Quantitative evaluations of heterogeneous polymer-metal joints by image analysis

S. Crâsteţi, D.R. Pascu
National R&D Institute for Welding and Material Testing - ISIM Timişoara

Keywords

Heterogeneous joints, algorithm, imaging, microstructural evaluation

1. Introduction

In order to apply the specific quantitative and qualitative evaluation techniques in the case if microstructural digital images analyse [1, 2], an initial computerised pre-processing of the images is necessary is necessary. During this process one has in view the following objectives:

- corrections regarding the lack of illumination uniformity;
- reduction of the background noise;
- spatial mediations of the collection of signals representing the digital image;
- applying operations destined to eliminate (reduce) distortions.

These supplementary imaging procedures are destined to pre-process (prepare) the image for the main processing evaluation modules, having as objective to evidentiate the areas of interest from the point of view of the informational content.

The final evaluation essentially depends on the quality of the pre-processing modules, so that to design evaluation systems one has in view the particular case of the application, as well as the specific pre-processing possibilities.

Among the main methods that characterize the further digital imaging processing stages aiming to isolate, putting in evidence and evaluate quantitatively the areas of interest, are the segmentation ones. Using these procedures one can implement as well a series of quantitative evaluation modules for the regions of interest in digital images [3].

To analyse and/or an automated interpretation of certain indication of interest embedded in digital images, software instruments capable of precisely identify the indications (areas) of interest are necessary. The processes of identifying there pixels are known as segmentation processes.

Based on segmentation one does obtain a partitioning of the images in distinct regions, for which one does further look to identifying some plausible correlations, with certain characteristics of interest that represent the objective of quantitative and/or qualitative evaluations in the microstructural evaluation systems.

Within the framework of the project [4] two classes of algorithms were analysed:

- the algorithms with a threshold specified by the user;
- the algorithms based on iterative threshold.

The threshold segmentation algorithms transform one set of data, belonging to an interval of values, into a new set of binary data. In imaging practice one has in view to classify the pixels into two categories: those which, according to a certain property, can be grouped under a specified threshold value mentioned as input data, and those which, according to the value criterion, belong over the threshold value.

During the activities on the project the mentioned algorithms were used to analyze and process the digital images acquired from the optical microscope, the results being presented in Figures 1 to 7.

2. Processing the digital images acquired from the microscope

The morphological processing methods, applied mainly on binary images, are used after applying pre-processing and segmentation on digital images, to remove the parasite elements embedded in the image matrix, like background noise or secondary effects that might appear during digitization. The techniques that are specific to the morphological algorithms do allow obtaining, with high accuracy, certain information regarding the geometrical and structural characteristics of the images. The processing methods based on morphological algorithms' implementation can be also applied in the case of monochrome images (256 nuances of grey), being used with the non-linear uniformization of some characteristics.

Using the (morphological) erosion algorithms it is possible to eliminate the parasite elements that accumulate during digitisation on the external and internal contours of the indications, the effect being an effective "erosion", which further allows the use of other algorithmic modules, like those destined to a more effective detection of contours. The erosion algorithms (like the rest of the mentioned morphological algorithms) can be implemented and applied both for binary images (the result of some segmentation processes) and for monochrome images, as a pre-processing stage. Applying one of these algorithms mainly depends on the specific characteristics of the application one has in view and on the particular objectives aimed at in each stage of the general processing algorithm. Practically, applying the erosion modules leads to a smoothness of the concave corners of some area (or object) belonging to an image.

Using the dilation algorithms one can add supplementary pixels (a "filling" effect) in the areas in which there are identified isolated accumulations (of a different nuance) inside some more extended and relative uniform from the point of view of the nuance, regions like pores or inclusions. In these cases, also, the main goal is to even the areas of potential interest, for further processing (including segmentation and contour detection). Practically, applying the dilation modules leads to a smoothness of the convex corners of some area (or object) in a digital image.

By using the opening algorithms one can obtain an "opening" (in the sense of a separation) between areas that appear to be connected due to the imperfections of the digitizing algorithms. Similar results can be obtained also by applying segmentation algorithms, but the advantage of the opening algorithms is that they are based on the combination of two complementary procedures, all the eroded areas being further dilated, so keeping a better similarity with the original image.

Using the closing algorithms one can obtain a supplementary filling of isolates regions of interest and one does maintain the original dimensions of these areas.

Figures 1 to 7 present a first set of results obtained in the case of heterogeneous polymer-metal joints in the case of applying the mentioned algorithmic modules, in the framework of a program of microstructural evaluation having the following objectives:

- determining the proportions of the components in the analysed materials;
- determining the distribution of the constituents;
- dimensional measurements (minimal and maximal dimensions);
- determining the number of small inclusions;
- repartition of inclusions;
- the distribution of inclusions depending on their dimensions.

The (open source) software package used during the project, ImageJ, designed and implemented based on the Java™ technology, available on freeware basis on the Internet (http://rsb.info.nih.gov/ij/), allowed us to perform all the necessary operations for the microstructural evaluation program.

The mentioned software package offers possibilities and options for all the pre-processing, segmentation and morphological processing algorithms presented previously, as well as some supplementary facilities regarding graphical files (digital images) manipulation.

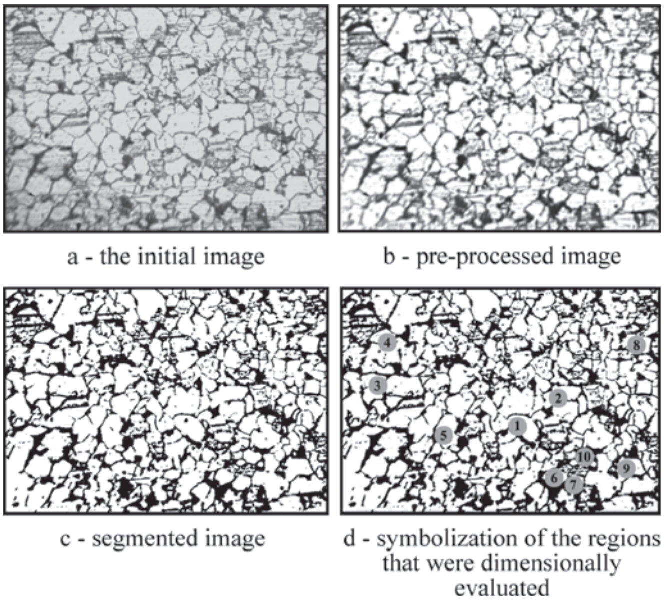
As an example, we mention some of the facilities offered by the ImageJ package, based on the graphical user interface (GUI); the program allows the creation of a new image by using a graphical window destined to the content of this new image. The GUI allows the user to specify the following elements:

- the name if the image;
- the type of the image, from the point of view of internal representation of the information inside the graphical file representing the image;
- the background color;
- the image width and height (in pixels).

Dimensions: 1426 × 1013 (pixels), 1200 × 850 (μm); 1 pixel ≈ 0.84 μm. Percentual composition: ferrite (white): 69.5% (1,004,604 pixels, out of 1,444,538 pixels), pearlite (black): 30.5% (439,934 pixels, out of 1 444,538 pixels). The dimensions of the sides of the smallest rectangle that can surround a ferrite grain with the symbolization in Figure 1d have the values mentioned in Table 1.

Analysing the determined values one can observe that the structure contains 69.5% ferrite and 30.5% pearlite. The ferrite granulation varies between 73.92 μm and 141.12 μm along the width and between 56.28 μm and 127.68 μm along the height; practically, equiaxial grains do appear attesting the uniformity of the analysed structure.

Dimensions: 1425 × 1004 (pixels), 1200 × 850 (μm); 1 pixel ≈ 0,84 μm. Percentual composition: polymeric base (white): 84% (1,203,519 pixels, out of 1 430,700 pixels) and pores with oxide mixtures (black): 16% (439,934 pixels, out of 1,430,700 pixels). The dimensions of the smallest circle that can encircle a pore, with the symbolization in Figure 2d are presented in Table 2.

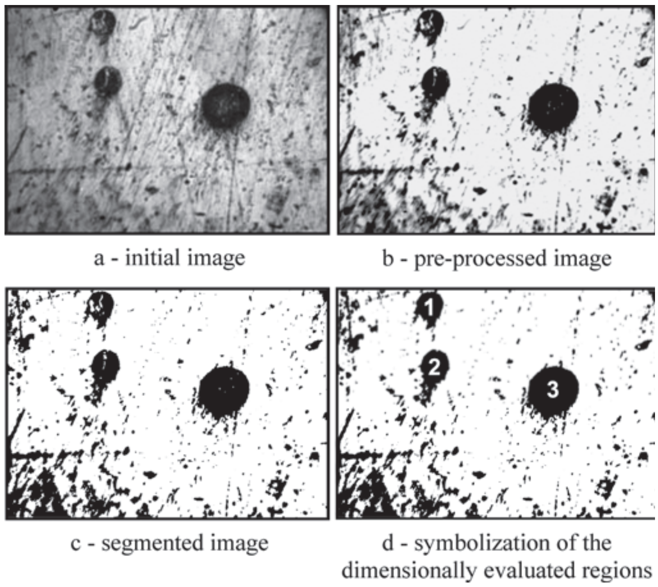


a - the initial image; b - pre-processed image; c - segmented image; d - symbolization of the regions that were dimensionally evaluated

Figure 1. S235JR steel, 100×; specimen 1: S235JR steel + Necuron Polymer 1050 + Ti1

Table 1. The dimensions of the sides of the smallest rectangle that can surround a ferrite grain

Nr.	Width [pixels]	Width [μm]	Height [pixels]	Height [μm]
1	139	116.76	116	97.44
2	168	141.12	102	85.68
3	114	95.76	140	117.6
4	115	96.6	67	56.28
5	103	86.52	152	127.68
6	81	68.04	77	64.68
7	82	68.88	72	60.48
8	99	83.16	83	69.72
9	134	112.56	104	87.36
10	88	73.92	68	57.12



a - initial image; b - pre-processed image; c - segmented image; d - symbolization of the dimensionally evaluated regions

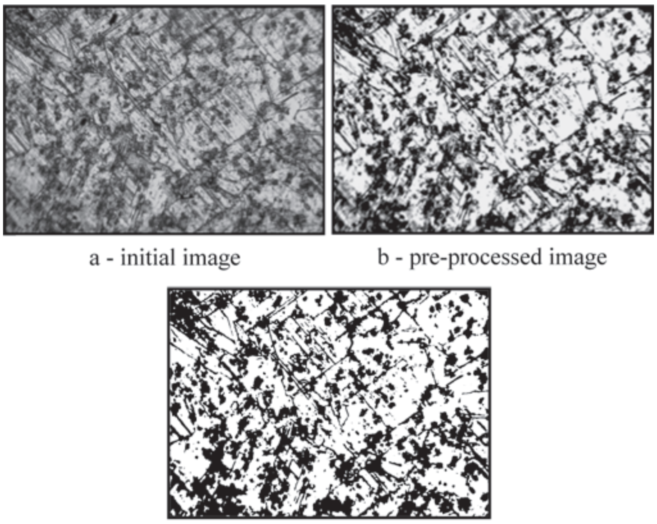
Figure 2. Necuron 1020, 100× [specimen 2: Cu98 with Necuron polymer 1020]

The Necuron 1020 material presents, in its polymeric structure, isolated pores and oxides mixtures in a proportion of 16%; the dimensions of the pores vary between 109.2 µm and 193.2 µm, measured along the diameter of the imperfections showing an acceptable porosity (under 25%).

Table 2. The dimensions of the smallest circle that can encircle a pore

Nr.	Diameter [pixels]	Diameter [µm]
1	130	109,2
2	144	120,96
3	230	193,2

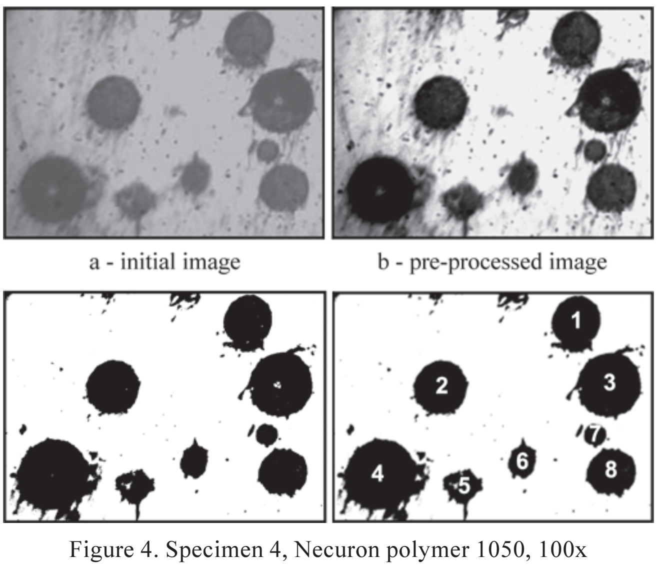
Dimensions: 1421 × 1010 (pixels), 1200 × 850 (µm) ; 1 pixel ≈ 0,84 µm. Percentual composition: solid solution α (white) 62% (889,162 pixels, out of 1,435,210 pixels) and inter-metallic composed oxides (black) 38% (546,048 pixels, out of 1 435,210 pixels)



a - initial image b - pre-processed image

c - segmented image

Figure 3. Cu98, 100× [specimen 3: Cu98 with Necuron polymer 1050]



a - initial image b - pre-processed image

Figure 4. Specimen 4, Necuron polymer 1050, 100x

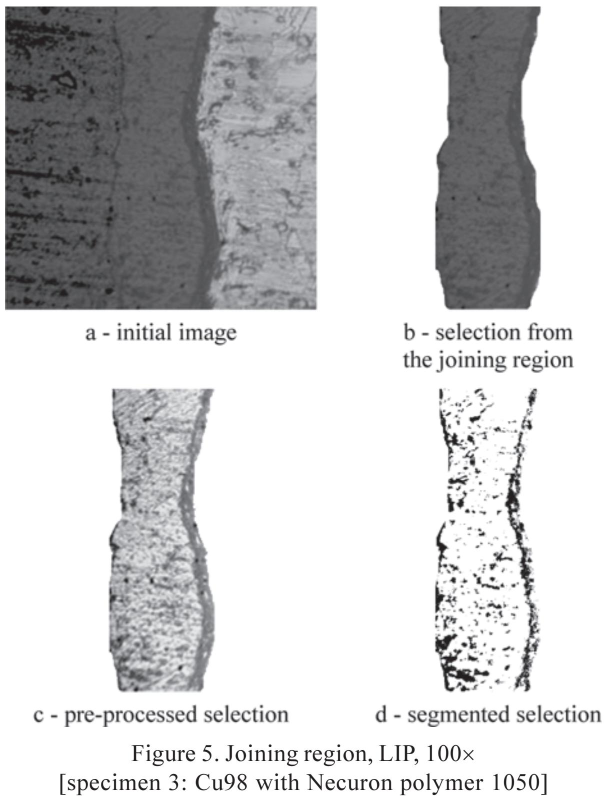
The analyze shows a high content of oxides and fine inter-metallic components of about 38% in the solid solution of the copper structure which represents 62%.

Dimensions: 1417 × 1012 (pixels) and 1200 × 850 (µm); 1 pixel ≈ 0.84 µm. Percentual composition: basic mass (white): 76% (1,092,380 pixels, out of 1,434,004 pixels) and pores (black): 24% (341,624 pixels, out of 1 434,004 pixels). The dimensions of the pores with the symbolization in Figure 4d are presented in Table 3. The Necuron 1050 polymer presents a pore concentration of 24%, the basic epoxidic mass representing 76%. The analyze of the 8 pores in the structure shows values of the dimensions between 85.68 µm and 241.92 µm, ensuring an acceptable porosity, under 25%.

Table 3. The dimensions of the pores

Nr.	Diameter (pixels)	Diameter (µm)
1	220	184.8
2	240	201.6
3	288	241.92
4	320	268.8
5	171 / 144 (ellipse)	143.64 / 120.96
6	126 / 144 (ellipse)	105.84 / 120.96
7	102	85.68
8	219 / 212 (ellipse)	183.96 / 178.08

Dimensions: 1404 × 1010 (pixels); selection: 352 × 1010 pixels, 1200 x 850 (µm); 1 pixel ≈ 0.84 µm. Percentual composition: basic epoxidic mass (white) 82,7% (253,785 pixels, out of 306,769 pixels in the selection) and oxide particles (black): 17.3% (52,948 pixels, out of 306,769 pixels in the selection).



a - initial image b - selection from the joining region

c - pre-processed selection d - segmented selection

Figure 5. Joining region, LIP, 100× [specimen 3: Cu98 with Necuron polymer 1050]

In the joining area (LIP) of specimen 3, the base epoxidic mass represents 82.7% in which fine oxide particles exist in a proportion of 17.3%, showing that the solidification process took place under normal cooling conditions; the oxide particles are not dissolved in the base solidified mass, being distributed uniformly.

Dimensions: 1421 × 997 (pixels), 1200 × 850 (μm); 1 pixel ≈ 0.84 μm. Percentual composition: solid solution (white): 68% (966,470 pixels, out of 1,416,737 pixels) and oxides + compounds Cu-Sn (black): 32% (450,267 pixels, out of 1,416,737 pixels). The dimensions of the black indications with the symbolization in Figure 6d are presented in Table 4.

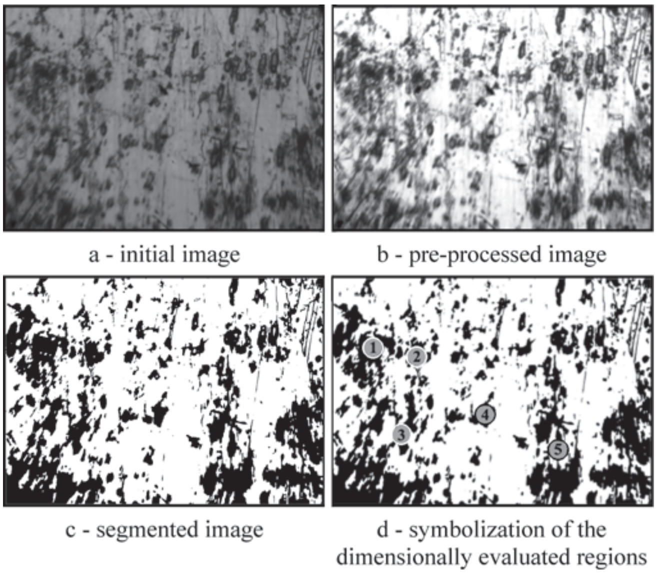


Figure 6. Alloy CuSn4, 100× [specimen 4: alloy CuSn4 with Necuron polymer 1050 + Ti1]

Table 4. The dimensions of the black indications

Nr.	Width [pixels]	Width [μm]	Height [pixels]	Height [μm]
1	156	131.04	137	115.08
2	91	76.44	131	110.04
3	92	77.28	276	231.84
4	79	66.36	158	132.72
5	47	39.48	129	108.36

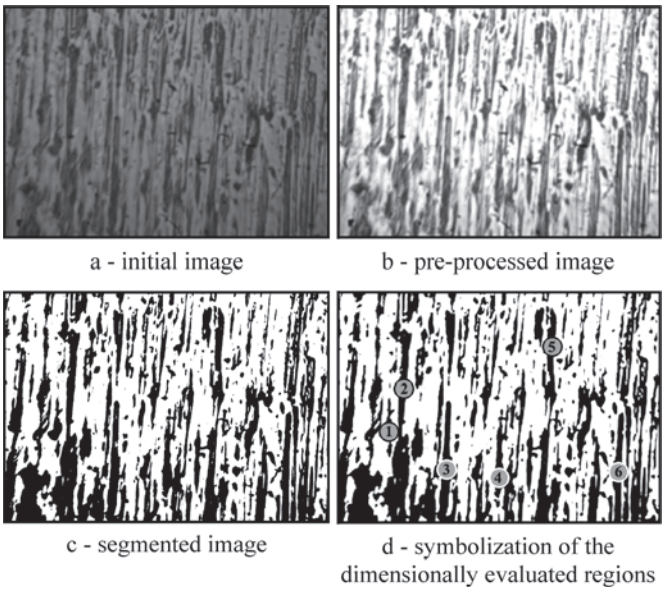


Figure 7. Alloy Ti1, 100× [specimen Necuron polymer 1050 + Ti1]

The dimensions of the black particles (inter-metallic Cu-Sn compounds and oxides) have values of the width between 39.48 μm and 131.04 μm, and values of the height between 108.36 μm and 231 μm, and a percentual concentration of 32%, showing a non-uniformity regarding the granulation of these phases.

Dimensions: 1417 × 1006 (pixels), 1200 × 850 (μm); 1 pixel ≈ 0,84 μm. Percentual composition: solid solution α (white) 60,6% (864,544 pixels, out of 1,425,502 pixels) and linear oxides (black): 39,4% (560,958 pixels, out of 1,425,502 pixels).

The dimensions of the black indications with the symbolization in Figure 7d are shown in Table 5.

Table 5. The dimensions of the black indications

Nr.	Height [pixels]	Height [μm]
1	192	161.28
2	850	714
3	531	446.04
4	356	299.04
5	492	413.28
6	472	396.48

The linear oxides in the technical titan structure cover 39.4% of the structural fund based on α solid structure, having heights between 161.28 μm and 446.04 μm, showing a high degree of deformation of this material, together with a high structural non-homogeneity due to the presence of these oxides.

3. Conclusions

3.1. The quantitative evaluation of the structural phases, by image analyse, in the case of heterogeneous polymer-metal joints depends on the quality of the pre-processing modules, regarding the specific pre-processing procedures.

3.2. In the characteristic areas of the polymer-metal joints no crack or micro-crack like defects were detected, but fine pores were observed.

3.3. Metallografic and HV1 hardness evaluations carried out for the polymer-metal heterogeneous joints showed the structures specific for the materials that were used, having a minimal hardness value of 14 and a maximal value of 205 HV1.

References

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