Design and validation of conformal anodes for thermal barrier coating on a triple vane

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Thermal barrier coatings (TBCs) are layered systems deposited on thermally highly loaded metallic components such as high pressure turbine blades or nozzle guide vanes in gas turbines. TRIBOMET® MCrAlY coatings are Praxair Surface Technologies' unique *electrodeposited* version of the high temperature oxidation and corrosion resistant MCrAly coating and typically contain "metal" (nickel/cobalt) chromium-aluminium-yttrium and other active elements. Praxair's MCrAlY coatings are produced by the carefully controlled co-deposition of CrAlY powder with nickel and/or cobalt from conventional electroplating baths. This is later followed by vacuum heat treatment to produce the MCrAlY alloy coating. To-date, design of the electroplating configuration is largely a combination of experiential and empirical approaches often consuming substantial labour and lead time. This paper describes how Elsyca's newly developed CAM tools were used to assess and guide the design of a conformal anode system with the objective of achieving a very uniform deposit on a triple vane configuration. The simulations are validated with experimental deposit thickness measurements on the actual parts and a very good agreement is observed for all test points on the triple vanes. From this it can be concluded that simulations are a relevant and very powerful tool to design complex plating configurations. Implementing such a *digital manufacturing* approach can significantly reduce labour costs in reaching an optimum tooling design, resulting in a reduction in time to market and time to revenue.

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Introduction

In industrial plating cells, the current density and layer thickness distribution over a substrate or workpiece are governed by the electrolyte characteristics, the reactor configuration and the electrical driving force. The key electrolyte characteristics (to be determined at operating temperature) are:

- ohmic drop in the electrolyte solution (electrolyte conductivity);
- cathodic polarisation and plating efficiency;
- anodic polarisation.

The reactor configuration is to be defined as the assembly of:

- position and shape of anodes, screens and current thieves;
- workpiece shape and dimensions;
- selective insulation of workpiece surfaces.

Most plating processes are current driven, in that case the electrical parameters are:

- total injected current or current per source (if multiple sources present);
- distribution of the current (single source) over multiple anodes.

The modeling approach that takes into account these phenomena is commonly denoted as the 'potential model'. In order to produce reliable simulation results, the physico-chemical input parameters (polarisation behavior, plating efficiency and electrolyte conductivity) need to be determined carefully for the electrolyte bath being used, at the proper operating temperature.

Plating cell design for optimizing the plated layer thickness distribution by trial and error will often attract huge labor costs, while the ultimate result on the layer thickness distribution might remain poor, or 'just' within specifications, mainly due to the large quantity of adjustable process parameters (see above).

In this paper, DC current simulations are performed for a triple vane cathode with conformal anodes. A Ni-Co bath is considered, developed by Praxair in house. This electrolyte bath is part of the Tribomet © MCrAlY coating series. The final layer thickness on each spot on the blades is governed by:

- current density distribution and Faraday's law;
- incorporation of CrAlY powder particles (estimated to be about 45 volume percent).

In practice, the triple vane configurations are rotated in the plating tank, in order to expose each surface in upward horizontal position to the CrAlY powder for at least a fraction of the process time (enabling the particles to settle and be incorporated into the deposit).

In order not to complicate this study, the laboratory characterisation of the plating bath is performed without CrAlY particle load, hence the simulated Ni-Co layer thickness distributions do not include this particle load either. In a later stage, it will be investigated whether there exists a simple correlation between local Ni-Co layer thickness values, and the experimentally observed layer thickness values with particle incorporation.

Plating bath characteristics

Polarisation measurements have been performed for the (powder free) bath sample, for an operating temperature of $44\ ^{o}C$. The conductivity of the electrolyte is measured to be *7.25 S/m.*

For the current density range of interest (approximately *0.0* to – *200* A/m^2), the cathodic polarisation curve shows a Butler-Volmer type (exponential) behaviour (figure 1).

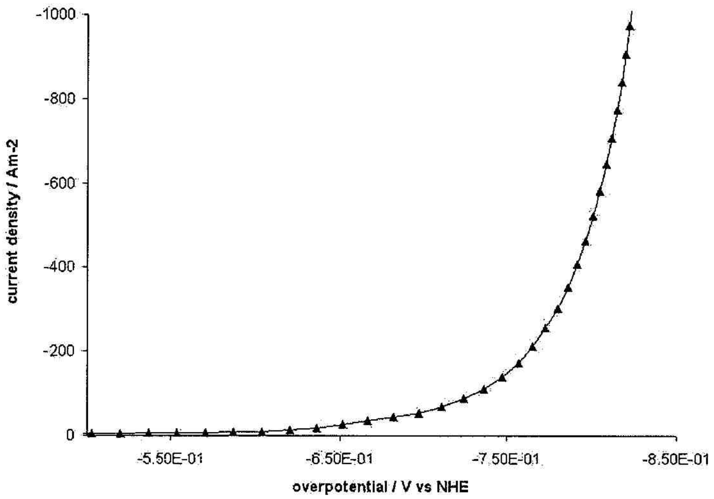

Figure 1: cathodic electrode polarisation curve obtained at a Rotating Disc electrode at *2000 rpm*, after electrolyte ohmic drop correction

The local deposit thickness can be computed based from Faraday's law:

$$d = -\frac{M\,\Delta t\,\theta\,j}{\rho\,z\,F}. \qquad (1)$$

with: d local deposit thickness (m);

θ efficiency of the plating process (depending on j);

z	Ni and Co ion charge (= *2*);
M	averaged atomic weight of Ni and Co (= $58.9\ g\ mol^{-1}$);
ρ	averaged Ni and Co material density (= $8.9\ kg\ dm^{-3}$);
j	local cathodic current density (A/m^2).

Since the physical data for Ni and Co are very similar, an average value for M and ρ will do. The plating efficiency θ is assumed to be very close to 100 percent. The total plating time Δt is *72 000 seconds* (*20 hours*).

The polarisation behavior of the platinised Ti anodes is approximated by a linear curve (taken from Elsyca's in house database):

$$j = 1.0E+3\ (V-U) - 1.5E+3. \tag{2}$$

where V is the electrode potential, and U the electrolyte potential adjacent to the electrode. j is the current density in A/m^2.

Plating configuration

The CAD model is a SolidWorks© assembly with several components as shown in figure 3:

- triple vane part;
- 4 Ti mesh anodes (see figure 2);
- anode rods and holders;
- fixtures for the triple van part at top and bottom.

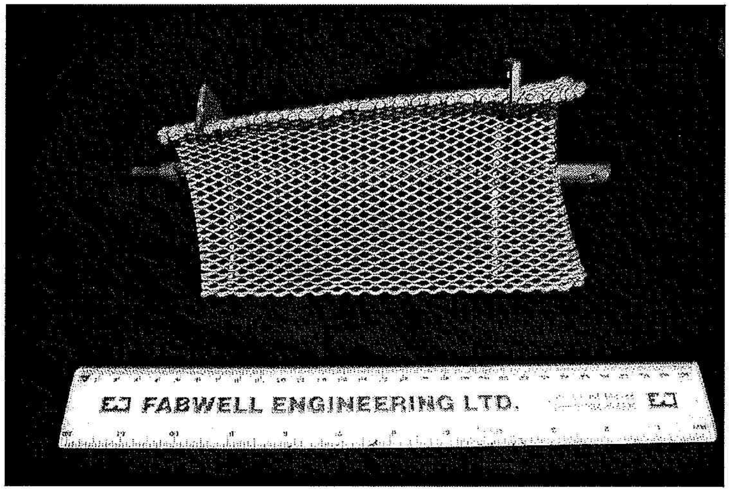

Figure 2: photograph of Ti mesh anode with holders and rod

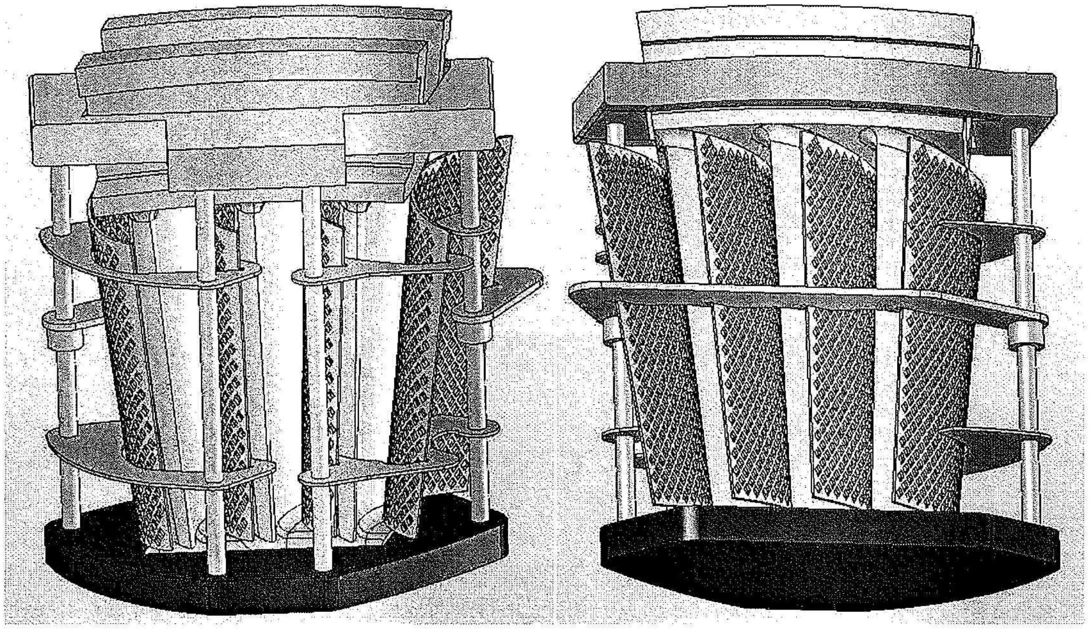

Figure 3: triple vane plating configuration for simulation purposes

Simulation results

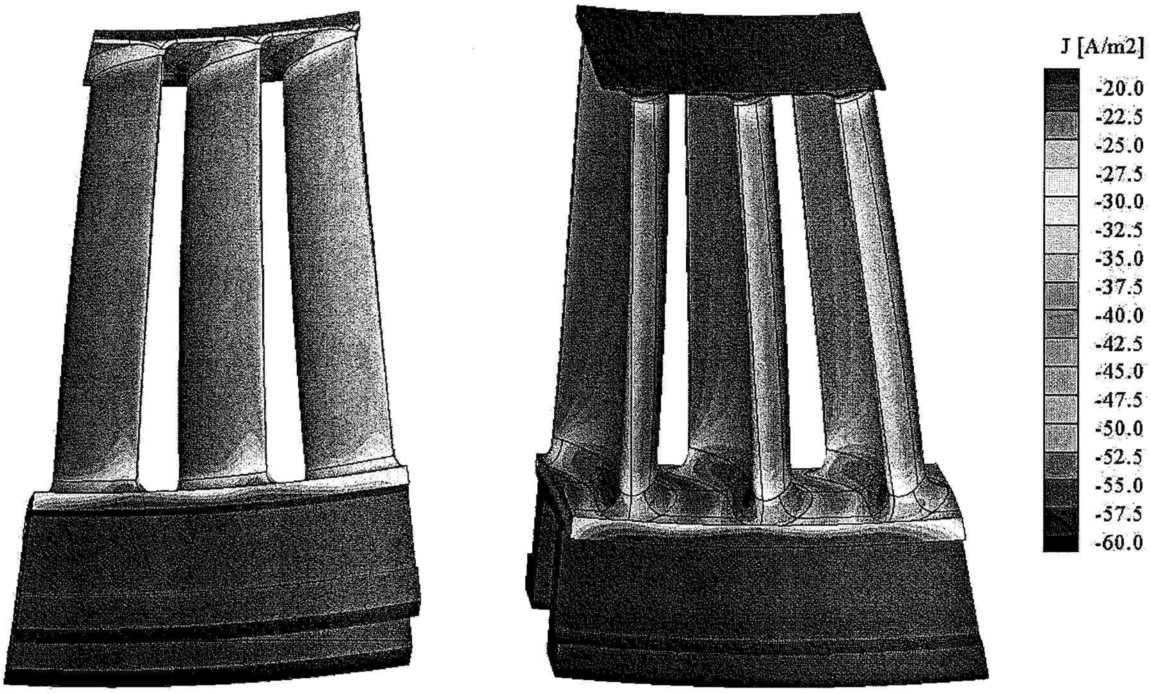

Figure 4: simulated current density distribution over the blades (in A/m-2)

The simulated current density distribution over the blades is plotted in figure 4, for a total impressed current of *5.65 A*, and a plating time of *20 hours*. It is observed that the current density over the triple vane head ranges from *5 – 12* A/m^2 (compared to an average value over the blades of about *40* A/m^2, hence the head is indeed acting as a non-negligible current thief robber.

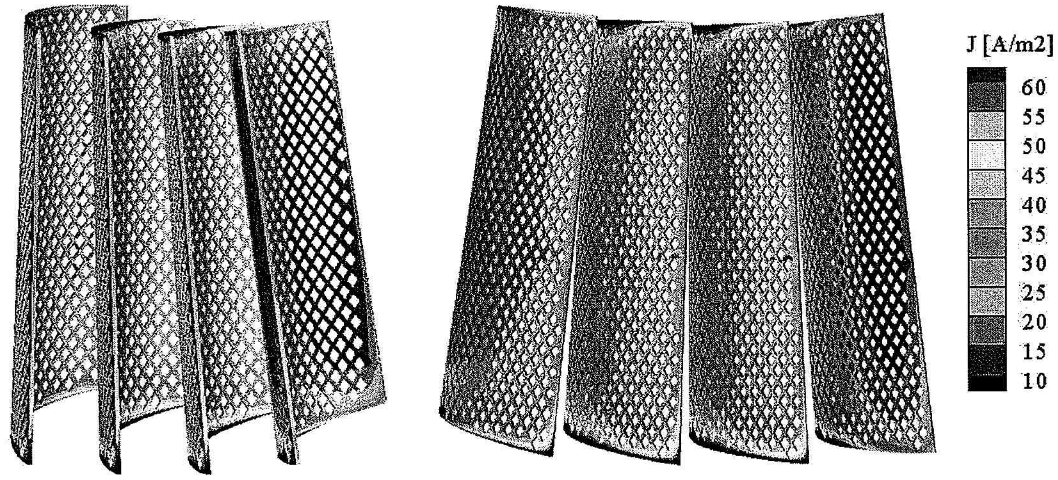

Figure 5: simulated current density distribution over the Ti mesh anode (in A/m-2)

The current density distribution over the anodes is plotted in figure 5, The surfaces of the outer anodes that are directed in opposite sense from the blades still deliver some current. The total current that is delivered by each anode (from left to right in figure 5) is computed as: *1.25 A / 1.69 A / 1.69 A / 1.02* A. This implicates that the outer anodes deliver significantly more current than would be expected from an ideal situation (i.e. half the value of the inner ones).

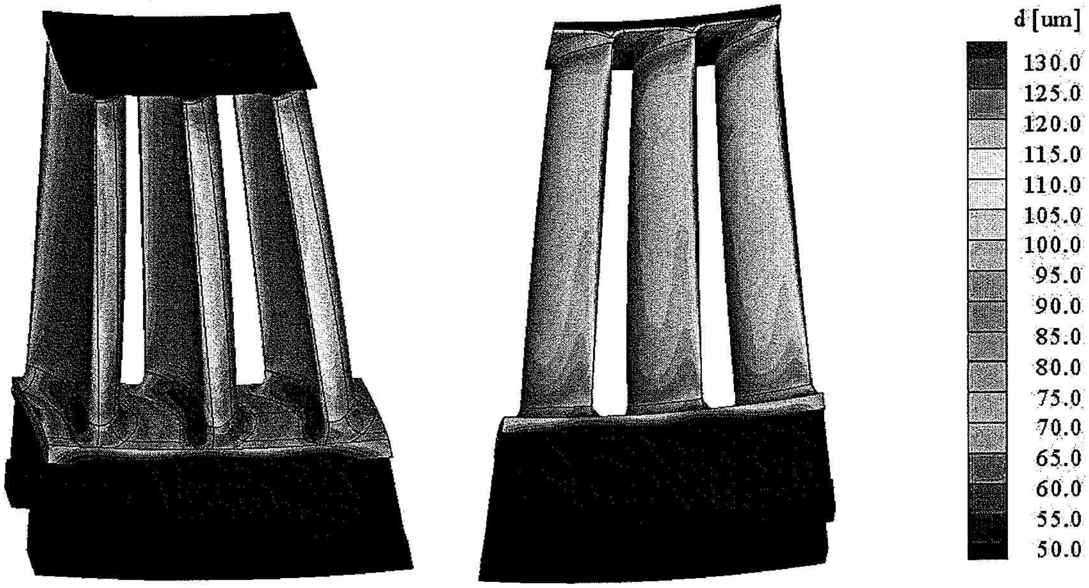

Figure 6a: simulated Ni-Co layer thickness distribution over the blades (in micron)

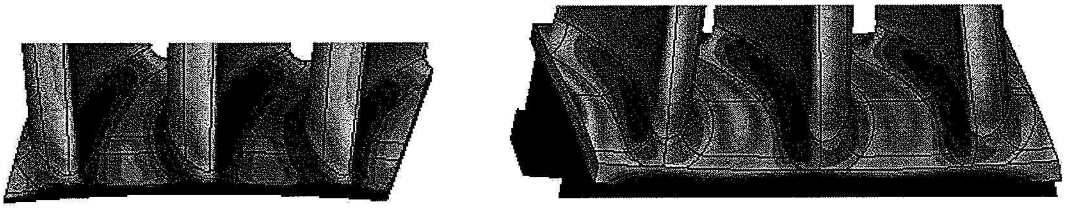

Figure 6b: simulated Ni-Co layer thickness distribution on inner (left) and outer platform (right)

The simulated layer thickness distribution is given in figures 6a and 6b. Values on the blades range from about 50 to 150 micron, with the lowest values observed at the inner platform fillets, and the highest ones at the trailing edges of the blades.

Comparison to experimental results

Table 1: experimental and simulated layer thickness values for different spots on the blades

	position A			position E			position K			position O		
	exp	sim	ratio	exp	sim	ratio	exp	sim	ratio	exp	sim	ratio
vane A 25 %	290	118	2.46	280	113	2.48	400	138	2.90	275	85	3.24
vane A 50 %	278	114	2.44	297	111	2.68	382	135	2.83	235	82	2.87
vane A 75 %	250	106	2.36	262	107	2.45	365	126	2.90	220	79	2.78
vane B 25 %	280	116	2.41	295	104	2.84	367	139	2.64	220	86	2.56
vane B 50 %	290	115	2.52	290	103	2.82	380	134	2.84	220	81	2.72
vane B 75 %	275	108	2.55	275	100	2.75	405	128	3.16	215	79	2.72
vane C 25 %	277	117	2.37	235	103	2.28	400	150	2.67	175	93	1.88
vane C 50 %	275	118	2.33	280	105	2.67	395	146	2.71	185	89	2.08
vane C 75 %	260	110	2.36	277	101	2.74	345	136	2.54	172	86	2.00
	aero			**fillet**			**platform**					
	exp	sim	ratio	exp	sim	ratio	exp	sim	ratio			
vane A outer convex	165	81	2.04	125	70	1.79	167	92	1.82			
vane A outer concave	172	74	2.32	165	54	3.06	207	80	2.59			
vane A inner convex	160	77	2.08	142	69	2.06	158	86	1.84			
vane A inner concave	185	57	3.25	155	47	3.30	207	67	3.09			
vane B outer convex	250	84	2.98	225	73	3.08	295	88	3.35			
vane B outer concave	125	59	2.12	150	52	2.88	152	73	2.08			
vane B inner convex	152	67	2.27	140	54	2.59	180	63	2.86			
vane B inner concave	135	55	2.45	130	45	2.89	175	55	3.18			
vane C outer convex	205	89	2.30	160	79	2.03	190	95	2.00			
vane C outer concave	75	60	1.25	62	51	1.22	75	65	1.15			
vane C inner convex	240	90	2.67	152	61	2.49	160	61	2.62			
vane C inner concave	110	64	1.72	85	49	1.73	105	62	1.69			

A comparison of simulated layer thickness values with experimental values is given in table 1. However, the experimental values are obtained with a powder loaded bath, whereas the simulated values hold for a powder free bath. It is interesting to note that the ratio or factor between the simulated and experimental results is fairly consistent, at 2.6 on the blade surfaces and 2.35 on the fillets and neighbouring spots. As already mentioned, the inclusion of the MCrAlY powder in the electrolyte will affect the resulting plating thickness for a number of reasons;

- the actual 'volume' of the powder particles will 'physically' increase the thickness of the deposited layer simply due to their inclusion
- the movement of the work piece in the bath will affect the rate at which the particles settle onto the surfaces and their inclusion into the deposit - a sediment of variable thickness is formed which will increase (thickness dependant) the resistance to current flow.
- the plating efficiency for the Ni-Watts type bath was assumed to be close to 100%, whereas, in reality there will be a decrease in efficiency in areas of low current density, such as in the fillets the results indicate that an adjustment is required to the anode design to improve fillet thicknesses.

Consequently, since the content of the MCrAlY power is 45% by volume then the thickness of the deposited layer will be larger by a factor of 1/0.45, that is, a factor of 2.22. This observation goes a long way towards explaining the difference in experimental and predicted thicknesses. Other, smaller effects will come into play, such as the current density effect on plating efficiency.

Since the components are rotated in the electroplating bath, it is sensible to assume that all surfaces will be *presented* to the settling MCrAlY powder for the same fraction of process time, and hence, in this particular process, the flow will not affect the final thickness distribution.

Scattering (noise) of experimental values seems to be higher on the fillets than on the blade surfaces.

Conclusions

The compared results from table 1 suggest that the simulations for a powder free bath can very well predict experimental values for a powder loaded bath. *Simple accounting* for the 45% volume fraction content of the powder would suggest a factor of 2.22, however, an across the board factor of 2.5 results in a better agreement. This is probably due to the variation of nickel plating efficiency in lower current density regions. Other deviations are explained by several factors:

- anodic polarisation behaviour of Ti anodes is only approximate (should be measured on laboratory scale for a sample of the Ti mesh) ;
- stochastical spread (noise) on experimental values ;
- approximate geometrical definition of sample points for comparison ;
- anode misalignments ;
- flow influence on particle incorporation .

One recommendation would be to re-visit the data and investigate if a variable factor can be determined as a function of varying current density and plating efficiency.

A simulation strategy for optimising the electrode / triple vane configuration will involve different steps:

step 1: defining the acceptance window for the definition of new auxiliary tools (anodes, screens, current robbers, …) and for modifications to the existing anodes;

step 2: defining some different configurations involving auxiliary anodes and / or screens and / or current robbers with a high potential improvement on the layer thickness distribution;

step 3: performing one or more exploratory simulations for each of these configuration (using full main anodes);
step 4: optimising the dimensions and position of the auxiliary tools for the selected configurations by consecutive simulations (using full main anodes);

step 5: fine tuning the dimensions and position of the auxiliary tools using perforated main anodes;
step 6: implementing the optimised configuration in practice and performing a wet run

step 7: measure the layer thickness distribution over the triple vane part (destructive test)

step 8: if spec's are not yet met, go back to steps 4 and 5 for further optimising the configuration and perform a new wet run afterwards.