SIEF VACATION STUDENT PROJECT VIC12-004 – STUDENT REPORT

STUDENT DETAILS:

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Study discipline and year: Aerospace Engineering and Commerce (double degree) Final Year

TITLE: Characterising the 3D microscopic surface roughness of carbon anodes and gray cast iron thimbles and investigating the relationship between the two quantities

Date: 21 February 2013

EXECUTIVE SUMMARY

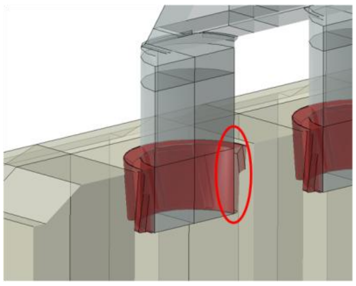
The project aim was to characterize roughness parameters at the critical interface between the carbon anode and cast iron thimble in the anode assembly of Hall Héroult cells. These are first steps towards better predicting the power loss over this interface through computational modelling of the assembly. Modelling is carried out using Finite Element Analysis (FEA) which facilitates the optimisation of component designs. Knowledge of surface roughness values allows the modelling of microscopic thermal and electrical interactions between the two surfaces which would, in turn, improve the quality of predictions of the model at the macroscopic scale.

Several pairs of samples comprising a carbon surface and the opposing cast iron surface were obtained and their surface roughnesses were measured using a high resolution optical profiler. We believe the S_a values generated in this project are the first characterisation of its kind in terms of roughness for the two surfaces involved. These will allow CSIRO to develop theoretical correlations for both electrical and thermal conductance which can be validated against published data derived from experimental studies.

The cast iron surface was found to be smoother than the carbon surface. It was also observed that, at the bottom of the thimble, the average surface roughness parameter S_a for cast iron remained around 75 µm whilst that of the carbon varied from 100 to 400 µm. The lack of an obvious correlation between the two surfaces is potentially explained by the sum of the effects of (i) surface tension of the cast iron melt not allowing the wetting of the carbon surface adequately during solidification and (ii) the subsequent flattening of peaks on the cast iron surface during the plastic deformation it underwent at elevated temperatures and pressures during heating in the oven to mimic cell operation conditions. It is also possible that the quantities measured and the relatively small surface areas scanned (4 mm x 6 mm) may be insufficient to completely describe the characteristics of the surface. Further work is recommended.

This 12-week project has provided me with exposure to a situation where mathematical modelling is used in an industrially relevant situation in a research organisation.

INTRODUCTION

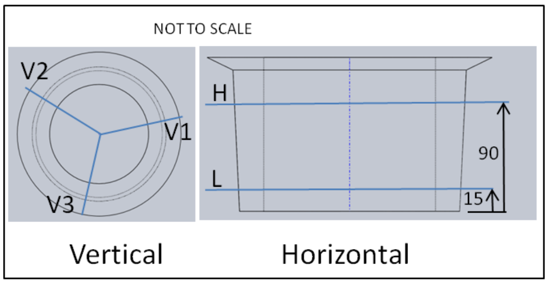


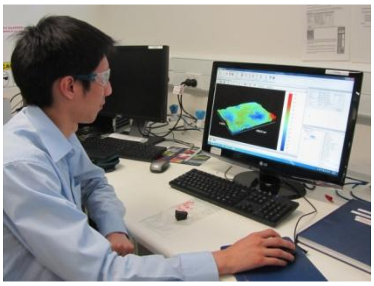
Amongst all the electrical connections found in the anode assembly, the carbon anode - cast iron thimble connection plays the most critical role in terms of power loss. This interface is currently modelled at the macroscopic scale assuming that the surfaces are perfectly smooth and thus current and heat flows are uniform across it. Improvements can therefore be made in the accuracy of predictions from models if the microscopic details such as roughness are considered. Given that there is no publicly available information quantifying the surface roughness of the two surfaces at this interface, this work aims to fill this gap.

AIM

Measure the microscopic surface roughness of the constituent surfaces at the anode-thimble interface.
Analyse correlations between the roughnesses of the two surfaces and their variation with height.

EXPERIMENTAL

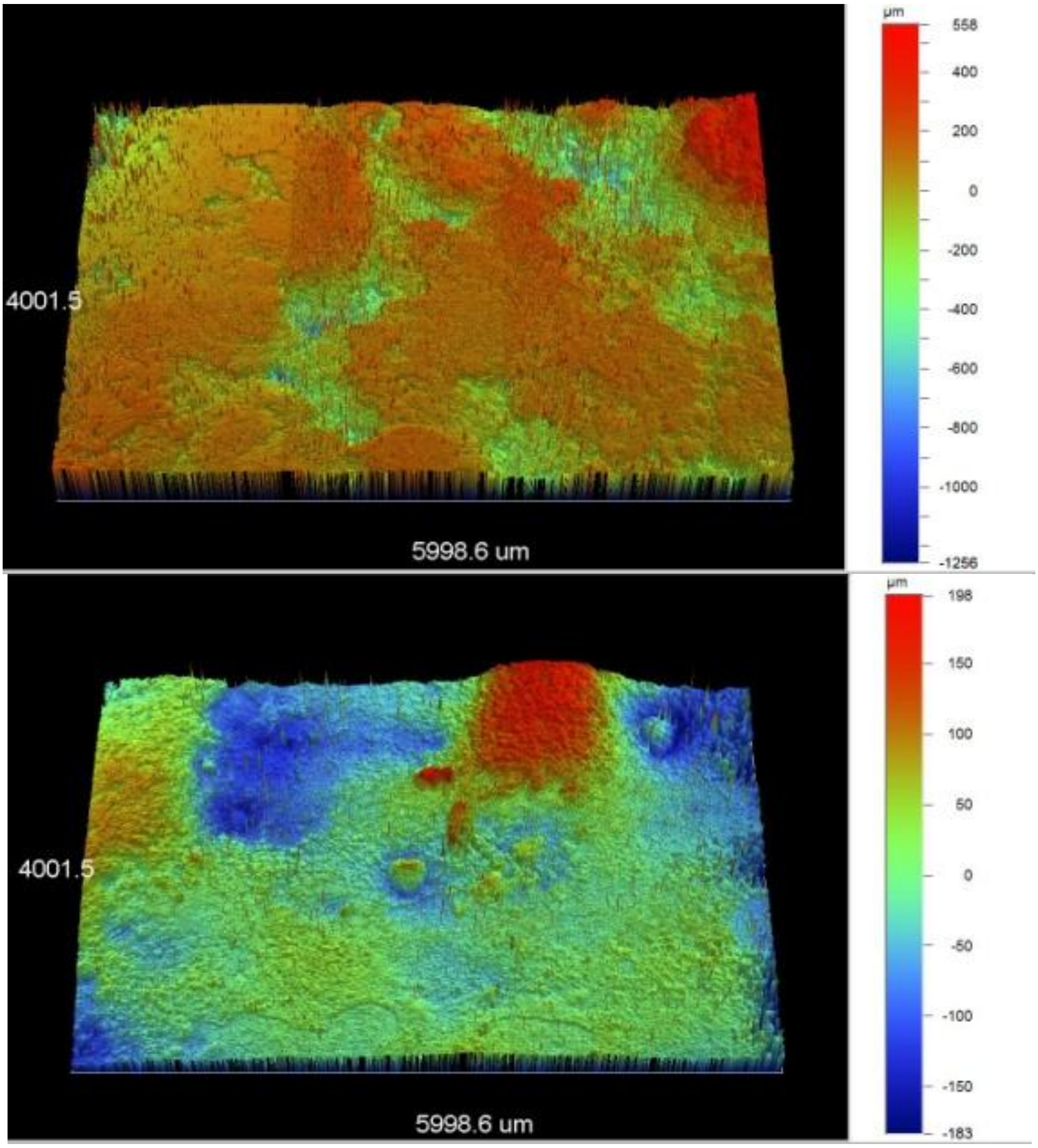




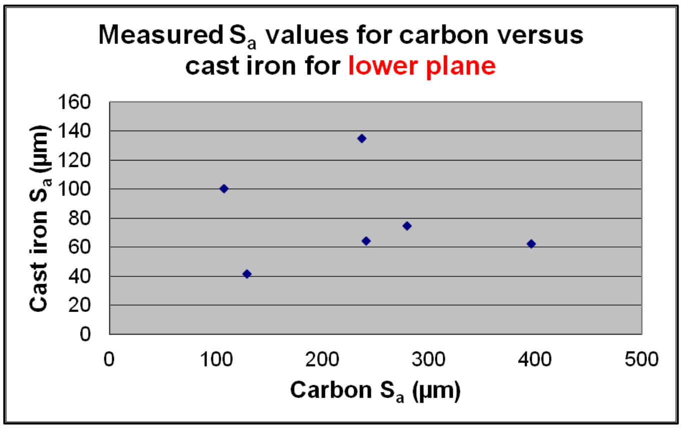
A sample anode assembly was heated in a furnace at CSIRO to about 800^{o} C over 5 days in order to generate surfaces representative of those found at operating conditions in an anode assembly. The samples were taken from the positions as shown (left). Matching pairs of cast iron and carbon samples were taken from three vertical planes equally spaced apart and from two horizontal planes, the latter to enable us to capture any variation with height. The samples were scanned using a Bruker Contour GTK1 3D optical profiler (right) over a sample area, 6x4 mm.

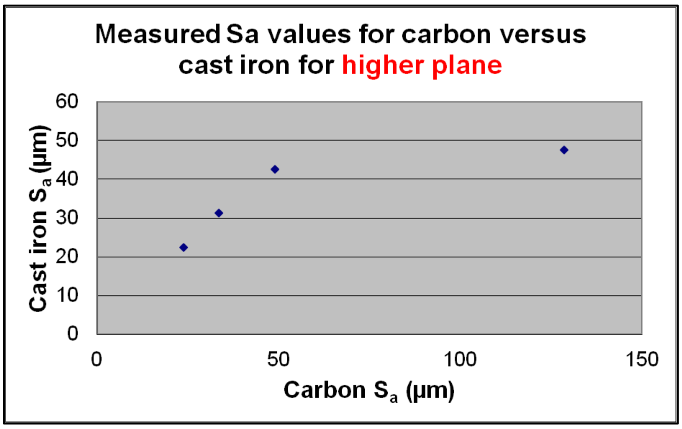
RESULTS

Sample 3D surface maps of a matching carbon (top, legend -1256 to 558 µm) and cast iron (bottom, -183 to 198 µm) pair are shown below.



The average roughness values S_a from above are plotted below for the lower and higher horizontal planes respectively.





DISCUSSION

All samples were measured. However it was observed that a layer of cast iron was found on the carbon surfaces from the top horizontal plane. This may have had the effect of altering the actual surface roughness values at this plane and therefore the values given for the higher plane (right) were disregarded in this work. It was therefore not possible to determine the differences in roughness attributable to variations in height.

As can be deduced from the plot above for the lower plane (left), the carbon surface is rougher than the cast iron surface. This is as expected since the cast iron melt does not fully conform to the surface of the carbon during casting due to the effect of surface tension. However, significantly, the cast iron surface roughness is seen to be unaffected by changes in the carbon surface roughness. The cast iron S_a values remained at an average of 75 µm whilst the carbon values vary from 100-400 µm. This may be partially owing to surface tension effects discussed above and partially due to the fact that peaks on the cast iron surface may have been flattened during the plastic deformation it underwent at elevated temperatures and pressures when it pressed against the carbon surface in the oven. Since the oven temperature (about 800^o C) was lower than the pouring temperature (1400^o C), it is unlikely the cast iron expanded sufficiently for the anode valleys to create corresponding peaks on the cast iron surface during the plastic deformation stage. It is also possible that the quantities measured and the relatively small surface areas scanned (4 mm x 6 mm) may be insufficient to completely describe the textural characteristics of the surface. Although much care was taken, the probability that the areas scanned on each of the carbon and cast iron samples may not have been exactly opposite each other is another potential contributing factor to the lack of an obvious correlation between the roughnesses of carbon and cast iron.

OUTCOMES

1. The surface roughnesses of anodes and thimbles being quantified for the first time;
2. These roughness values were compared at various positions on the anode-thimble interface, revealing a potential lack of an obvious correlation. Whilst potential reasons were discussed, this requires further investigation
3. This knowledge allows CSIRO to develop improved correlations for electrical and thermal contact resistances over the anode-thimble interface to improve the accuracy of FEA modelling. of electrical connections in the aluminium production process.
4. The 3 months I spent at CSIRO provided me with exposure to a situation where mathematical modelling was used in an industrial relevant situation in a research organisation.

BIBLIOGRAPHY

D. Tay, D. R. Gunasegaram, D. Molenaar (21 Feb 2013), 'Characterising the 3D surface roughness of carbon anodes and cast iron thimbles', CPSE Vacation Student Report.

ACKNOWLEDGMENTS

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