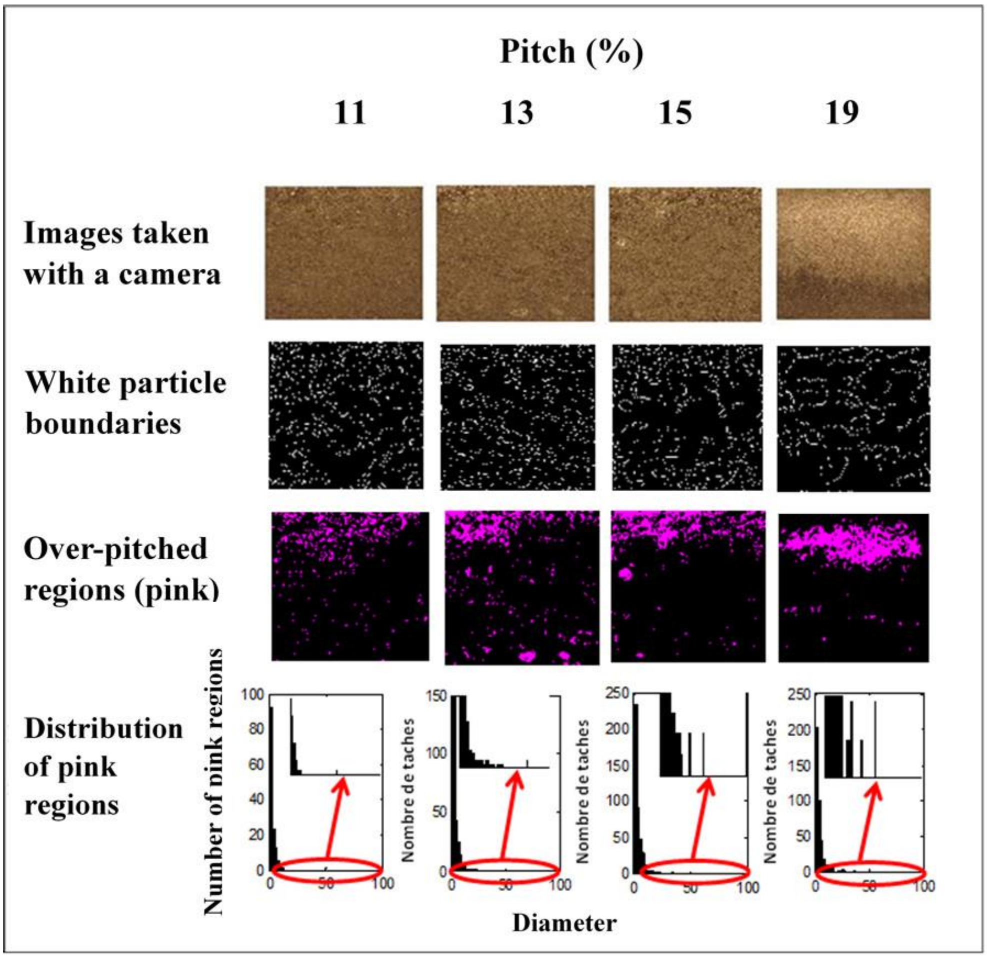


Figure 4. Image analysis results for the small surfaces of laboratory anodes containing different pitch percentages.

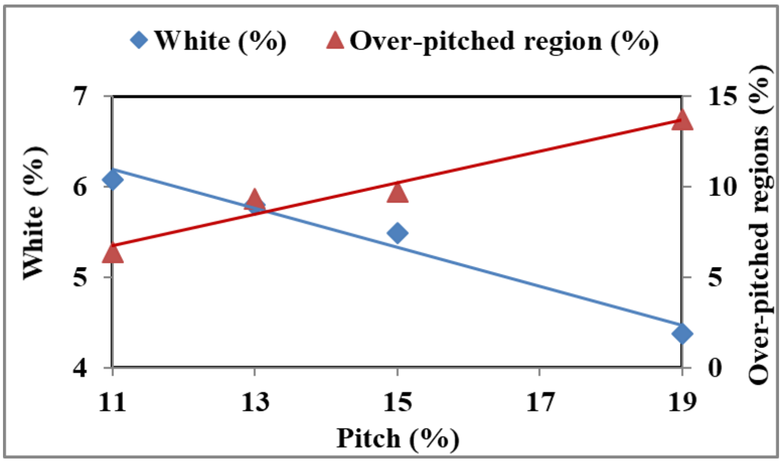


Figure 5. Evolution of the percentage of white and over-pitched regions as a function of the pitch percentage for the anodes with different pitch percentages.

3.1.2 Effect of using Cold Mold

Anode 5 (Table 2) was produced without heating the mold of the vibro-compactor. The percentages of white particle boundaries and over-pitched regions of this green anode are shown in Figure 6. The result for anode 3 (standard anode with 15 % pitch percentage) is also shown on the same figure. Although anode 5 has the same pitch percentage as 3, the value of the percentage of white boundaries indicates a rougher anode surface compared to that of the 3. The cold mold cools the liquid pitch too quickly, thus pitch migrates less slowly towards the anode face. The density of the anode 5 is lower (1.44 g/cm^3, see Table 2) since the pitch cannot penetrate well into the pores of the anode. The roughness could give the impression of an under-pitched surface on visual inspection. The image analysis software predicts the percentage of over-pitched regions, which is slightly higher than that of anode 3.

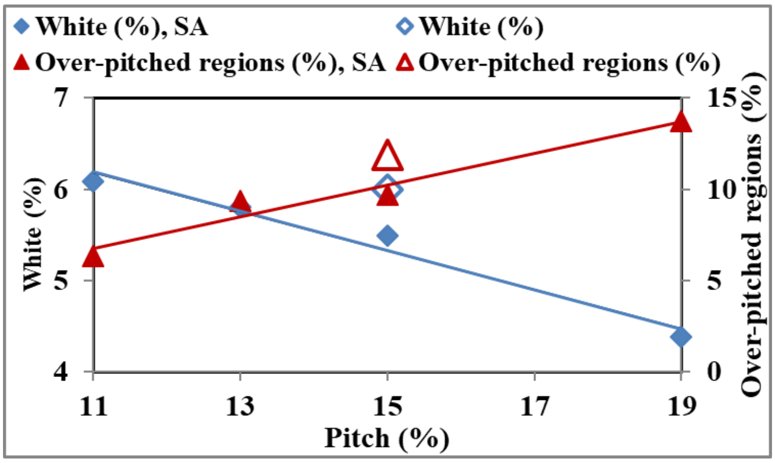


Figure 6. Evolution of the percentage of white and over-pitched regions as a function of the pitch percentage for the anode produced with cold mold (SA: standard anode).

3.1.3 Effect of the Presence of High Pitch Regions on the Surface

The results obtained for the green anode 6 (Table 2) produced with visible pitch spots on the surface and that of anode 3 are compared in Figure 7. For this anode, the percentage of white is very low compared to that of the standard anode. This suggests that the anode is highly over-pitched. The abundance of pitch added to the surface makes it seem artificially smoother. Visual inspection in this case might indicate an over-pitched anode, but the software predicts the pitch percentage which is slightly higher (15.2 %) compared to that of the standard anode (15 %). The density of anode 6 (1.56 g/cm^3) is also similar to that of the standard anode (1.59 g/cm^3).

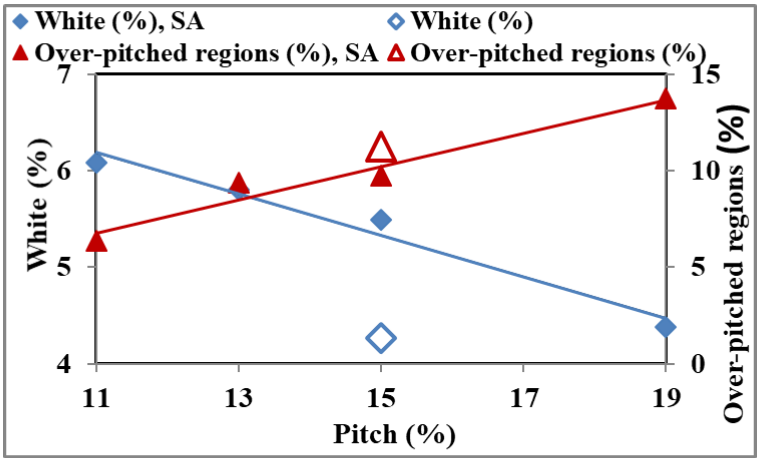


Figure 7. Evolution of the percentage of white and over-pitched regions as a function of the pitch percentage for the anode with high pitch regions on the surface (SA: standard anode).

3.1.4 Effect of the Presence of Oil Patches on the Surface

The results obtained for the green anode 7 (Table 2) produced with oil spots on the face by applying too much oil on the mold surface are shown in Figure 8. For this anode, although the pitch percentage is 15 %, the white percentage indicates an anode with a rough surface (under-pitched), because the oil cools the mold which in turn cools the pitch.

Adding too much oil also changes the appearance of the surface and the software predicts an under-pitched anode. If such a case is detected, but the pitch level is normal and the density is acceptable, there is a strong possibility of an anomaly in the operation (excess oil on the anode surface in this case). As it is mentioned previously, although the result of the software does not predict the actual condition of the anode, it predicts what the operator would see.

This case is similar to the one where the anode is produced using a cold mold (anode 5). Since the oil is at room temperature, it cools the mold. However, the mold in this case is gradually cooled whereas the mold was always cold from the beginning for anode 5. The density of the anode 7 is 1.57 g/cm^3, similar to that of the standard anode compared to the much lower density (1.44 g / cm^3) of anode 5 (Table 2).

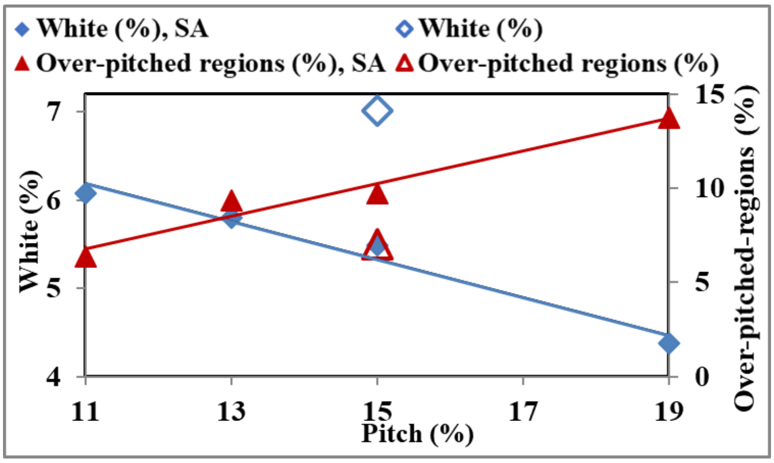


Figure 8. Evolution of the percentage of white and over-pitched regions as a function of the pitch percentage for the anode with oil patches on the surface (SA: standard anode).

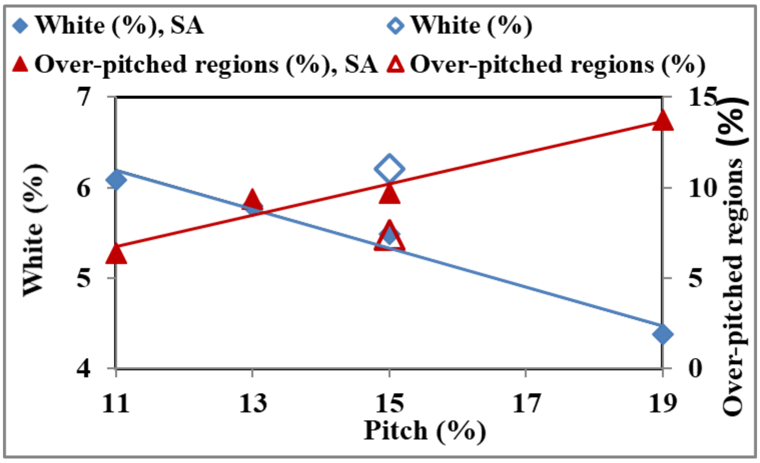


Figure 9. Evolution of the percentage of white and over-pitched regions as a function of the pitch percentage for the anode surface cooled with water jet (SA: standard anode).

3.1.5 Effect of Subjecting the Anode Surface to Water Jet

The results obtained for the surface of the green anode 8 (Table 2) which was exposed to water jet are shown in Figure 9. For this anode, although the pitch percentage is 15 %, the percentage white value indicates an anode with a rough surface, because the water jet cools the mold, which in turn cools the pitch too quickly.

This case is similar to that of anode 5 which was produced using a cold mold as well as the anode 7 where an excessive amount of oil is added to the surface. The density is lowered to 1.55 g/cm^3 due to cooling effect of the water jet (Table 2). The pitch level is underestimated due to the low temperature of the water which cools some areas of the surface rapidly. Again, the software's prediction of this case with a normal pitch level and acceptable density does not represent the anode's quality, but it represents what the operator sees.

3.1.6 Influence of Granulometry on Image Analysis

The images of anode 10 surface and its analysis is visualized in Figure 10. This anode contains layers with different granulometry (Table 2). This figure clearly demonstrates the presence of layers (stratification) of different types of particles and the importance of particle size in the production of a high-quality anode. The density of this anode is very low (1.43 g/cm^3, Table 2). The regions of the anode surface where the fine particles are found, the appearance of the anode is smooth due to the high quantity of pitch surrounding these particles. Smaller particles have larger surface, hence more pitch is needed to cover their surfaces. On the other hand, a rough appearance is observed where the large particles are present due to the high porosity. Regions of large particles have much less white than those of fine particles. Overall, the software predicts a smoother surface compared to the surface of the standard anode containing the same pitch percentage (anode 3).

Figure 11 compares the percentages of white and pink regions of anode 9 with those of anode 3. These percentages are found to be slightly lower for anode 9 compared to those of the standard anode due to the anomaly created by the manufacturing conditions discussed above. Certainly, such an anode would never be produced by industry. However, the predictions of the software are as expected.

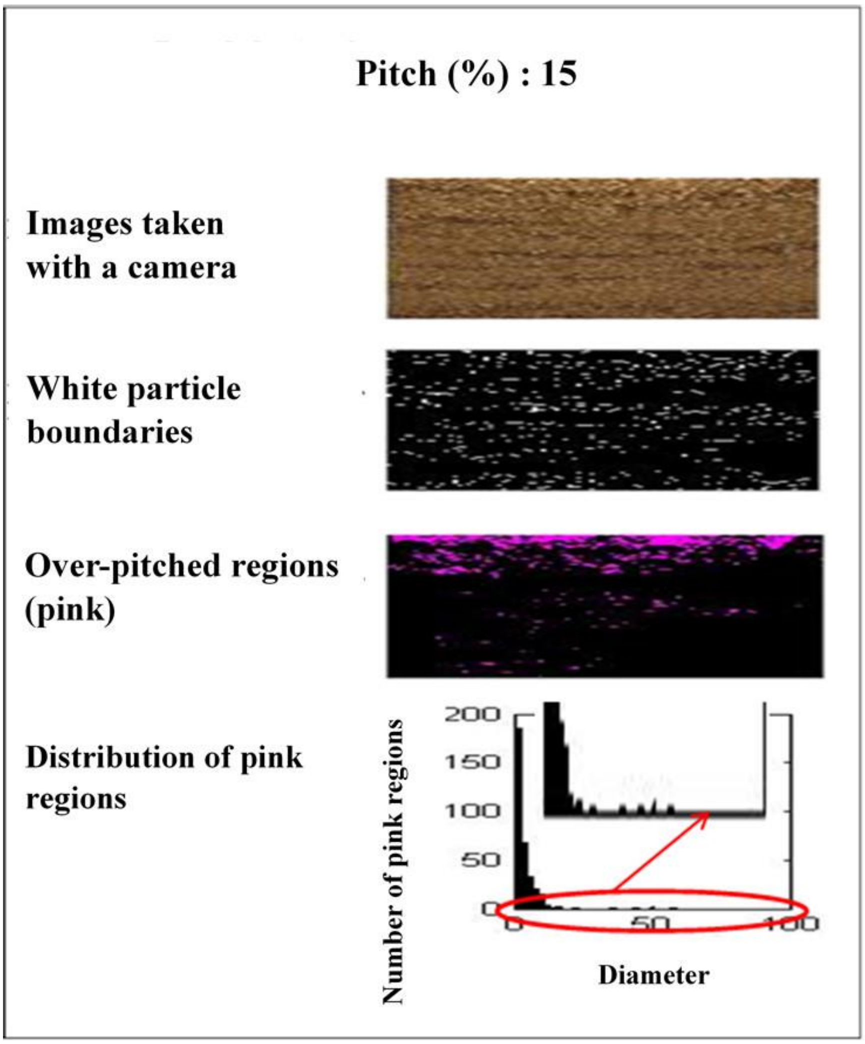


Figure 10. Image analysis results for the small surface of the laboratory anode composed of different layers containing different granulometry.

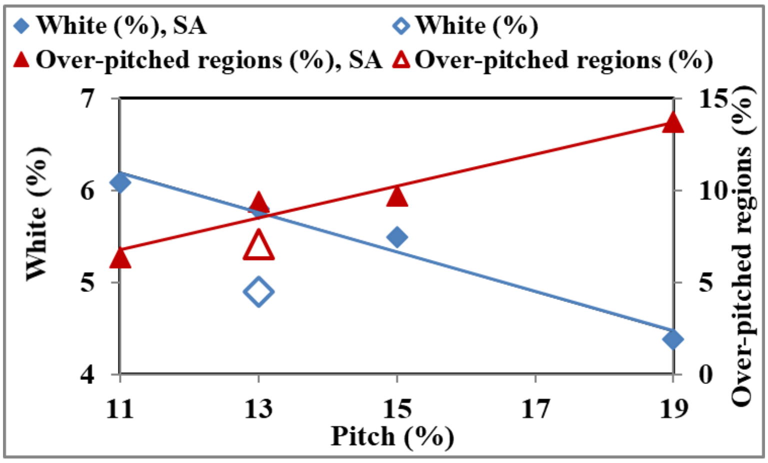


Figure 11. Evolution of the percentage of white and over-pitched regions as a function of the pitch percentage for anode with layers of coke of different granulometry (SA: standard anode).

3.1.7 Influences of Butt Particle Sizes

The results obtained for anode 10 (Table 2) are demonstrated in Figure 12. For this anode, the pitch rate is the same as that of the standard anode 3 (15 %). The percentage white value indicates a rough-faced anode. The pitch level indicates an under-pitched anode.

The butt is the recycled part of the anode and contains pitch-coke. Thus, it is less porous than the fresh coke and constitutes about a quarter of the dry aggregate. Since the particle size distribution is the same as the distribution used for anode 3, the use of the larger butt particles in the anode recipe means that the majority of the smaller particles are the coke particles. Given that each particle fraction is fixed in the recipe, the amount of large coke particles is also reduced. It is well known that small particles have a larger surface area (including pores) than large particles. Therefore, more pitch penetrates into the coke particles resulting in under-pitched surface. The software predicts a rougher surface and an under-pitched anode as expected. The density is 1.61 g/cm^3 which is slightly higher than that of the standard anode (1.59 g /cm^3) due to the large butt particles.

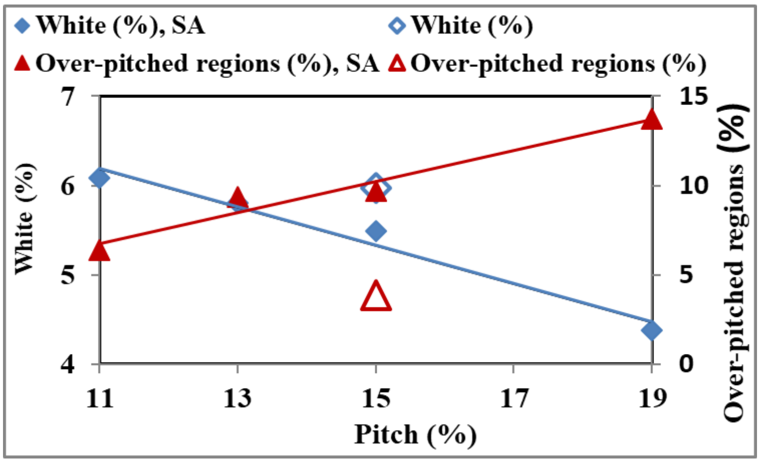


Figure 12. Evolution of the percentage of white and over-pitched regions as a function of the pitch percentage for the anode with large butt particles (SA: standard anode).

4. Spectrometry Results: Validation of the Software

Table 3 compares the spectrophotometer readings for different standard anodes produced with different pitch percentages. As it can be seen from this table, the spectrophotometer readings increase with increasing pitch percentage. This is because the absorption of light is proportional to the concentration of pitch in the anode. Thus, the spectrophotometric analysis of laboratory anodes confirms the results obtained with the image analysis software.

Table 3. Comparison of the spectrophotometry results with the predictions of the image analysis software for three anodes with different pitch percentages.

Anode no	1	2	3
Pitch (%)	11	13	15
Spectrometer reading	3.498	3.696	3.996

Sixteen sections of face 1 of each anode (Figure 3) were also analyzed with a spectrophotometer and the results are compared with the software predictions. Figure 13 shows the results for anode 1. The spectrometry results are shown with a histogram whereas the percentages of pink regions of the same section measured with the image analysis software is shown with the triangles. It can be seen that the trend is similar. The pitch percentage of interior and the outer layers are comparable. The higher the spectrometer reading is, the higher the percentage of pink (over-pitched) regions is. Similar results were obtained for all the anodes. These results show that the over-pitched regions can be identified with the image analysis software.

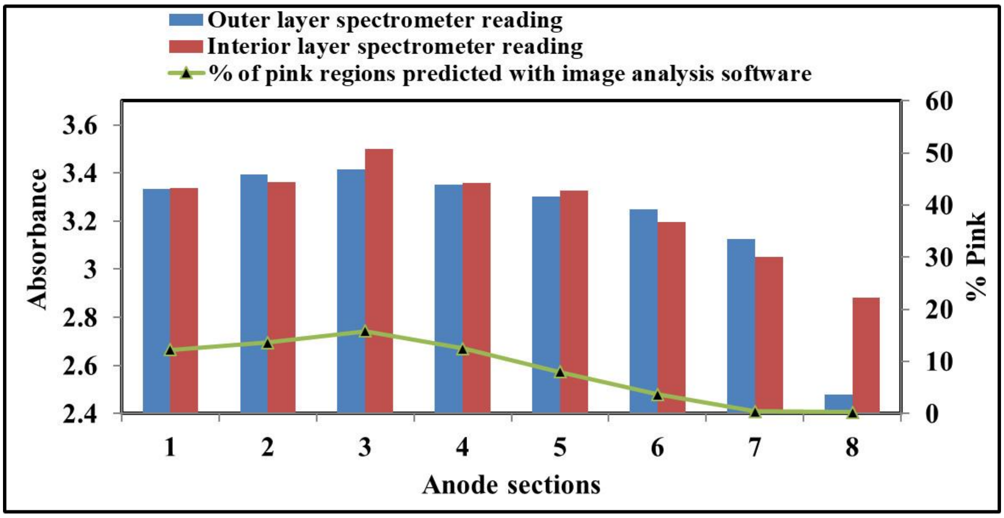


Figure 13. Spectral readings for pitch and image software predictions of pitch percentage (pink regions) for different sections of anode 1.

5. Conclusions

A simple system consisting of a camera and a light source was constructed to illuminate the anode surface. The developed image analysis software can quickly analyze the distribution of pitch on the surface of green anodes. It also determines whether the anode surface is over-pitched or under-pitched.

As it is well-known, it is difficult to predict the overall quality of the anode only from the conditions of its surfaces. However, the surface conditions are inspected by the operators, and the interpretation of each operator might be different. This software is meant to automatize the evaluation of the anode surface and eliminate the human error. It seems to be working well. The regions identified as over-pitched by the image analysis software on all the anodes were analyzed with spectrophotometry and the results confirm the predictions of the software.

Acknowledgements

The technical and financial support of Aluminerie Alouette Inc. as well as the financial support of the National Science and Engineering Research Council of Canada (NSERC), Développement économique Sept-Îles, the University of Québec at Chicoutimi (UQAC), and the Foundation of the University of Québec at Chicoutimi (FUQAC) are greatly appreciated. The authors would also like to thank Dr. Samir Sahli for his valuable suggestions on the improvement of the efficiency of the analysis.

References

1. Kristine L. Hulse, *Anode manufacture: raw materials, formulation and processing parameters*, 1st edition, R & D Carbon Ltd., Sierre, Switzerland, 2000, 416 pages.
2. Dipankar Bhattacharyay et al., Determination of Coke, Pitch and Pores/Cracks in Green Anode by Image Analysis, *Journal of Surface Engineered Materials and Advanced Technology*, 2013, vol. 3, pp. 1-6.
3. André Proulx, Optimum binder content for prebaked anodes, *Light Metals* 1993, pp. 657-661.

4. Yann Le Meur, *Analyse automatique de la qualité des images issues de détecteurs plats à rayons* X, Ph.D. thesis, Institut Polytechnique de Grenoble, Grenoble, France, 2009.
5. Su Liang, Majid Ahmadi, and Malayappan Shridhar, A Morphological Approach to Text String Extraction from Regular Periodic Overlapping Text/Background Images, *CVGIP: Graphical Models and Image Processing*, 1994, vol. 56, pp. 402-413.
6. Carl-Pete. Reip, Reinhert Flender, and Matthias Frommert, EBSD analysis of complex microstructures of CSP (R) processed low carbon micro-alloyed steels, *Characterization of Minerals, Metals, and Materials*, 2012, pp. 11-18.
7. Keri Ledford, Stephanie Lin, and Jason Nadler, Processing and microstructural control of copper foams for thermal wick material systems, *Characterization of Minerals, Metals, and Materials*, 2012, pp. 69-75.
8. Karoly Solymar, Ferenc Madai, and Dimitri Papanastassiou, Effect of bauxite microstructure on beneficiation and processing, *Light Metals* 2005, pp. 47-52.
9. Valerie Martinent-Catalot, Jean-ichel Lamerant, and Sonia Favet-Cossoul, A new method for smelting grade alumina (SGA) characterization, *Light Metals* 2004, pp. 87-92.
10. Slawomir Swillo and Marcin Perzyk, Automated vision system for inspection of surface casting defects based on advanced computer techniques, *in TMS 2012 141st Annual Meeting & Exhibition - Supplemental Proceedings*, Vol 2: Materials Properties, Characterization, and Modeling, ed Warrendale: Minerals, Metals & Materials Soc, 2012, pp. 387-394.
11. Stein Rorvik, Arn P. Ratvik, and Trygve Foosnaes, Characterization of green anode materials by image analysis, *Light Metals* 2006, pp. 553- 558.
12. Jason Tessier et al., Image analysis for estimation of anode cover material composition, *Light Metals* 2008, pp. 293-298.
13. Randall Bowers et al., New Analytical Methods to Determine Calcined Coke Porosity, Shape, and Size, *Light Metals* 2008, pp. 875-880.
14. Angelique N. Adams, Jonathan Paul Mathews, and Harold Schobert, The use of image analysis for the optimization of pre-baked anode formulation, *Light Metals* 2002, pp. 547-552.
15. Saravanan Chandran, Color Image to Grayscale Image Conversion, *Second International Conference on Computer Engineering and Applications Proceedings*, 2010, Vol 2, pp. 196-199.
16. Yasar Kocaefe et al., Testing of SERMA Technology on Industrial Anodes for Quality Control in Aluminum Production, *Light Metals* 2020, 1189-1195.
17. Marc Gagnon et al., Mirea: An On-Line Quality Control Equipment Integration in an Operational Context, *Light Metals* 2016, pp 979-984.