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Contribute to quantitative identification of casting defects based on computer analysis of X-ray images

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Abstract

The forecast of structure and properties of casting is based on results of computer simulation of physical processes which are carried out during the casting processes. For the effective using of simulation system it is necessary to validate mathematica-physical models describing process of casting formation and the creation of local discontinues, witch determinate the casting properties.
In the paper the proposition for quantitative validation of VP system using solidification casting defects by information sources of II group (methods of NDT) was introduced. It was named the VP/RT validation (virtual prototyping/radiographic testing validation). Nowadays identification of casting defects noticeable on X-ray images bases on comparison of X-ray image of casting with relates to the ASTM. The results of this comparison are often not conclusive because based on operator's subjective assessment. In the paper the system of quantitative identification of iron casting defects on X-ray images and classification this defects to ASTM class is presented. The methods of pattern recognition and machine learning were applied.

Keywords: validation of simulation codes, X-ray testing, casting defects, image recognition

1. Introduction

It is commonly know that only suitably carried out validation of efficiency mathematic-physical models with respect to the description of phenomena of structure and properties of castings, gives credence to the usability of simulation system as a tool to forecast of casting quality. The optimization of the casting technology and the possible correction of casting construction can be conducted only on the basis of reliable simulation results. One of the validation methods is bringing to conformity of temperature fields (virtual to reality) during so called 'energetic validation' [1,2]. Such procedure was used during the determination of thermophysical properties of materials (databases of mould materials) in the conditions of real cast-mould system [3,4,5]

The validation can be lead using several complementary methods:

1. the analysis of thermal effects of processes e.g. through the comparison of local values of simulation temperatures with the real temperatures in the cast-mould system,
2. the comparison of real state of the quality of casting with the simulation results e.g. on the basis of distribution of shrinkage defects in casting:
   - after cutting the casting (the destructive testing e.g. penetrating (PT) or magnetic (MT)
   - without destroying the casting with the utilization of NDT

methods (ultrasonic testing UT, radiographic testing RT) this validation is called VP/NDT (virtual prototyping/non destructive testing),

3. the state of structure or stresses needs special approach (the destructive testing of e.g. fracture, trepanned sample or non destructive testing of stresses on the surface).

The first validation method is quite often used independently. Its application is normally limited to test castings [4,5]. Great amount of work is necessary to prepare and assemble in the casting mould before filling. It is also necessary to take into consideration that in the industrial casting after the machining there can not be left any ceramic protective element of the thermo-element

The second method VP/NDT (virtual prototyping/non destructive testing) is based on the NDT (non destructive testing) evaluation of condition of the casting interior. It allows performing comparison between real and virtual quality of industrial castings. This validation allows to check to what extent the brave statements of authors of simulation systems are right: e.g. motto of the MAGMA company stand at the GIFA 2007 exhibition was: – "In the Heart of Casting" what shows very well the expectations concerning MAGMASOFT system and other similar simulation systems [6].

Non-destructive testing (NDT) are universally used during the reception of castings therefore their results should be, when necessary, used to the validation of the simulation system Mainly UT and RT methods are taken into consideration in such cases. Such procedure is usually implemented in foundries which administer the appropriate equipment or such examinations are commissioned to outside companies. However there is problem, which has never been solved: the simplified, or rather primitive, procedures of the assessment of quality of the castings. They are based on NDT results what was discussed exhaustively in [7,8,9]. Some castings, due to their design, are not suitable at all for the UT validation. Therefore only the RT validation is suitable. Other procedures allowed e.g. in the ASTM norm do not have character typical for quantitative examinations.

In the article we will talk about the state of the problems connected with the RT validation, its usefulness for classification of the quality of castings, and mainly about the basis for the quantitative „reality" comparison in the casting with the „virtual" forecast regarding intensity and spreading of porosities in it.

2. Conception of utilization of the RT control methods for the validation of the virtual forecast of the quality of castings

Since certain time there is implemented in the automotive industry the standard of a hundred percent inspection of aluminum castings (of safety critical parts) for the presence of internal defects. Advanced devices for illuminating of castings with X-rays are unrolled. They are equipped with ADR systems (Automatic Defect Recognition) [10,11,12,13]. ADR systems are able to automatically recognize the casting defects thanks to the comparison of X-ray image with the perfect image of the same element. Next generations of ADR systems enable the filtering of X-ray images, recognizing areas of defects and determining their size and intensity. These systems have been commonly applied at the inspection of aluminum alloy castings (on Fig.1 an example of testing the ring of a car wheel on the basis of the X-ray image is presented [14]).

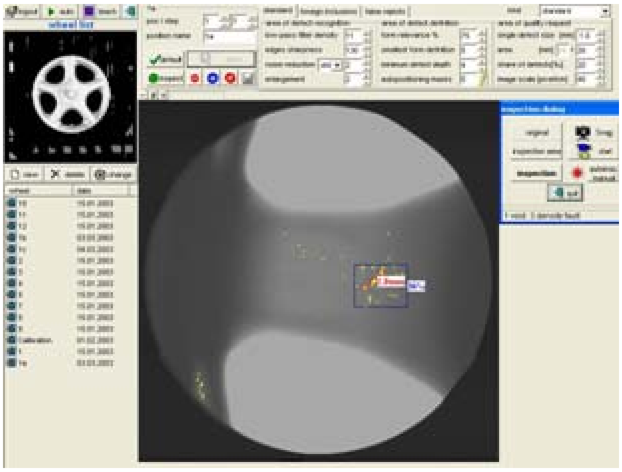


Fig. 1 Identification of casting defects in the Xpect program [14]

Devices for X-raying of aluminum castings are characterized by high resolution (digital image on the matrix with 16-bite's record of grayscale is obtained). It allows to detect very small defects at the low contrast in the X-ray image and big defects with low intensity that "hide" behind the structure of the part [10,15].

In the case of iron alloys castings, where the irradiation (exposure) time is even two rows longer, the image is obtained (irradiated) is on negatives of RT films The identification of the defect consists of comparison of the RT negative with model negative films in ASTM casting defects atlas. An experienced staff, having obligatorily required entitlements in the area of NDT examinations must make comparison of it and assign to the appropriate class and intensity. However the result is often is ambiguous since it is based on the operator's subjective assessment of two cases (of the examined cast and the ASTM model), differing in intensity and/or in dispersion of discontinuities images which are visible in the form of stains (of local blackouts).

Working solution would be elaboration of the assessment explicit criteria of RT negatives. Is it possible to make comparison through the computer analysis of the image, which very often has weak quality and low contrast?

Quantitative VP/RT validation (on the pattern of the principle of the energy validation) of simulation system should rely on authenticating the forecast of internal defects obtained from the simulation with the help of results of the inspection of casting soudness, on the basis of analysis of RT negative films, more precisely than it done up to now. The forecast of casting defects obtained from the simulation codes is based on relatively small resolution. The defect is determined within an accuracy of the volume (cells) assigned to the node of the 3D mesh. Depending of the shape and the size of the casting has usually size from a few to a few thousand cubic millimeters. The shrinkage can include single cells or their clusters. Every cell, depending on the course of calculations, can be „empty” entirely or partly if the algorithm has taken it into consideration during the calculations balancing the shrinkage and the feeding.

3. Methodological assumptions of the system

The assumptive aim of the research is to develop the automatic system which will classify an X-rays of castings according to defined a priori classes of defects, the methods of pattern recognition and by machine learning. The images will be classified on the basis of standards of casting defects placed in the ASTM atlas of casting defects. Classes of defects will be considered for ASTM E-186 2 – 4,5 CA 1-5, CB 1-5 and ASTM E-802 <4,5 GRAY IRON 1-5.

All the images (model and of real castings defects) have been digitalized by taking digital pictures. The pictures were taken with digital camera with the “dark field” (light passing through the negative).

Elaborated images contain interferences, which are caused by:

- chosen technique of making RT films (among others: problems with the homogeneity of irradiation by the source, the sensitivity of negatives, problems with necessary, long-lasting marking of the number of examination, the sensitivity of the places of examination, and diversification of the thickness partitions)
- seizing of the image from the RT negative (among others; adjusting the white balance, the diversity of highlighting namely the gradient of the illumination visible with great negatives and the noise produced by the CCD converter).

Digitalized images should have been the subject of standardization in order to correct all the lighting unevenness which considerably lowers the quality of the analyzed image and influences the result.

The process of defects classification consists of the measurement of textural characteristics (texture). There has been made an assumption that the shape (envelope) of defect is less essential than its texture. Diversification of defects is carried out by the textures method analysis which is applied to the recognition: of images of the cooccurrence matrix.

The cooccurrence matrix is created on the basis of digital image *f*. Let *P* be the operator of position (the relation which can exist between two points of the image). The *P (p,r)* means, that points *p* and *r* are in the spatial relation *P* (e.g. *p* is a left upper neighbor of *r*). Now we are defining matrix A as the matrix with $k \times k$ sizes (*k*-the number of levels of brightness) with the elements with values:

$$a_{ij} = \left|\{p : f(p) = i \wedge P(p,r) \wedge f(r) = j\}\right|$$

that is: the element of the matrix on the intersection of verse *i* and the column *j* contains the number of pairs of points of the image (*p*, *r*) as follows:

– the brightness of the point *p* gives *i*
– the brightness of the point *r* gives *j*
– the points *p* and *r* are in the spatial relation P

The coocurence matrix C is a matrix A with the standardized size of the image

$$c_{ij} = \frac{a_{ij}}{\left|D(f)\right|}$$

Therefore c_{ij} is the estimation of total probability distribution of coming across the pair of points with defined brightnesses, remaining in the relation P.

Applying coocurence matrix to classify defects we use more sophisticated neighborhood relation P. The learning goes thanks to the calculation of cooccurrence matrix C for every model defects. The results are matrices: *C*CC1, *C*CC2, *C*CC3, *C*CC4, *C*CC5… etc.

The classification of new image *f* takes place by calculating the cooccurrence matrix C_f for the image *f.* Next step is to analyze the resemblance of the matrix CO with the matrixes CCC1, CCC2, CCC3, CCC4, CCC5. As a result of analysis, the image *f* is classified to this class, where resemblance to the matrix is the biggest.

4 The prototype system of automatic castings defected classification using the image recognition method

The application was created in the MS.NET environment. Apart of the classification itself, it also realizes the preliminary processing of image, especially the standardization of the entrance image from the point of view of the brightness (the majority of images shows considerable irregularities of gradient in the corners of negative film).

The correction of lighting unevenness is carried on thanks to the graphic interface, where the operator intuitively determines parameters of the correction process (fig. 2). The result of lighting unevenness correction was shown in figure 3. The image before correction contains distinct gradient of the brightness, whereas after the correction the brightness is approximately uniform.

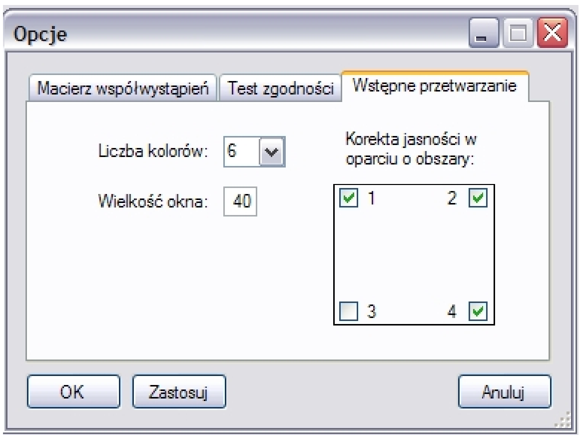


Fig.2 Graphical interface - correction of the brightness

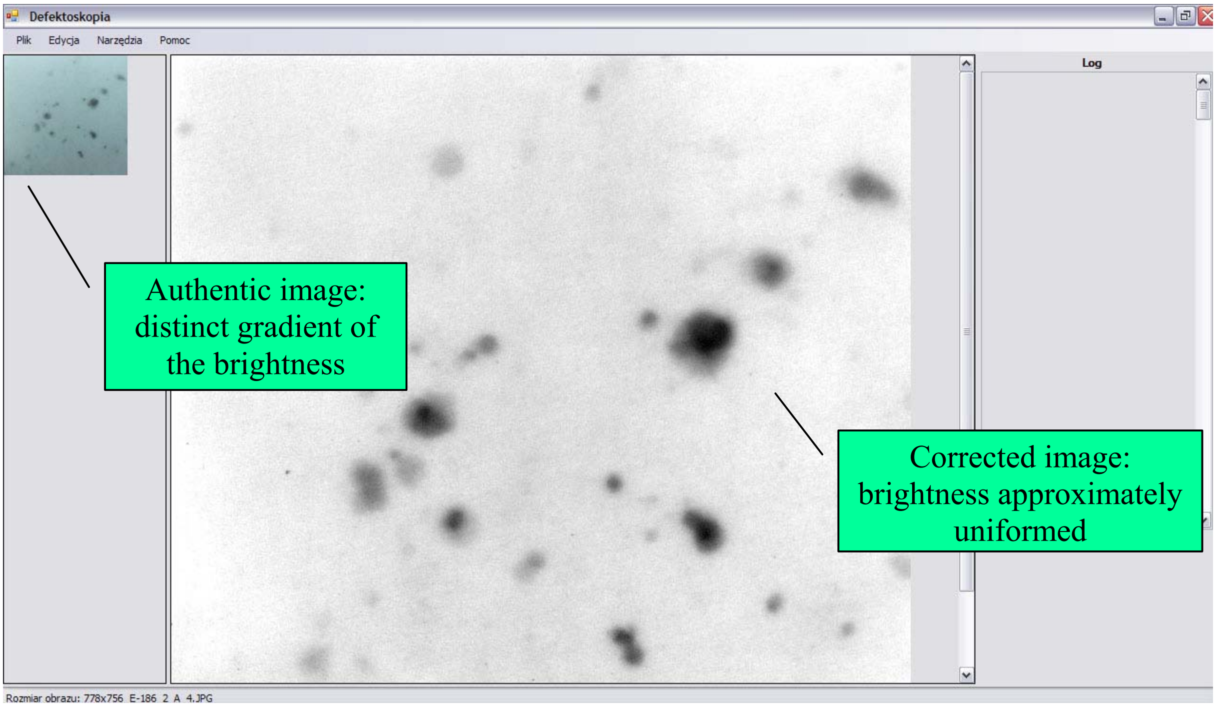
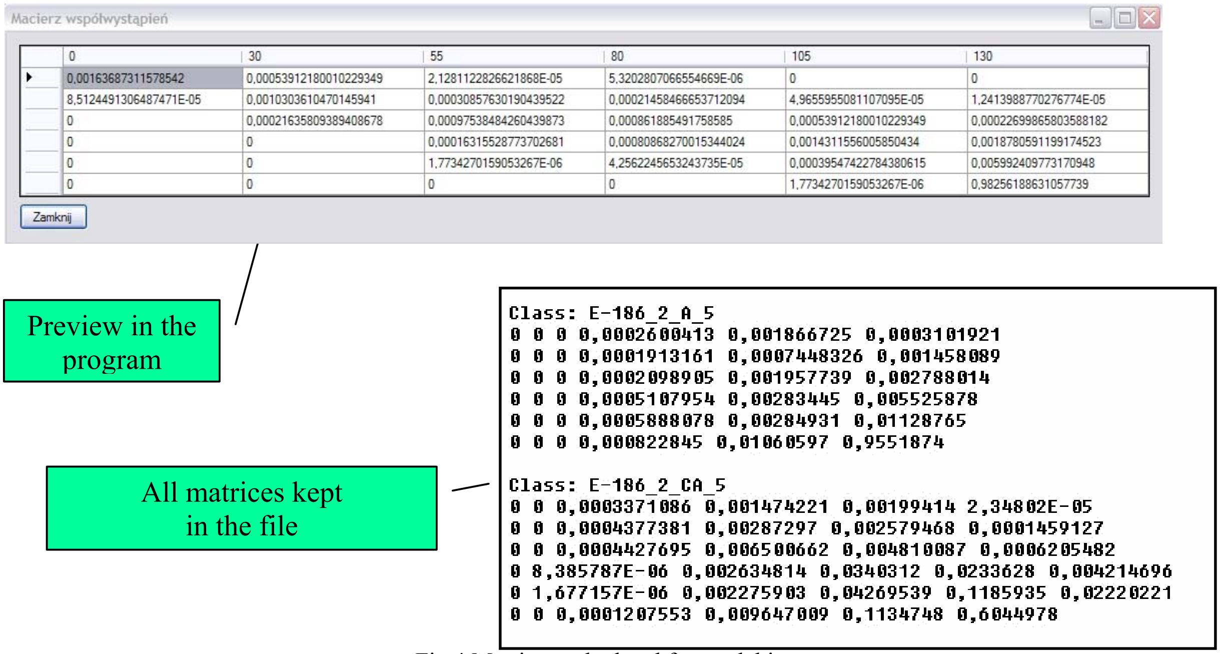


Fig.3 Model result of lighting unevenness correction.



0	30	55	80	105	130
0,00163687311578542	0,00053912180010229349	2,1281122826621868E-05	5,3202807066554669E-06	0	0
8,5124491306487471E-05	0,0010303610470145941	0,00030857630190439522	0,00021458466653712094	4,9655955081107095E-05	1,2413988770276774E-05
0	0,00021635809389408678	0,00097538484260439873	0,000861885491758585	0,00053912180010229349	0,00022699865803588182
0	0	0,00016315528773702681	0,00080868270015344024	0,0014311556005850434	0,0018780591199174523
0	0	1,7734270159053267E-06	4,2562245653243735E-05	0,00039547422784380615	0,005992409773170948
0	0	0	0	1,7734270159053267E-06	0,98256188631057739

Fig.4 Matrixes calculated for model images

The first stage of classification process is the creating the base of cooccurrence matrixes, which are estimated for model images. Model results of calculations are shown on figure 4.

After the base of model matrixes is built and saved in the file, the identification of casting defects saved on digitalized RT images is possible. On figures 5 and 6 exemplary images: model one and the images ready to classification are shown. The result of the classification process is determination the kind of the defect by the program according to ASTM E-186 and assigning it to one of classes from 1 – 5 are with estimating the level of the certainty at the same time (fig. 7).

Fig.5 Model image

Fig.6 The image ready to categorize (class of the defect is not known)

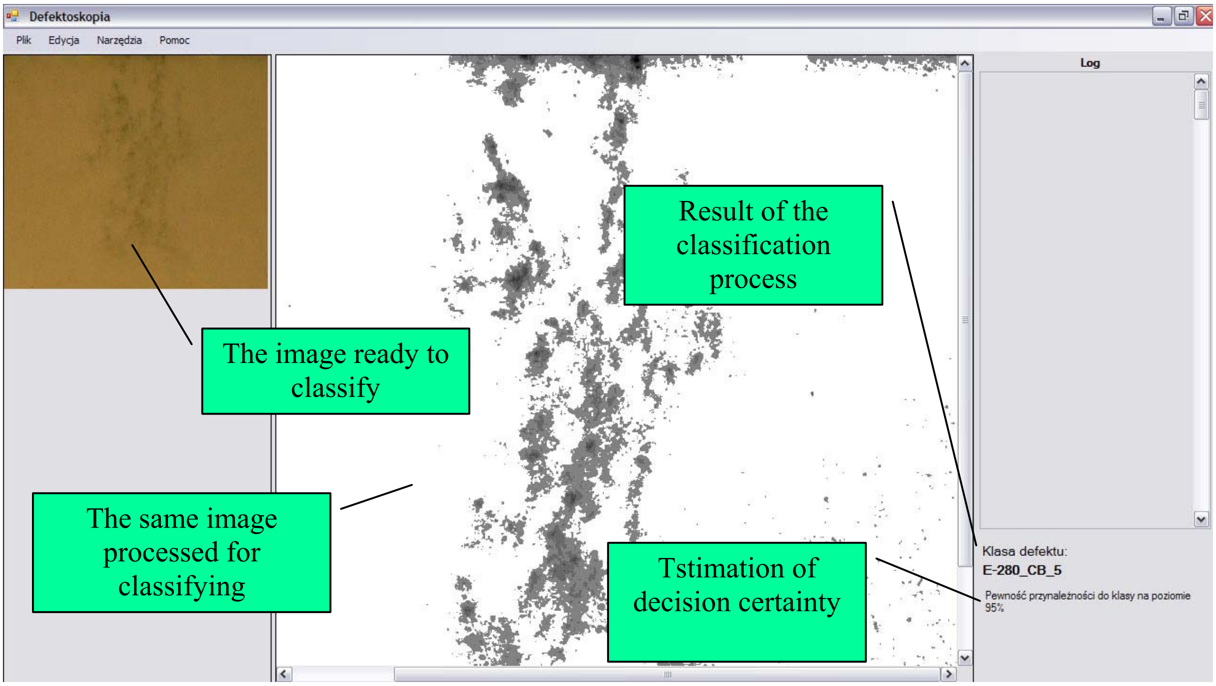


Fig 7. Result of the classifying process

5. Summary

The method of the image recognition to the assessment of the quality of castings on the basis of analysis of negative films RT allows for implementing clear criteria of the estimation of NDT methods.

In the created application the process of classification was based on the measurement of texture characteristics, a method of cooccurrence matrixes was adopted to analysis. The classification of the matrixes was based on the simple method of cooccurrence matrix analysis and good results of identifying defects were obtained. More advanced variant is also possible, where the resemblances of each model matrixes are analyzed more thoroughly.

The prototype elaborated out of the classification system of casting defects enables the analysis of digital image with the weak quality and low contrast (the photograph of negative film made with digital camera). Only castings of simple shape can be analyzed, the system do not recognize the shape of the casting (every edge e.g. the rib causes disruptions of identification process and is treated as the defect). The next stage increasing the functionality of the system will be extending the program with the functions which preliminarily processes the image thanks to the functions of filtering disruptions caused by the parameters of the casting and marking characteristic places.

It is also important to sensitize the designers of parts (and users) in order to define zones of the quality, more courageously and more consciously, including permissible discontinuity casting defects, with estimation of the probability of approaching the standards of faults presented e.g. in ASTM atlas. The proposed tool is trying to meet them.

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