ARCHIVES
of
FOUNDRY ENGINEERING
Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences
ISSN (1897-3310)
Volume 11
Special Issue
3/2011
231 – 236
40/3

Automatic inspection of surface defects in die castings after machining

S. J. Świłło*, M. Perzyk
Institute of Manufacturing Technologies, Warsaw University of Technology, Narbutta 85, 02-524 Warsaw, Poland
* Corresponding author. E-mail address: s.swillo@wip.pw.edu.pl

Received 20.06.2011; accepted in revised form 27.07.2011

Abstract

A new camera based machine vision system for the automatic inspection of surface defects in aluminum die casting was developed by the authors. The problem of surface defects in aluminum die casting is widespread throughout the foundry industry and their detection is of paramount importance in maintaining product quality. The casting surfaces are the most highly loaded regions of materials and components. Mechanical and thermal loads as well as corrosion or irradiation attacks are directed primarily at the surface of the castings. Depending on part design and processing techniques, castings may develop surface discontinuities such as cracks or tears, inclusions due to chemical reactions or foreign material in the molten metal, and pores that greatly influence the material ability to withstand these loads. Surface defects may act as a stress concentrator initiating a fracture point. If a pressure is applied in this area, the casting can fracture. The human visual system is well adapted to perform in areas of variety and change; the visual inspection processes, on the other hand, require observing the same type of image repeatedly to detect anomalies. Slow, expensive, erratic inspection usually is the result. Computer based visual inspection provides a viable alternative to human inspectors. Developed by authors machine vision system uses an image processing algorithm based on modified Laplacian of Gaussian edge detection method to detect defects with different sizes and shapes. The defect inspection algorithm consists of three parameters. One is a parameter of defects sensitivity, the second parameter is a threshold level and the third parameter is to identify the detected defects size and shape. The machine vision system has been successfully tested for the different types of defects on the surface of castings.

Keywords: Non-destructive testing, Castings defects, Machined aluminum die castings, Image processing algorithms; Vision system inspection

1. Introduction

Aluminum alloys (Fig.1) are widely used in all fields of technology, especially in aviation, the railway and road communication, in the marine industry, chemical industry and machine constructions. The casting process can result in the occurrence of internal discontinuities such as cracks, blowholes, shrinkage porosity and gas porosity, etc. The presence of these defects is often the cause of casting rejects, as they deteriorate the mechanical properties, make casting walls lose their tightness and, as a consequence, reduce the quality of the joined surface. The typical structural elements extremely sensitive to the quality of the joined surfaces include: handles of transmission systems, cylinder pistons and cylinder front faces in engine bodies. Their functionality and quality is a critical factor for the failure-free operation. Additionally, small dimensions of pores cause various difficulties when it comes to revealing the presence of defects in castings by non-destructive methods of inspection. Thus, the detection and measurement of surface defects in products are among the problems of production quality most important and difficult to solve in many industries.

The purpose of the project is to create a computerized system for the determination of quality of aluminum castings, such that will open new scientific and research capabilities and will create opportunities for a better understanding of the phenomena accompanying the formation of surface defects in castings. This will lead to better understanding and scientific exploration of factors limiting the casting process of aluminum parts. Studies of this type will help future efforts for an early elimination of surface defects.


Fig. 1. Examples of aluminum castings

Special importance, therefore, gains the possibility to create a relatively easy system detecting the defects in castings after machining, thus eliminating their negative post-effect during operation and ensuring proper back flow of information on the presence and type of defects from the casting user to the producer of castings.

The commonly used solutions based on visual inspection of the surface appearance of the examined part are suitable only in the production area of varied assortment and short lots of the manufactured products, and as such are characterized by the high cost and an outcome which largely depends on the human factor.

Building an integrated vision system for on-line control and inspection will make a basis for the development of this type of industrial equipment, the use of which can bring significant benefits through improvement of the quality and economics of a significant part of the engineering and automotive industry production.

2. Current state of knowledge

In recent years, various solutions were presented in the search for defects on the surface of cast aluminum engine blocks (Fig.2). One of them is the method of ultrasonic evaluation of the degree of porosity in castings of aluminum alloys [1, 2]. This method is based on measurements of the damping coefficient and velocity of ultrasonic waves. Changes in the amplitude of these waves due to attenuation contain information about the reasons which cause their occurrence. The major limitations of this method include the size and shape of defects and their orientation, making this method less accurate.

Another technique, which actually belongs to the most famous non-destructive methods is the technique based on X-rays [3, 4]. However, this method is very expensive and difficult in adaptation to the conditions of production line without stopping the assembly line.

Using computer vision inspection is another, cheaper alternative, with no need to interrupt the assembly process to take the measurements. Currently, in the methods of computer vision inspection, two solutions are mainly used [5, 6]. The first is based on matching techniques, where the surface to be tested is compared to an ideal surface and any type of the detected deviation is regarded as surface defects. The second solution searches for predetermined types of defects. Both solutions are characterized by a high ratio of bad betting patterns and appear to be insufficient for the exploration of surface defects in products such as cast aluminum engine housings. Therefore, the authors of the project proposed a new method, based on a combination of advanced lighting and a modified algorithm for edge detection of defects, aided with analysis of the learning systems (e.g. neural networks), allowing for an unambiguous identification and classification of surface defects.

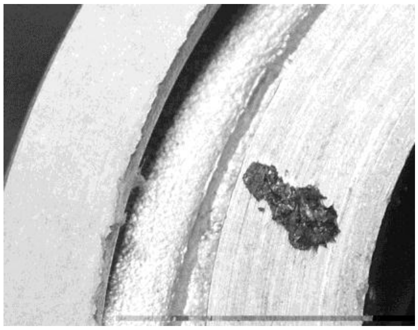
Fig. 2. Example of surface defect

The problem of measurement of defects in aluminum castings is a widely understood aspect concerning defects in the foundry industry regarded as the most important element of the production quality of such products. There is a large group of cast parts, which are subjected to high working loads during operation, which makes the task of obtaining high quality of the joined surfaces in these devices the one of a paramount importance. Unfortunately, these surfaces are exposed to the formation of numerous surface defects as a result of the operation of mechanical, thermal and corrosive effects. Depending on the design and workmanship technology, casting processes may contribute to the formation of surface defects such as cracks or pores, which significantly limit the suitability of the material to carry heavy loads.

In spite of a significant progress in monitoring and controlling processes, the presence of defects in castings is an important issue. This is particularly true in the case of defects that become apparent only at customer's premises, after removing an outer layer of the casting skin in the machining process, rarely during operation. Frequently, especially in the case of mass production, the inspection carried out in foundry does not have the possibility to examine all castings for the occurrence of internal defects, and hence having them disclosed by the customer is the situation rather inevitable. This is why quite special importance has the opportunity to create a relatively easy way for the detection of defects in castings after machining, which will eliminate the adverse effects of their presence during operation, ensuring at the same time proper back flow of information on the presence and type of defects from the customer to the producer of castings.

Preventing defects always consists of four stages: defect detection, identification of its type, establishing the causes and measures leading to a removal of the source of the defect.

a) b) c)

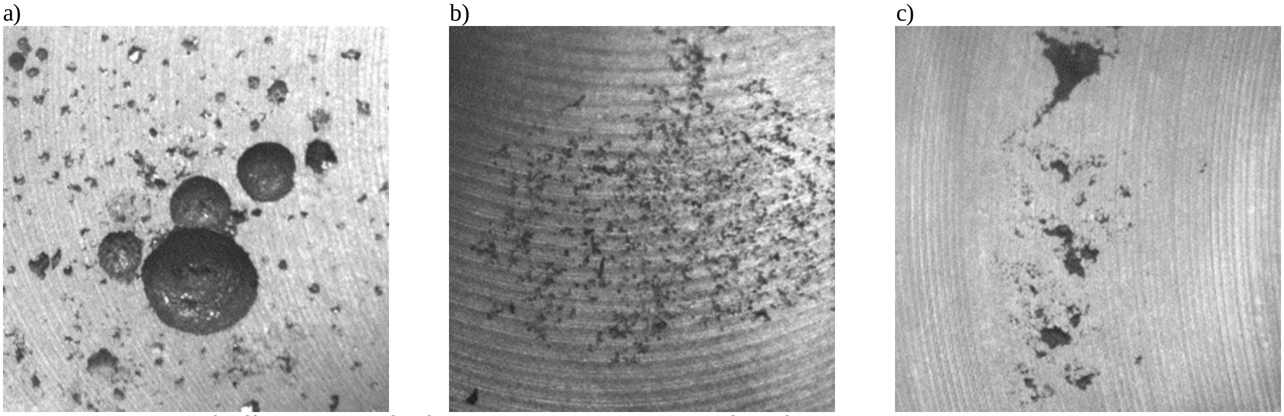

Fig. 3. Examples of different types of defects revealed on the casting surface after machining: a) blowholes, b) shrinkage porosity, c) shrinkage cavity

The first two stages must be completed in the place where the machining of castings is done.

About 50 types of defects were classified, of which internal defects in the form of areas of different size and shape not filled with metal, i.e. voids or foreign matters – contaminating the metal, though forming a relatively small group, are the most severe, because of problems with detectability and impact they have on the operational properties of the product. This group includes the following defects (Fig. 3) [7,8]:

1) Blowhole, representing a void in metal, round or oval in shape with smooth walls. Blowholes can occur in different parts of the casting, usually in groups. There are two main reasons that account for the formation of blowholes: gas emitted from the sand mould or core, and gas emitted from the metal during solidification (rarely).

2) Porosity, representing a cluster of numerous, small and situated close to each other, voids, sometimes contaminated with sand or oxides. Generally, it can arise as a result of processes similar to those that are responsible for the formation of blowholes, but in the case of gas evolution from metal during solidification, porosity is usually combined with metal shrinkage.

3) Shrinkage cavity, representing a void in metal, typically of conical or cylindrical shape, often with irregular, coarse-crystal (very rough) surface. It arises as a result of shrinkage (reduction in volume) of alloy during solidification, in the case of an insufficient feeding of the casting with liquid metal.

4) Microshrinkage (or shrinkage porosity), which forms a dense cluster of small (or very small - microscopic) voids with sharp contours and rough walls. It arises as a result of non-compensated shrinkage during solidification (lack of liquid metal feeding) and can be treated as a scattered shrinkage cavity. The nature of the microshrinkage (centered cavity or scattered) mainly depends on the chemical composition of the alloy, and on the temperature gradient in casting [9].

5) Slag inclusions, which are the inclusions of different origins, shapes and sizes, occurring in the melt. Most commonly it is the slag on the surface of molten metal in a pouring device.

6) Sand inclusions, which are irregular, varying in size, places in the alloy volume, filled with molding material. Sand inclusions are caused by erosion on the mould cavity surface or penetration of molding sand into the mould cavity due to other reasons.

7) Foreign metal, which in the case of aluminum alloys can occur in the form of non-melted pieces of the alloying elements.

Among the above-described defects, the most frequent internal defects revealed during machining of aluminum alloy castings are blowholes, and gas and shrinkage porosities. On defects of this type, studies described in this project will focus. When the surfaces with defects are put in service, there is an imminent danger of sudden and unexpected failure, which clearly disqualifies the functionality of the casting leading to grave losses in material and replacement costs. Typical structural elements that are extremely sensitive to the quality of the joined surfaces include: handles of transmission systems, cylinder pistons and cylinder front faces in engine bodies. Their functionality and quality is a critical element of their operation. In such cases, careful inspection of the appearance of the surface in the examined cast piece is of paramount importance. This method is one of the most important non-invasive techniques belonging to studies of this type of damages, and visual technique is one of the most frequently used. A commonly used control system based on visual inspection is well adapted to operate in the area of a large variety of products, but it is characterized by high costs, is slow, and the results largely depend on the human factor. Therefore, a method for computer vision inspection, which is an alternative to visual inspection, has been proposed.

3. Inspection methodology

The research on identification of defects include, first of all, the development and configuration of the vision, lighting and mechanical systems combined with advanced image processing. This combination of measurement devices and computational technique will constitute the essence of a solution leading to design and construction of a computerized vision system. It is expected to capture images of the examined surfaces jointly with the triggering of alternately operating lighting and numerical processing of these images. The starting point for a computer-aided image analysis of casting quality will be the design of proper lighting system, allowing for visual distinction of casting defects on the machined surface. Hence, the proposed solution of a lighting system (Fig.4) is based on the diffuse illumination in a direction perpendicular to the sample 3. The picture of the examined surface 5 with well visible pores and other on-the-surface objects 4 passes through the lens 2 to camera 1.

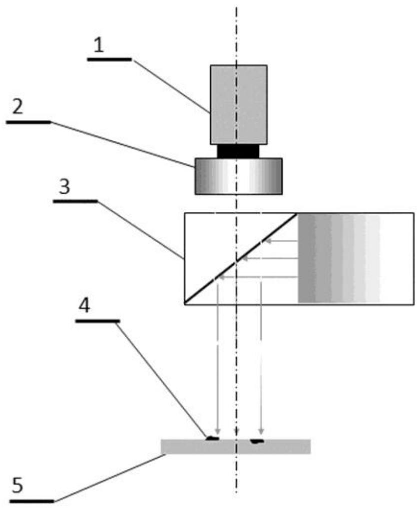

Fig. 4. A new camera based machine vision system for the automatic inspection of surface defects

Owing to the proposed solution in the form of an integrated vision system it will be possible to eliminate the interference in the visibility of the examined object falsifying the correct identification of surface defects. Next part of the project was numerical processing of the image to highlight the obvious defects in castings. To achieve this goal, a modified filter called "Laplacian of Gaussian", commonly used as a numerical tool to identify areas with abrupt changes of contrast edges was used. This filter has a high sensitivity, hence the two-step process of implementation. First, smoothing the image using Gaussian filter, and then designate the edges of objects with variable contrast using Laplace filter. In practice, however, these two operations are combined into one, using an alternative character of the second derivative operator, and bringing the Laplace- Gaussian combination into a single equation, which is the solution proposed by Marr and Hildreth [10]:

$$LoG(x,y) = -\frac{1}{\pi \cdot \sigma^4}\left[1 - \frac{x^2+y^2}{2\cdot\sigma^2}\right]\cdot e^{-\frac{x^2+y^2}{2\cdot\sigma^2}} \qquad (1)$$

where the characteristics of this filter are determined, first of all, by the value of the sigma factor (σ). This will allow continuous adjustment of the sensitivity of the detection of defects, allowing the user to specify the sensitivity level at which he can accept the defects in the casting. To complete this solution it is important to modify the filter described above by introducing to the numerical procedure, an additional parameter (T), allowing the user to change the sensitivity of the detection of defects (flaws), which is an factor limiting the use of this filter. To summarize the subject of the numerical procedure for image processing, a single discrete convolution operation was used, thanks to a simplified form of notation of the combined Gaussian and Laplace filters (1) at a specific sigma value (determining the accuracy of the designation of defects - the first parameter). In the next step, an identification procedure was run where the thus calculated function passes through a zero point and ultimately reject those areas where the average intensity values are smaller than the present value (the second parameter which determines the sensitivity threshold of the casting defect detection). Finally, to group the identified defects the third parameter (λ) was used, which enables determination of how to identify the detected defects basing on their characteristic size and shape.

The model of a vision system presented earlier and the description of proposed numerical analysis of the images of defective casting surfaces suggest that it is possible to make the quality control of casting defects fully automatic. The proposed algorithm for numerical image processing will allow the detection of defective areas, combined with continuous adjustment of sensitivity and quality of defects using the above mentioned three parameters, which gives the user complete control over the process of elimination of defective items.

In addition to the developed numerical algorithm for image processing, it is planned to use an advanced learning process, based on the methods of computational intelligence (CI), which will allow automatic selection of the aforementioned coefficients (σ, λ, T), defining the quality of the process of detection of defects and eliminating user's participation in the system at the initial stage of the search for its appropriate value. The input quantities will be values of these factors, while the output quantity will be the correctness of detection. The latter quantity is inherently of a discrete character, which means that it is not continuous (e.g. 1 - the correct result of detection, 0 - wrong). However, experience has shown (among others, the experience of the authors of the proposal [11]) that it is advisable to treat this type of an output quantity as continuous, although the learning set will contain only the extreme values, i.e. 0 and 1. This allows easier evaluation of the importance and nature of the influence of individual input quantities on final decision. It is expected to use mainly artificial neural networks of MLP type as learning systems, well verified in numerous similar technical problems. Since artificial neural networks require large data sets (in the sense of the number of records), as an alternative learning system CART prediction trees will be applied, to obtain reliable results also for scarce collections. Regression trees and, additionally, classification trees operating on the output values of 0, 1 type, will be tested and compared with neural networks. The source of input data to the learning process will be examples of the sets of images of samples with defects. The result will be generating sets of coefficients, allowing for the start up of the process of numerical image analysis, enabling the correct detection of defects.

a) b) c)

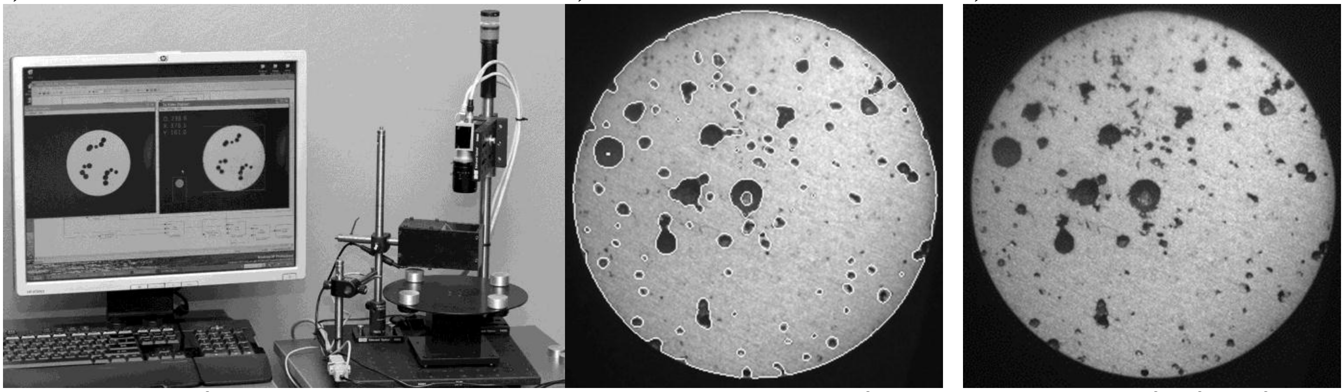

Fig. 5. The results of preliminary studies: a) a new camera based machine vision system for the automatic inspection of surface defects; b) results of identification of surface defects, c) original image

4. Application results

To verify the proposed methods for identification of defects in castings, preliminary studies have been conducted. For this purpose, a vision system has been designed and prepared (Fig. 5a) to determine the feasibility of implementation of the tasks covered by project design. The basis for analysis were images of the aluminum alloy samples and examining the possibility of identification of surface defects using the proposed numerical solution. The studies helped to demonstrate that image processing and the technique of lighting allow the identification of surface defects. Examples of samples with well visible detected defects are shown in Fig. 5b and 5c.

Additionally, studies carried out in recent years by the authors, both in Poland and abroad, in the research centers and companies implementing the latest measurement techniques in the automotive industry, helped to develop a number of solutions to promote better understanding of the causes of surface defects. The studies resulted in the development of a patent [12], in numerous presentations, projects and publications [13-15], and in the participation in numerous works on the adaptation of some of the solutions to the needs of the automotive industry [16]. The results of these studies have become a source of information for the newly created solutions in the field of computer vision inspection of surface defects in cast aluminum.

5. Summary

The scientific objective of the project was to develop and build computer based vision systems for on-line inspection of surface defects in products, especially discontinuities which appear in castings after machining. The essence of the research is to provide a method for obtaining and analyzing images of the inspected surfaces, to allow an unmistakable and consistent finding of defects and specifying their type.

In addition to the developed numerical algorithm for image processing, it is planned to use an advanced learning process, based on the methods of computational intelligence, which will allow automatic selection of the filter coefficients, defining the quality inspection process. Presented in this paper a new vision inspection system and image processing algorithm were successfully implemented to control and identify of surface defects in die casting after machining.

References

[1] Kupperman, D.S., Reimann, K.J., and Abrego-Lopez, “Ultrasonic NDE of Cast Stainless Steel”, NDT International, Vol. 20, No. 3, June 1987, pp145-152.

[2] Nelligan, T.J., "Ultrasonic testing of nonferrous castings", Die Casting Engineer, Vol. 36, pp14-16, March 1992.

[3] D. Mery, Th. Jaeger, and D. Filbert, “A review of methods for automated recognition of casting defects,” Insight, 44(7), 2002. pp. 428-436

[4] F. Herold, K. Bavendiek, and R. Grigat, “A third generation automatic defect recognition system,” Proc. 16th World Conference on Non Destructive Testing, Montreal, Canada, Aug. 30-Sep. 3, 2004.

[5] Z. Xu, M. Pietikainen, and T. Ojala, “Defect classification by texture in steel surface inspection,” Proc. QCAV 97 International Conference on Quality Control by Artificial Vision, Le Creusot, Burgundy, France, pp. 179-184, May 1997, pp. 28-30,

[6] J. Kyllonen, and M. Pietikainen, “Visual inspection of parquet slabs by combining color and texture,” Proc. IAPR Workshop on Machine Vision Applications (MVA’00), Tokyo, Japan, pp. 187-192, November 2000. pp. 28-30,

[7] Z. Falęcki: Analiza wad odlewów. Wydawnictwa AGH, wydanie drugie, Kraków 1997.

[8] Analysis of Casting Defects. Publ. American Foundrymen’s Society, 3d edition, Des Plaines, Illinois, USA.

[9] M. Perzyk i inni: Odlewnictwo. WNT Warszawa 2003r.

[10] Marr, D. and Hildreth, E., "Theory of edge detection," Proceedings The Royal Society London, Vol. 207, 1980, pp. 187–217.
[11] M. Perzyk, A. Kochański: Detection of causes of casting defects assisted by artificial neural networks. Journal of Engineering Manufacture, Proceedings of the Institution of Mechanical Engineers, Part B. Vol. 217, (2003). pp. 1279 - 1284.
[12] S.J. Swillo, K.A. Iyer, S.J. Hu, "Optical system and method for measuring continuously distributed strain", US Patent # **7,036,364** (Uniwersytet Michigan), 2005
[13] S. J. Swillo, G. Lin, S. J. Hu, K. Iyer, J. Yao, W. Cai, M. Koc: Detection and characterization of surface cracking in sheet metal hemming using optical method, Transactions of NAMRI/SME, Vol. 33, Aug. 2005,
[14] S. J. Swillo, K. Iyer and S. J. Hu: Angled line method for spatially continuous strain distribution measurement in sheet bending, Journal of Manufacturing Science and Engineering, Vol.128, Issue 3, Aug.2006, pp.651-658,
[15] S. Świłło, A. Kocańda, P. Czyżewski, P. Kowalczyk, Hemming process evaluation by using computer aided measurement system and numerical analysis, 10th ICTP, Aachen, Germany, September 25th-30th, 2011, accepted