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Quality analysis of the Al-Si-Cu alloy castings

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Abstract

The developed design methodologies both the material and technological ones will make it possible to improve shortly the quality of materials from the light alloys in the technological process, and the automatic process flow correction will make the production cost reduction possible, and - first of all - to reduce the amount of the waste products. Method was developed for analysis of the casting defects images obtained with the X-ray detector analysis of the elements made from the Al-Si-Cu alloys of the AC-AlSi7Cu3Mg type as well as the method for classification of casting defects using the artificial intelligence tools, including the neural networks; the developed method was implemented as software programs for quality control. Castings were analysed in the paper of car engine blocks and heads from the Al-Si-Cu alloys of the AC-AlSi7Cu3Mg type fabricated with the "Cosworth" technological process. The computer system, in which the artificial neural networks as well as the automatic image analysis methods were used makes automatic classification possible of defects occurring in castings from the Al-Si-Cu alloys, assisting and automating in this way the decisions about rejection of castings which do not meet the defined quality requirements, and therefore ensuring simultaneously the repeatability and objectivity of assessment of the metallurgical quality of these alloys.

Keywords: Casting defect; Technological process; Computer image analysis; Artificial neural networks; Al-Si-Cu

1. Introduction

To meet the customer requirements car manufacturers need to develop new technologies related to safety and comfort of travel. As a result the car weight and dimensions are increasing. At the same time the fuel consumption and exhaust emission are increasing too. Thanks to light materials such as aluminum alloys, car manufactures may aim to reduce their weight. These alloys have become popular in automotive industry owing to their low weight and some casting and mechanical qualities. The casting defects occurring during the technological process may be identified by various research methods including microscopy and defectoscopic methods such as X-ray method. The technological progress in material engineering causes the continuous need to develop product testing methods providing comprehensive quality evaluation. In material engineering it is the images obtained by various methods that have become the source of information about materials. The type of image being the subject of analysis depends on the selected registration method. Metallographic structures of images are obtained by light and electron scanning microscopy. These images are the source of information on material structure, ongoing processes and its properties. Images obtained by defectoscopic methods such X-ray and ultrasound methods provide information on material defects occurring at various stages of technological processes [1-9].

The specific character of images does not always allow using directly the methods and means of the classic image recognition and digital processing theory. The lack of the uniform theory and general approaches renders extremely difficult selection of image processing and recognition algorithms and acquiring the right assessment of their effectiveness. Computer assistance is used more and more often to optimise the image processing task and improve its efficiency. Computer "vision" features the relatively new image technology developing very rapidly. Its main goal is the desire to furnish the computer with the image recognition and processing potential comparable with the living organism endowed by nature with the power of seeing. This stands for furnishing the computer with the artificial intelligence algorithms, whose goal is providing it with the capability of the autonomous use of its own input sensors for detection of the spatial information [11, 12].

Modern computer science applications including methods of artificial intelligence are more and more widely applied in different domains of science and technology. A growing interest in those methods justify their wide application possibilities. Neural networks are becoming the more and more often used tool in material engineering as shown by many publications in which the results of the examinations of many world research centres are presented. Artificial neural networks have been created for the identification and anticipation tasks and steering which make them useful for flaw detection and distinguishing them from other component parts of the image [13, 14].

2. Materials and experimental procedure

Examinations were carried out on the car engine elements' castings, i.e., blocks and heads from the AC-AlSi7Cu3Mg (EN 1706:2001) aluminium alloy.

The defect detection examinations were carried out with the X-ray method for the castings of the six- and eight-cylinders car engine blocks made with the "Cosworth" method. The examinations were made on the Philips MGC 30 rentgenograph at voltage of 100 kV and current of 10 mA. Exposure time was always 10 seconds. Several hundred electronic photos were made with the size of 1760x2140 pixels, which were saved in the JPG format. The set of the defect detection photos of the analysed castings of the combustion engines' blocks and heads is the base for further analysis. Photos with no casting defects were not used for further analyses. Classification of casting defects identified in castings of the combustion engines elements was carried out based on the ASTM E155 standard (Tab. 1).

Table 1
Types of the flaws taken into consideration in classification

Symbol	Flaw type	Number of classes
GH	Gas hole	1÷8
PR	Porosity	1÷8
SC	Shrinkage cavity	1÷8
SP	Shrinkage porosity	1÷8

Methodology of processing the information contained in images showing the examined castings of the engine blocks and heads, using the developed computer program, includes [15]:

- normalising parameters describing images of castings,
- carrying out analysis of digital images showing sections of engine blocks and heads to extract casting defects from the image,
- calculation of areas, perimeters and geometrical coefficients of casting defects according to formulae,
- calculation of the geometrical values of casting defects, used as independent variable for the neural networks training.

Extracting images of defects consists in such data processing and further applying image analysis methods, so that the defect image is represented in 1-bit format, neglecting the objects which are the technological openings and are not defects.

In Fig. 1 there has been a diagram presented consisting of logical bloc with the proceedings to be taken to improve the quality of castings of the car engine elements, cast from light metals.

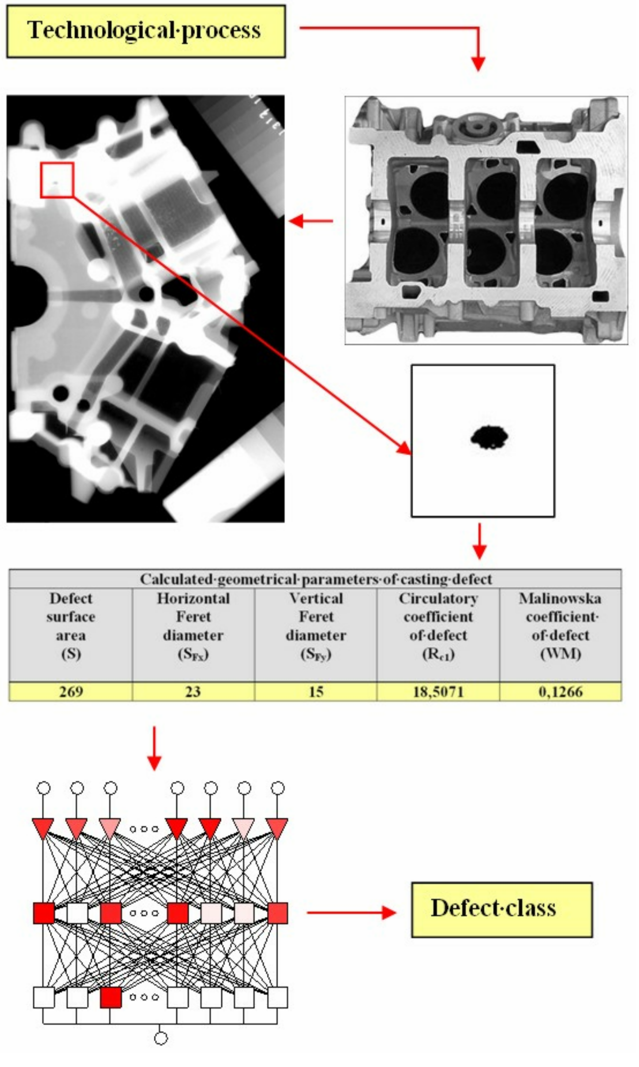

Fig. 1. Outline of the quality evaluation computer system

3. Discussion of the experimental results

The variability of shapes and sizes of casting defects identified by X-ray methods enabled the preparation of methodology based on casting images obtained by defectoscopic research. The class of casting defect calculated by the neural net on the basis of the calculated geometrical parameters in casting defects applied for model construction should be characterised by the proper similarity to the size corresponding to the class of defect of the model included in ASTM standard.

For determining the class of flaws developed in the material, 5.5 Statistica Neural Networks software was used. The data set (1256 vectors) employed, together with the neural network, in the model development process, was split into three subsets: learnedly (1056 vectors), test (100 vectors) and validation.

Neural networks input data were the geometrical parameters of casting defects respectively: defect circumference (L), defect surface area (S), horizontal Feret diameter (S_{Fx}), vertical Feret diameter (S_{Fy}), Feret coefficient (WF), nondimensional shape coefficient of the casting defect (BWK), circulatory coefficient of defect (R_{c1}), circulatory coefficient of defect (R_{c2}), Malinowska coefficient of defect (WM), centrality coefficient (C_t).

The number of neurons in a hidden layer (layers) and training method were selected depending on the network type, and on the effect of these quantities on the neural network quality coefficients.

The classification task was evaluated by analysing the quantities determined for the test data: number of correct classification cases, concentration plots.

The obtained analysis is of considerable importance in proper extracting of casting defects from X-ray images. Another important coefficient is the quality of the X-ray images because poor quality images (eg. overexposed images) affect the correctness of the analysis. Thanks to the applied analysis of sections of images of automotive engine blocks and heads it is possible to prepare such image of casting that enables to detect the edges of objects on images and furthermore to extract those that qualify as casting defects.

The obtained results indicate the significant dependence between the defect classes and values of selected geometrical parameters describing casting defects such as: circumference, surface area, Feret diameters, nondimensional shape coefficient, circulatory coefficients and roundness coefficient. Also the obtained results indicate the lack of dependence between defect classes and Feret coefficient and centrality.

To improve the efficiency of the classification of the casting defects, genetic algorithms were applied. The optimisation of input variables being the calculated geometrical parameters of the defects applied for training neural nets was possible. Such prepared data enables the improvement of the quality of classification of casting defects thanks to neural nets. The block diagram of the data analysis for the developed methodology is presented on Fig. 2. The best net applied (MLP 5-27-108) enables the correct classification of over 97% of all defects of presented input nets. In this case the error concentration for the specified classes falls below 10%. Defect classification errors of 7.9% relate mainly to the SP2 defect types (shrinkage porosity).

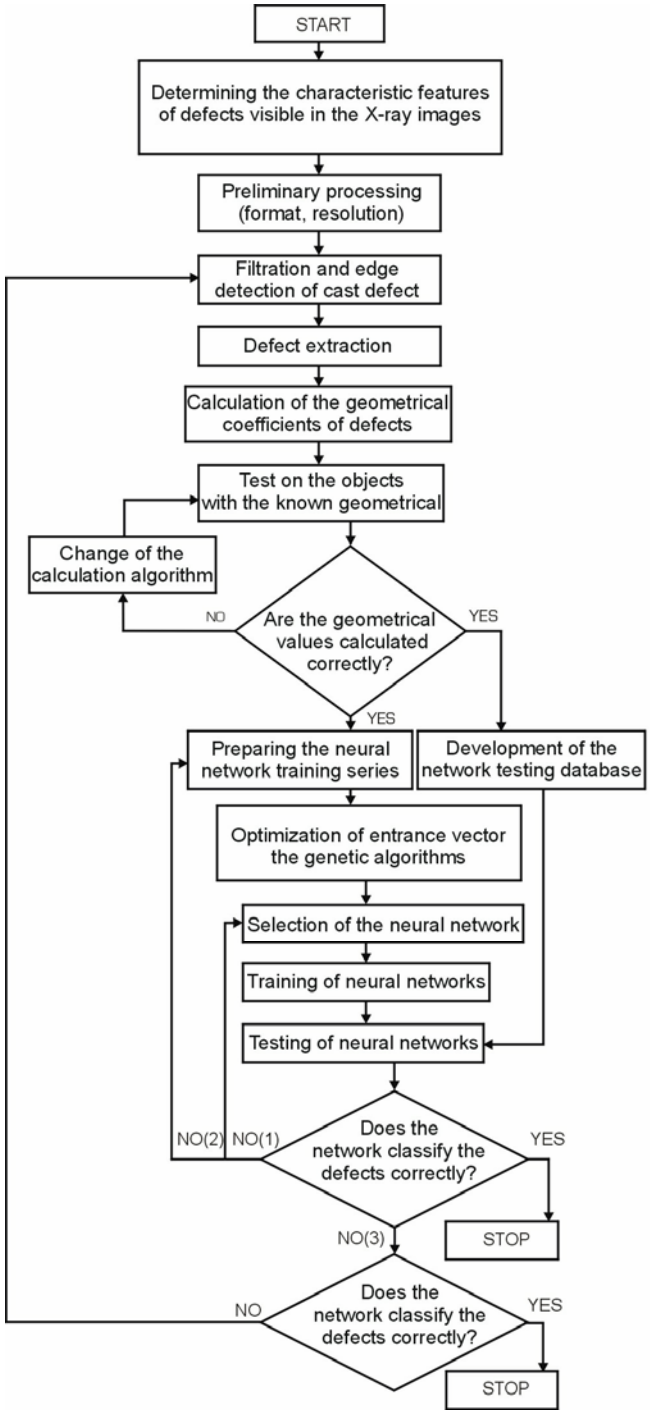

Fig. 2. Block diagram of the developed methodology of data processing pertaining to casting defects observed in the examined castings of the internal combustion engine elements from the Al-Si-Cu alloy

For cast quality control the computer program was made, its main window is shown on Fig. 3. Worked computer programme makes it possible to manage the data of the tested casts. Program makes it possible to search information about cast date, X-ray date and searching casts, in which specified cast defects are detecting (Fig. 4).

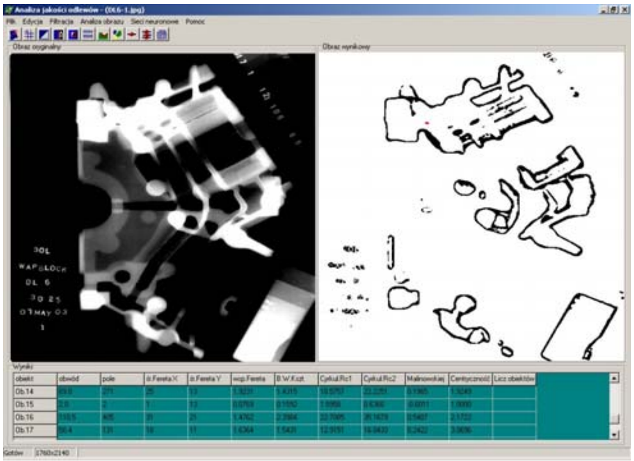

Fig. 3. The program window for the assessment of casting defects class

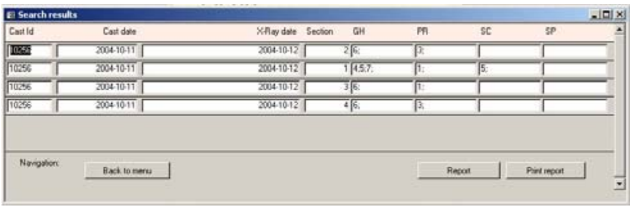

Fig. 4. The data base window with the information about tested casts

4. Conclusion

The variability of shapes and sizes of casting defects identified by X-ray methods enabled the preparation of methodology based on casting images obtained by defectoscopic research. The class of casting defect calculated by the neural net on the basis of the calculated geometrical parameters in casting defects applied for model construction should be characterised by the proper similarity to the size corresponding to the class of defect of the model included in ASTM standard.

The developed methodology of the automated assessment of quality and properties of the light Al and Mg based alloys may be used by manufacturers of subassemblies and elements of engines (e.g., car engine bodies made from the light alloys with the low-pressure casting in the sand moulds).

Correctly defined quality of products makes further possible such control of the technological process that the number of defects occurring in the castings may be decreased by the relevant process correction. Controlling the technological process basing on the information acquired from the computer system developed for determining the quality of products makes optimisation of this process possible and therefore, reduction of the number of defective casting, and in consequence reduction of costs and environment pollution.

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