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METALLOGRAPHIC INVESTIGATIONS OF AUTOMOTIVE Al-Si CAST COMPONENTS

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ABSTRACT
The merit of the project consists in the interdisciplinary joining of the knowledge in the area of light metal alloys, including Al and/or Mg, in the area of materials processing connected with the entire scope of problems connected with manufacturing of products and their elements, in the area of the automated low-pressure die casting, and also in the methodology of structure and properties assessment of the engineering materials with, among others, the X-ray flaw detection and computer image analysis methods.
Aluminium alloys have become popular in automotive industry owing to their low weight and some casting and mechanical qualities. The main component of aluminum alloy casting is Si. The eutectic structure in Al-Si casting alloys and Si concentration largely affect the porosity (pore volume). The alloy 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.
Keywords: aluminium alloys, metallographic structure, cast defects, artificial intelligence

1. INTRODUCTION
Castings from aluminium alloys are widely used in production of machines and car engine elements made in the technological processes. Aluminium alloys are especially preferred in designs thanks to their good mechanical properties and possibility to make very complicated castings with high service properties. Thanks to the contemporary casting and heat treatment technologies, castings from the aluminium alloys have the suitably high mechanical properties and simultaneously decrease the part weight. Therefore, there are more and more frequently used in the means of transport industry [1-5]. The images are used in materials examination methods that feature the information source on material's structure, processes taking place in it, and its properties. The type of image being the subject of analysis depends on the selected registration method [6]. 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 [7-10].

2. MATERIALS AND EXPERIMENTAL PROCEDURE

This paper presents both the general assumptions for the application of selected methods of artificial intelligence and the statistical study of classification of defects by X-ray methods in aluminium alloy castings.

Examinations were carried out on the car engine elements' castings, i.e., blocks (Fig. 1 and heads from the AC-AlSi7Cu3Mg (EN 1706:2001) aluminium alloy (Table 1).

Table 1. Chemical composition of AC-AlSi7Cu3Mg aluminum alloy

Mass fraction of the element, %							
Si	Cu	Mg	Mn	Fe	Ti	Zn	Ni
6,5-8	3-4	0,3-0,6	0,2-0,65	≤ 0,8	≤ 0,25	≤ 0,65	≤ 0,3

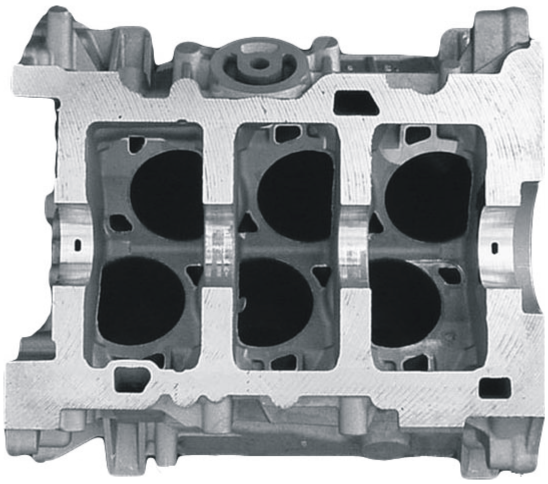


Figure 1. The picture showing a car engine blocks

Following investigations were performed:

- investigation of the alloy structure and cast defects morphology coming into existence in the aluminium alloy (etching 30% HBF_4) using light microscope MEF4A supplied by Leica (Fig. 3) and confocal laser scanning microscope Olympus LEXT OLS3000 (Fig. 4),
- 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 of the analysed castings of the combustion engines' blocks used for further analyses (Fig. 2).

Classification of casting defects identified in castings of the combustion engines elements was carried out based on the ASTM E155 standard.

Methodology of processing the information contained in images showing the examined castings of the engine blocks and heads, using the developed computer program, includes [10]:

- normalising parameters describing images of castings (size, scale),
- 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,
- 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. The purpose of the applied methodology was to identify the casting effects that occurred during the casting process.

The interval estimation was applied to estimate the interval which should comprise all the values of geometrical parameters describing the morphology of castings defects. In this way the image objects that become casting defects have been specified. The image analysis and calculation of geometrical parameters were applied. The confidence intervals for mean values were specified assuming that the tested values of geometrical parameters are of normal distribution N (μ,σ).

For determining the class of flaws developed in the material, 4.0F 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, test and validation.

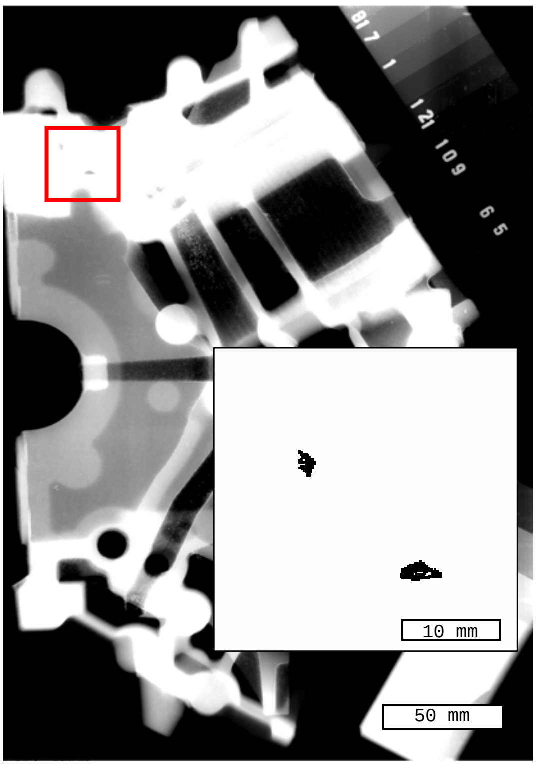


Figure 2. The fragment of picture showing a section of car engine blok

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 optimum network type was selected for the successive tasks from the following:

- MLP multilayer perceptron,
- RBF radial base functions network,
- PNN probabilistic neural network.

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.

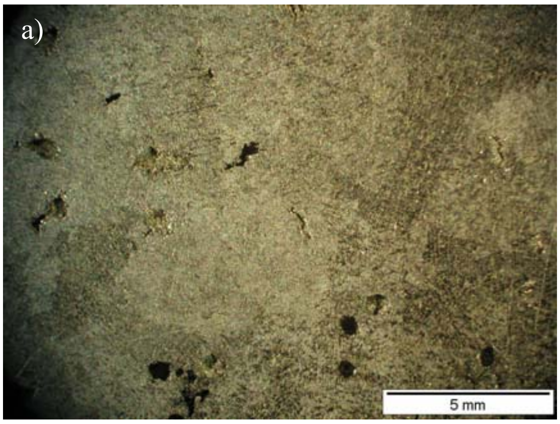
The classification task was evaluated by analysing the quantities determined for the test data:

- number of correct classification cases,
- concentration plots.

3. DISCUSSION OF THE EXPERIMENTAL RESULTS

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.



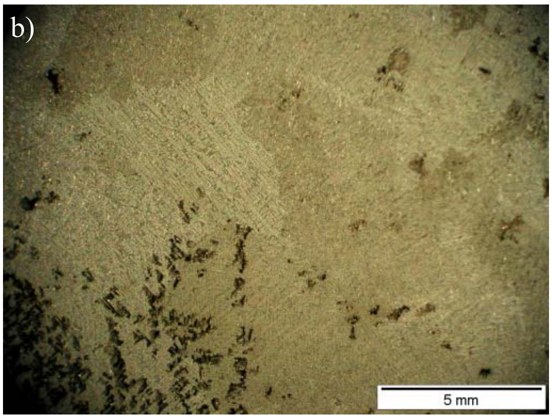


Figure 3. Light microscope image of casting defect: a) gas holes, b) shrikage porosity

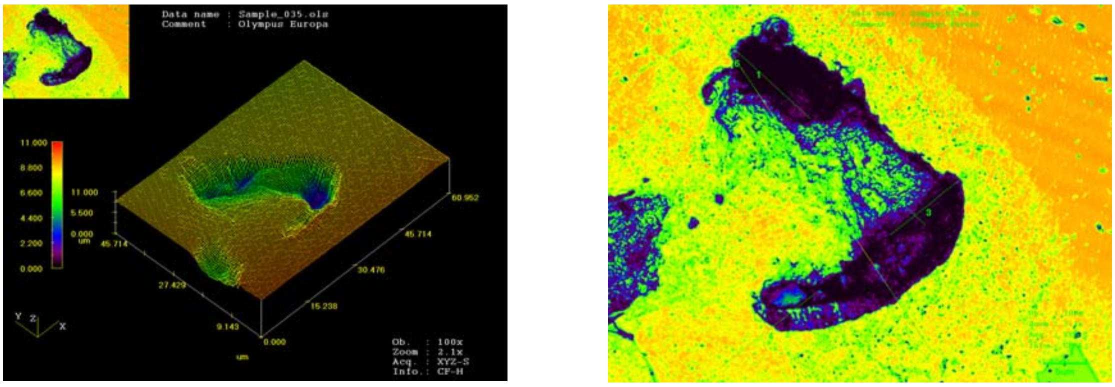


Figure 4. Casting defect, confocal laser scanning microscope

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 networks was possible. Such prepared data enables the improvement of the quality of classification of casting defects thanks to neural networks. The best net applied (MLP 5-27-108) enables the correct classification of over 97% of all defects of presented input neural networks.

4. SUMMARY

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 network 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 advantage applying neural networks rather than the statistical methods is also the correct classification of various types of defects regardless of the similar values of geometrical parameters describing morphology.

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