CLEMEX

Image Analysis Report

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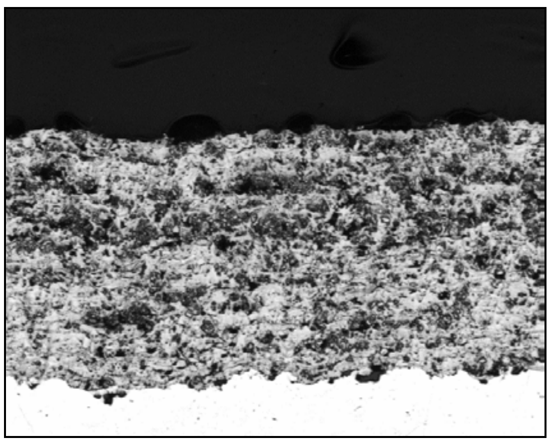

Coating and Inconel Characterization

Description of Samples

Six inconel samples with different coatings:

- Sample #1: 12% Cobalt, 4% Carbon, 1% Iron, 83% Tungsten,
- Sample #2: 75% Chromium Carbide, 20% Nickel, 5% Chromium,
- Sample #3: 95% Nickel, 5% Aluminum,
- Sample #4: 95% Nickel, 5% Aluminum / 12% Silicon, 88% Aluminum,
- Sample #5: 95% Nickel, 5% Aluminum / 85% Nickel, 15% Graphite,
- Sample #6: 95% Nickel, 5% Aluminum / 60% (12% Silicon-Aluminum), 40% Polyester.

Purpose of Analysis

Demonstrate the ability of the image analyzer to perform the following analyses:

- Average thickness of coatings
- Distribution of the coating constituents
- Particle distribution of coatings
- Porosity percentage of coatings
- Length distribution of oxides (globular or stringer) within the substrate
- Thickness of the gap on the bond/substrate interface
- Thickness of the gap on the bond/bond interface

Apparatus

Image Analysis System:	Clemex Vision 2.0 software
Microscope:	Nikon Optiphot-2 (1.5, 5.0, 10, 20, 40X) with reflected light
Stage:	Motorized marzhauser ek8b-s1 (100 x 100 mm) with auto focus drive
Camera:	Sony XC 77CE, B/W

Procedures

Only the routine used to analyze the coating thickness and porosity is described here. The other routines are discussed in the last section of this report.

The magnification was set at 100X for a calibration factor of 0.9810 µm/pixel. The analysis was performed on a varying amount of fields (depending of how many fields could be aligned on one row due to the curvature of the sample).

Figure 1a shows the binarization by *Thresholding* of the original image (front page). The coating, inclusions and dust particles are shown in red, the mounting media and porosity appear blue while the substrate is shown in green. In Figure 1b, several binary operations such as *Boolean, Transfer, Chordsize* and *Closing* were combined to remove inclusions and dust particles from the coating (red to yellow detection). Figure 2a shows the coating once holes have been *Filled* and partial holes have been *Closed*. In Figure 2b, the porosity (green) was isolated from the blue detection using a *Boolean* operation. This green detection represents the porosity as it was measured. Figure 3 shows the coating converted into measurement lines by a *Boolean* operation between the coating and a *Grid*. Measurements were performed on these lines to obtain a distribution of the coating thickness, as shown in Figure 4. Results are summarized in the next section.

The most significant image modifications and final results are as follows:

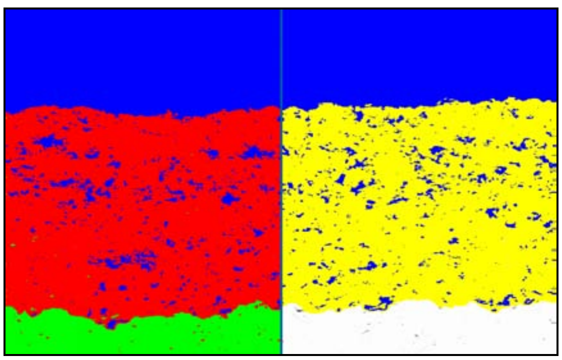

Figure 1a: Binarization by *Thresholding* of the original image.

Figure 1b: Binary operations remove inclusions and dust particles from the coating.

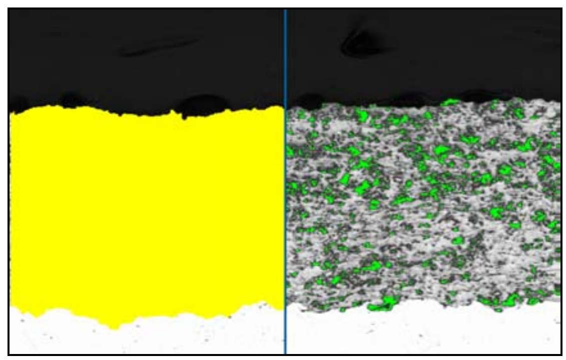

Figure 2a: Coating (holes have been *Filled* , partial holes have been *Closed)*.

Figure 2b: Porosity (green) isolated from the blue detection using a *Boolean* operation.

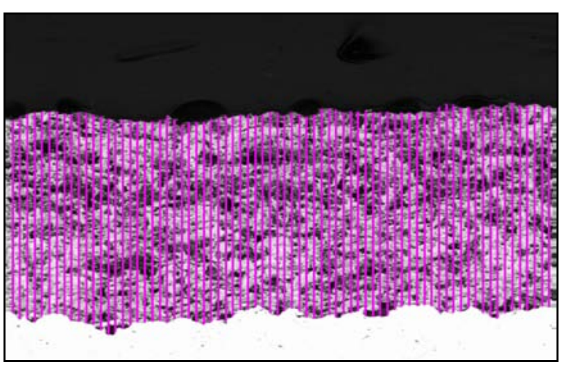

Figure 3: Coating converted into measure lines by a *Boolean* operation between the coating and a *Grid*.

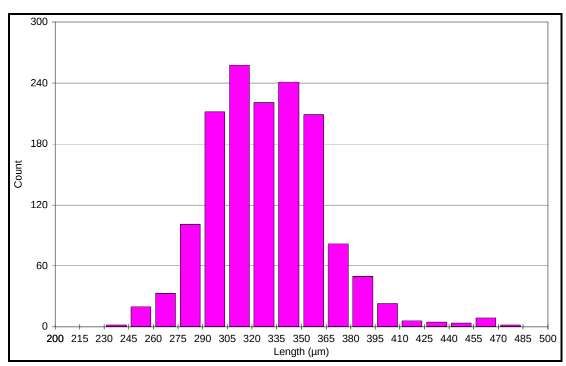

Figure 4: Coating thickness distribution.

Result Summary

	Coating Thickness ***(microns)***
Minimum	243.3
Maximum	477.7
Average	329.6
Standard Deviation	34.5

	Coating Porosity ***(%)***
Total	8.25

Discussion

The image analysis system can perform all the requested measurements. However, no gap between the bond/substrate interface or bond/bond interface was observable. Some dispersed porosity was found.

Average thickness of coatings

Coating thickness measurements are easily performed as long as the mounting is sufficiently dark. The addition of an opaque object on the top of the sample is sometimes necessary to darken the mount or to avoid shadow formation.

Different magnifications can be used to perform this analysis. The smallest suitable magnification allows the operator to rapidly analyze a large surface. It is also easier to align several fields, which is more representative of the variation of the coating thickness throughout the sample. This fact notwithstanding, the precision of the length measurements would, however, be improved if a higher magnification was used.

In practice, it is the thickness of the coating that determines the highest suitable magnification, because the entire coating (height) must fit into the field of view. When a high magnification is used on a curved sample, fewer fields can be aligned on the stage pattern. Performing a run in manual mode could be useful in this case, since manually positioning the stage would allow more fields to be analyzed at a higher magnification.

When the coating is too thick to fit into the field of view at the lowest possible magnification, another analysis technique can be used. This consists in reconstituting the coating using a *Tile* instruction and performing the thickness measurements on the final bitplane, after the run has been completed.

One difficulty that may sometimes be encountered, regardless of the method used, stems from the possibility of undetected porosity on top of the coating. This would tend to reduce the thickness of the coating. This problem does not appear significant, however.

On a more general level, it is a good practice to map the thickness distribution and glance at the longest and shortest lines to ascertain that they, in fact, represent the coating thickness accurately.

Constituent/particle distribution of coatings

The constituents analysis is easily performed when only the coating is included in the field of view. For this, the selected magnification has to be high enough to distinguish all constituents. For example, sample #1 was analyzed at 500X (0.1970 µm/pixel) to discriminate all constituents or particles, while sample # 6 was analyzed at 100X (0.9810 µm/pixel) since the particles that were present in this sample were very coarse. To ensure that results are representative, we recommend that more fields be analyzed when a high magnification is used.

Porosity percentage of coatings

To save time, the percentage of porosity analysis can be integrated into one of the routines described above. If it is included in the coating thickness measurements, special care must be taken in selecting a magnification factor. The operator must ensure that the porosity can be discriminated from the other dark gray phases or else, binarization by *Thresholding* becomes somewhat arbitrary. This situation must be avoided since poor thresholding would undoubtedly affect the porosity measurement.

A more suitable method would be to analyze the porosity percentage at the same time as the constituents distribution. Using this approach, the operator simply detects the appropriate gray level range into a new bitplane and the percentage of porosity can be obtained.

Length distribution of oxides (globular or stringer) within the substrate

The length distribution analysis of oxides required that only inconel be visible in the field of view. The magnification used was 100X (0.9810 µm/pixel). This was sufficient to detect objects as thin as 1 or 2 microns. A *Chord Size* instruction was used to exclude small objects that should not be considered in the analysis.

The main difficulty consisted in removing scratches and dust from the detection before measurements were performed. In an attempt to address this problem, binarization was performed by setting threshold limits such that as few artifacts as possible would be detected. This did not prove very effective since many artifacts were nonetheless detected as oxides. These artifacts were then removed by *Object Transfer by Limits,* using a variety of criteria. Objects that were closer than 10 µm from each other were reconnected as a string by applying 10 cycles of *Horizontal Closing* (1µm ≈1 cycle).

Despite all this, many artifacts remained and were subsequently identified as oxides by the system. When this occurred, the unwanted inclusions had to be deleted from the Data Browser after the run was completed using the mapping view feature. This procedure was feasible largely because all statistics are updated each time an object is removed from the database.

The inclusion rating analysis could have been performed more easily with *Clemex CIR* - a specialized computerized inclusion rating system.