Journal of Achievements in Materials and Manufacturing Engineering

Volume 73 • Issue 2 • December 2015

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Review of innovation in using X-ray tomography for non-destructing analysing of the green parts

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ABSTRACT

Purpose: Article concern studies of the method using X-ray as a source to analyse products made of the steel mixture powder after compaction "green parts" on the example of the engine and gearbox parts. Mentioned methods are used to detect defects like surface cracks and inner material cracks, as well as density distribution without violations of their functional properties.

Design/methodology/approach: Presented techniques are evaluating on the typical sintered engine and gearbox parts like pulley and synchronizing hub. All methods have advantages and disadvantages, therefore are compression between them essential, especially concerning used in industrial conditions including zero waste manufacturing.

Findings: Evaluation of the nowadays used methods and trends used for "green part" made of steel mixture powder are very important. Moreover presents a future trends and future development directions will be provided by this article.

Research limitations/implications: Methods are tested on the "green parts" made of the steel mixture powder for automotive application and mostly depending on the industrial conditions for such products.

Practical implications: Methods should be able to use in the industrial conditions to assure good quality parts without defects and well-documented density distribution without destroying the object.

Originality/value: Analyse of the nowadays methods using for evaluation of the "green parts" quality after compaction of the steel mixture powder are still undergoing rapid development.

Keywords: X-ray, Green parts, Measurement

Reference to this paper should be given in the following way:

Ł. Karaś, G. Matula, Review of innovation in using X-ray tomography for non-destructing analysing of the green parts, Journal of Achievements in Materials and Manufacturing Engineering 73/2 (2015) 139-143.

METHODOLOGY OF RESEARCH

1. Introduction

Traditional powder metallurgical way of the producing parts is still rapidly developed and improved, especially for the most demanding market of sintered parts for automotive industry. A traditional way of producing parts is consist of the compacting, sintering. It has been brought to the limits, therefore are already extended on additional operation like for example surface densification, carbonitriding, machining (drilling, polishing), and the final step chemical cleaning. Nowadays are also modification of the presented technology possible like for example technology know like "double sintering double compacting".

The most important task for each step is to provide necessary quality of the produced parts, which sometimes narrow possibilities for the next production step, therefore it is so important to provide measurement methods which brings good repeatability of the results and not destroying of the parts by reducing of the scrubs especially in the green stage of the part.

A green-state compact is an intermediate step in the powder metallurgy manufacturing process, which is produced when a metal powder–lubricant mixture is compacted in a press. This compact is subsequently sintered in a furnace to produce the finished product.

Non-destructive material testing is most cost effective in the green state because early flaw detection permits early intervention in the manufacturing cycle and thus avoids scrapping large numbers of parts. Unfortunately, traditional methods have largely been unsuccessful when applied to green-state compacts. As well as such approach is very important for the new production philosophy "zero waste manufacturing", which is the most important market demand nowadays. To assure such approach non-destructive methods using X-ray as a source are very popular for analyses.

Such demands are reflecting in the development of the measurement devices and new measurement concepts, which are compared in this paper.

Such devices have to have good accuracy and precision most retaliated by the concentration of the X-ray beam.

Additionally they should be able to implement on the production line, therefore they have to be rapidly suitable for the production cycle, reliable and exhibit data analysis simplicity. In the case of X-ray devices, common difficulties are to analyse picture which they have to give guarantees an unambiguous outcome of the test for the automatized process. Such problems are solved by using advanced picture analysis algorithms, which are also briefly shown in the following paper.

2. Non-destructing methods using X-ray for analyse on the "green part" in industrial conditions

2.1. Non-destructing density measurement method

The density after geometry and the weight, is one of the most important technical parameter in mass production line, which have to be measured and control in line. One of such device is Gamma Densomat produced by GAMMATEC Engineering GmbH. This device was used for the density measurement and it works as follow: in an insulated test chamber X-ray beam is incident on the selected object and passes through it to the detector, where the intensity of the beam is measured. With the known thickness and chemical composition (metal powder, graphite and lubricant), it is possible to determine density value in the measured point.

For the determination of density mass-absorption law was used, as follow eq. 1:

$$\frac{I(\lambda)}{I_0(\lambda)} = \exp\left\{-\left(\frac{\mu}{\rho}\right)\lambda\rho x\right\} \tag{1}$$

where $I(\lambda)$– measured X-ray intensity, $I_0(\lambda)$ – base beam intensity, x – thickness of the material, λ – wave length, μ - mass attenuation coefficient, for the material composition is express as sum of attenuation coefficient of each component depend on the quantity θ as follow eq. 2

$$\mu = \left(\frac{\mu_c}{\rho_c}\right)_1 \theta_1 + \left(\frac{\mu_c}{\rho_c}\right)_2 \theta_2 + \cdots \tag{2}$$

and final search density value ρ.

As an example of density distribution was done on a cross-section of a belt pulley made of Ancorsteel FD 4600A powder base mixture shown in Fig. 1,

In production line the local density value can change during not optimal production condition. Usually such part like belt pulley is compacted with the speed of 6-9 cycle per minute, therefore it is big challenges to measure all part in production line.

The accuracy of this measurement depends on the ability to focus of the ray in conjunction with the thickness of the element and the time of exposure. Exposure time can vary between 10-120 sec. depending on the type of the object; error value may be up to ±0.1% of the measured value with normal distribution, but the error of standard density measurement devices using Archimedes' Principle cannot be bigger than the real value (underestimated).

It is a device that can be used to check the density of the material under industrial conditions.

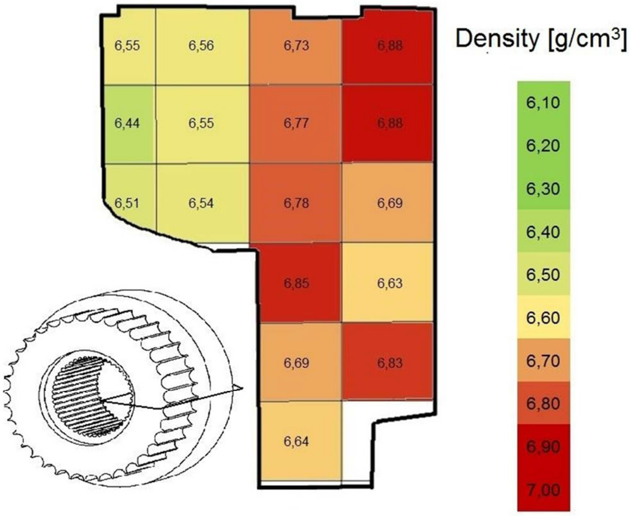

Fig. 1. Density distribution on a cross-section of a belt pulley

Table 1.
Advantages and disadvantages of the Gamma Densomat device

Advantages	Disadvantages
Rapid measurement device	The beam diameter determines the area of measurement, therefore only local measurement
Measurement of the local density	Measurement accuracy comparable with the standard density measurement devices using Archimedes' Principle
Easy using, since the process is highly automatized	For some areas of measurement possible only after cutting of the object as shown in the Fig. 1
Can be use for a variety of metallic materials and powder mixture	Training of personnel in the field of radiation safety
Can be use in production environments	

2.2. Crack detection devices

Another important production parameter is quality of the green stage part. Unfortunately the most dangerous are cracks, which they appear during last step of the compaction know like ejection stage. Nowadays it is necessary to prove all parts, especially for the engine and gear box, because they transfer big moments with high revolution and they have to work properly long time. Unlikely each crack even very small (2-5µm long) provide in the long term to additional stress concentration which can make available destruction of the part and therefore engine which have to be avoid. Consequently each method and device to assure gut quality is under big interest of the powder metallurgy industry.

Another device using X-rays is made by Accent Pro 2000 Ltd. It is used to detect cracks on the surface in industrial conditions.

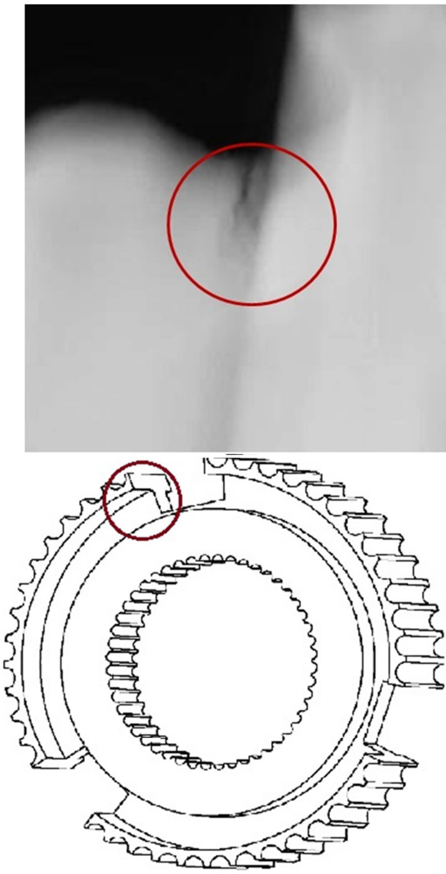

Fig. 2. X-ray analyse of synchronization hub part for the 3th gear in manual gear box

This device exposes the object in a test chamber at the rotary table having 3 degrees of freedom, which allow to make pictures from different angles.

One of the advantages of this method is quite fast examining of the object at predefined critical locations without the need for the destruction of the object, which may be intended for the further production. Unfortunately, contrast is the biggest limitation of the ability to detect defects. Surfaces located in the corners of the samples, especially with reflex angle are critical. In such a case, it is not possible to detect defects; because the cracks are covered through another surface.

Table 2.
Advantages and disadvantages of the device from company Accent Pro 2000 Ltd

Advantages	Disadvantages
The speed of the device, only required a few pictures	Difficulty in the analysis due to low image contrast
Can be easily automatizing	Only for predefined critical localizations
Can be used for various types of metallic materials and different powder mixtures	Comparable results with the Magnetic Powder Inspection (MPI) method
Can be used in production environments and directly in production line	Difficulties detecting internal cracks of the material
	Training of personnel in the field of radiation safety

Similar investigation have been done in Fraunhofer Institute in Germany. They use the computer tomography method to build from X-ray images the three-dimensional object. It is possible to connect separate images only using advanced algorithms, as can be seen in the following Fig. 3.

Such algorithms need to have the ability to proper filtrate obtained information to avoid an influence of overlapping surfaces and guarantee a good quality of the measured object.

In such way, it is possible to examine the external structure and internal volume of the object, which is the biggest advantage of this method. In presented case shown at fig. 3, the object has a surface defect, which was already found previously with MPI method. After analysing the three-dimensional object were possible to detect crack and also it deep without destroying the object. Unfortunately, without the information about the localization of the defect was almost impossible to use it, because of the contrast problem and difficulties of analyse 3D object on the 2D screen.

By using computed tomography, can detect cracks and other defects, including the interior, which is an important advantage of that method. A disadvantage is the very large number of images of the object, which takes time, as in the industrial conditions is not always possible, and therefore, is mainly used in research work.

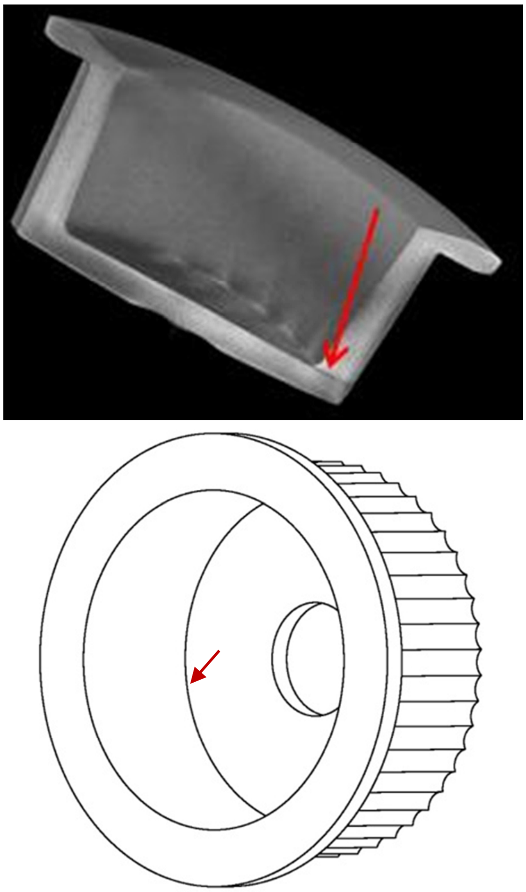

Fig. 3. 3D Computer Tomography of the pulley

Table 3.
Advantages and disadvantages of the device used in the Fraunhofer Institute

Advantages	Disadvantages
Possibility of the fully analyse of the object (internal and external)	Time-consuming, because of so many images
Can be used for various types of metallic materials and different powder mixtures	Difficulty in analysing the 3D object
	Nowadays only for small objects, because of the small chamber
	Not possible of automatizing in industrial conditions
	Visualization 3D object in 2D screen
	Training of personnel in the field of radiation safety

2.3. Image processing algorithms using X-Ray for analyses

All presented in this paper method require advance image processing algorithms suitable for X-Ray pictures, which has sometimes very poor contrast and consist of the gray grade scale. Therefore are required very specific methods suitable for such situation. Such research has been already begun and it is presented for example by GIERLE-Mayer [3] and Kroll [5], which assist the user in his task and improve detectability of the materials errors, for example.

During the evaluation process of the nowadays used method, it was found, that it is needed a simple and effective test object in order to compare different devices. The simplest solution is standardized samples for testing, which have deliberately relevant defects whether surface or internal, to be able to calibrate and test the device. Over such issues, scientists are currently working with the Technical University of Vienna [2]. They proposed a method for the production of standard samples with defects such as scratches, cracks, etc. which allow for better evaluation of the common method.

3. Conclusions

Current testing methods using X-ray as source has potential and need to be further developed. The methods for evaluation density of the objects are very perspective for the future, especially for the most demanding market of sintered parts for automotive industry. This method can be use in inline production and bring very important information about the part and improve the quality of the product. On another hand, the method for detecting errors in the parts has much more requirements, therefore, it devices are more complex.

Unfortunately, each presented in this article methods has drawbacks, of which users should be aware. Further improvements are needed, and require easier and valuable methods during the production of materials using powder metallurgy.

Acknowledgements

The authors would like to acknowledge Miba Sinter Austria.

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