

Application of Nondestructive Testing Methods for Packaging Examination

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Abstract. Nondestructive testing (NDT) methods are applicable in many ways for defect detection as well as optimization of packaging production processes. The visual inspection method is the technique which is mostly used, although neither the customer nor a skilled inspector may be aware of this.

Techniques like ultrasound for wall thickness measurement, the application of x-ray techniques or the use of dye penetrant techniques for crack detection are rather well known to the NDT family. However, acoustic emission techniques can also be helpful for the characterization of packaging materials. In this paper the employment of x-ray computer tomography (CT) for measurement of wall thickness in plastic jerrycans, especially on the edges, and its possible optimization of production processes will be discussed.

A comparison of the CT and ultrasonic examinations of wall thickness and the reliability of this measured data are also important points for the discussion, especially if some safety factors can be derived from the results.

The leakage test is also good for jerrycans, IBCs or other kinds of drums for the transportation and storage of dangerous goods. The disadvantage of this kind of test is that a lack of quality, e.g. wall thickness deterioration, cannot be detected if the wall thickness withstands the internal pressure. Therefore, especially for quality assurance, the other, previously mentioned techniques are better for a statistical assessment of a batch. This paper is focused on the comparison of different NDT results with special emphasis on the large range of material mechanical properties.

Introduction

The mechanical properties of fabricated plastics jerrycans made of High Density Polyethylen (HDPE) are strongly dependent on the physical properties characteristics of the granulate material used for their fabrication and the chemical consistence as well as the parameter necessary for the fabrication like pressure, temperature, time etc. All this parameters have an influence on the flow behavior during the fabrication process. Even if the granulate material is in the range of the specification, different drum properties can be occurred. In the frame of a R&D work “simple” plates with a constant wall thickness, within the frame of the accuracy during the production are prepared for the estimation of the material properties. These mechanical properties are measured using tensile tests as well as Charpy-V-notch test specimens. These tests should give information about the influence of the granulate material. By using the gained knowledge of these experiments,

investigations were carried out on real jerrycans. The test specimens for the determination of the mechanical properties of the jerrycans are made from the side walls of it. Because of the lack of the material on the more critical areas like sharp geometrical changes (the edges of the cans), there is no possibility to produce tensile or Charpy-V test specimens. On these special areas other methods must help to determine the mechanical behavior. A theoretical model e.g. Finite Element Model (FEM) (can) is able to overcome this problem if the mechanical properties are well known and if the real wall thickness on these areas are known, too. Famous techniques for measuring the wall thickness are for example the application of magnetic forces, the employment of ultrasound and X-ray techniques as inspection methods of the Non-Destructive Testing (NDT) family.

In the presented paper the use of the X-ray technique under special emphases of the Computer Tomography (CT) will be discussed. Examples are shown and compared with the results of magnetic forces measurements.

To achieve an integral information about the behavior of the jerrycan, in addition to the measurement on the plates (tensile and Charpy test) an internal pressure test was performed too. The drawback is that the jerrycan can withstand this pressure but the material behavior degradation in the mentioned critical areas are likely to be on the limit e.g. without a safety factor. The evidence of this test for steering fabrication processes can be neglected.

Wall Thickness Measurements

Due to the fact that jerrycans or other bottles made from HDPE have wall thicknesses of only a few millimeters, mostly between 1 and 2mm, one of the classical NDT methods, namely ultrasonic testing (UT) is not the favored method for wall thickness measurement. X-ray testing (RT) employed for wall thickness measurements of pipes, with the advantage that insulations must not be removed, are optimized for wall thicknesses up to some millimeters. Fig. 1 shows a principle sketch of both techniques. The evaluation of the time of flight, by knowledge of the sound velocity of the material, delivers the wall thickness or the position of a defect [1-3]. Special ultrasonic probes for different applications were developed and are commercially available [4, 5].

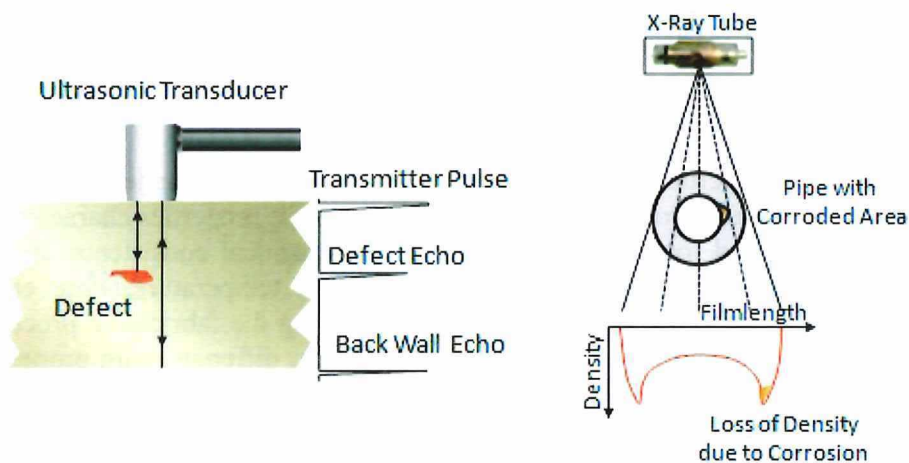


Fig. 1: Wall thickness measurement using ultrasonic (left) and X-Ray Techniques (right)

Wall thickness measurements at plastic bottles or jerrycans for the transportation and storage of fluids i.e. articles of daily use can be done by employing magnetic forces (Fig. 1). The basic correlation between the magnetic forces F and the area A is given by the equation below.

$B = \mu_0 \mu_r H$	B	magnetic flux density
	μ_0	permeability coefficient of vacuum
$F = \frac{1}{\mu_0 \mu_r} B^2 \cdot A$	μ_r	relative permeability
	A	area

This technique, also known as magneto static method, was used for the verification of the wall thickness measurement carried out with CT at jerrycans used for the transportation and storage of dangerous goods. The advantage of this technique is the easy handling, the disadvantage is that for a good overview of the wall thickness distribution of the jerrycan a lot of measurement points at the surface of the can are needed. This disadvantage can be tackled with the application of X-ray methods /6-8/.

Dimensional Measurements using CT

Nowadays the CT is a powerful measuring device in the fabrication e.g. for aluminum engine blocks in the automotive industry [9]. In the meanwhile some applications are available and the performance of this technique is comparable or has sometimes been superior to tactile measurements. One of the benefits of CT is the dimensional measurement of hidden dimension e.g. inside of a motor block. This technique was used for wall thickness measurement of plastic jerrycans. The principle of the computer tomography is illustrated in Fig. 2.

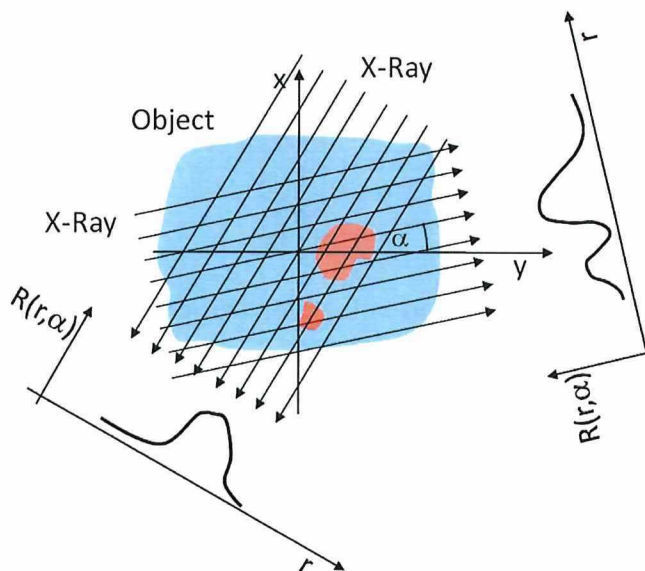


Fig. 2: Principle of Computer Tomography

The projection of all absorption R in one direction as a function of the distance r and the angle α is measured. In the figure two positions of this behavior are shown. For inhomogeneous objects, the absorption coefficient μ is a function of (x, y) and this regards the application of CT using the Radon-Transformation (Johann K.A. Radon) as described in the equation below. The principle can be described as: Measurement of the integral (sum) of the absorption for a number of angles α (total circumference). The result of the measurement is the Radon-Transformation of the X-ray absorption of the object [10]. The two dimensional image will be received through the inverse transformation. From this image, an evaluation of material density behavior as well as the estimation of changes in the dimension is possible.

$$R(f)(r, \alpha) = \int_{-\infty}^{\infty} f(r \cos \alpha + t \sin \alpha, r \sin \alpha - t \cos \alpha) dt$$

Dimensional metrology with Computed Tomography (CT) at inner and outer component structures is mostly used for the optimization of the process technology especially for the evaluation of production tolerances. The whole measuring chain including the experimental set up was realized and optimized. In the focus of this special application of CT was the measurement of the different dimensions and geometry changes in relation with a reference as well as shrinkage and distortion. The advantage of NDT methods lies in the basic idea of these methods i.e. inspection without destroying the test object. Quantitative information's of the whole structure are achievable in a relatively order: rather short time. The application of X-rays are significant for the inspection of components like engine blocks made of aluminum, gear boxes etc in the automotive industry. Industrial CT systems are available since the middle of the 80s of the last century, for nondestructive testing and newly also for dimensional measurements. For the experimental set up a computer tomograph as available in the lab at BAM was used. The data listed below, have been the basis for the experiments at the jerrycans.

High-voltage	250 kV
Electric current	0,7 mA
Filter	3 mm Al
Number of detector pixels	1024 x 1024
Size of one pixel	0,4 x 0,4 mm ²
Distance between tube and detector	1500 mm
Exposure time for each projection	1,1 sec
Number of rotation angles	1200
Total time for measurement	ca. 3h

The conformance of the measured volume of the jerry can (180x180x180 mm³) to the real size (250x250x250 mm³) regards two steps:

- With the two-circle method, the beam-opening angle in the horizontal region can almost be doubled.
- The enlargement of the measured volume in the vertical direction was achieved due to the change of the vertical position of the test object in relation to X-ray tube and the flat detector. In this particular case three vertical positions were performed.

Figure 3 shows an example of a jerry can. The wall thickness distribution at the whole can is clearly cognizable. The evaluation was done by employing the thickness scale at the right side of the figure. The left and the right side of the jerry can are pictured. The left side has some particular measured wall thickness values in addition. The advantage of this

testing method compared with the image presentation is obvious and can be summarized as follows:

- The visualization of the wall thickness distribution.
- Data storage of all measured jerrycans in a data file.
- Evaluation of these data to find statistical variations within the production batch.

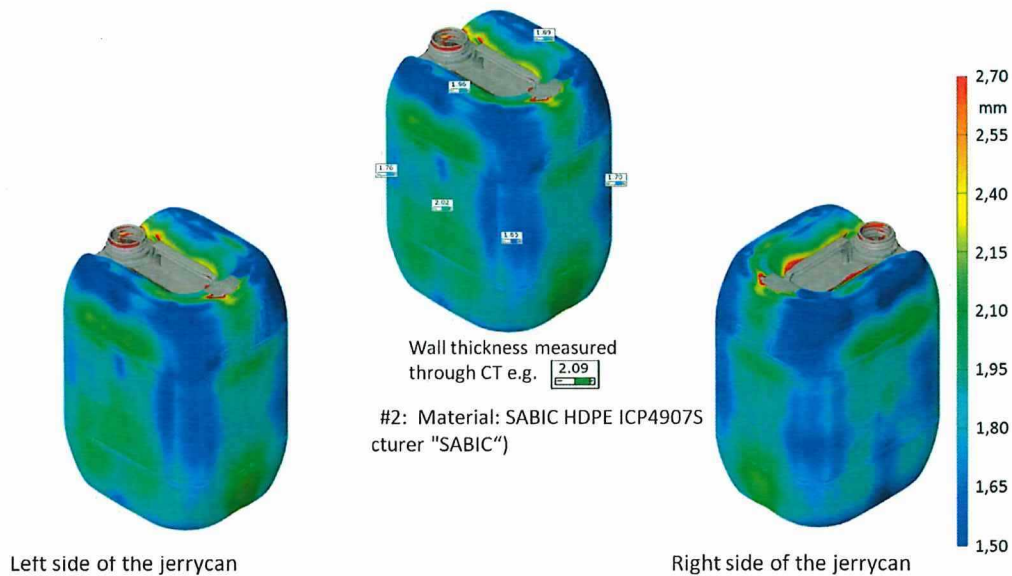



Fig. 3: Wall thickness measurement at a jerry can using CT

The wall thicknesses of the presented jerry can are received after the correction of the scale factor depending on the experimental set up conditions (correction of the optical distortion). The measured wall thicknesses in the areas, as shown in the picture, are in the range between 1.6 mm and 2.0 mm. Clearly recognizable are the regions in which an abrupt change of the geometry of the jerry can appears. In addition, the overviews of the cans are impressive.

The visualization of the results measured with CT gives a good overview of the wall thickness distribution of the whole jerry can (Fig 4). This is a big advantage compared to the measurement with magnetic forces, because by the application of the magneto static method only selective measurements are possible.

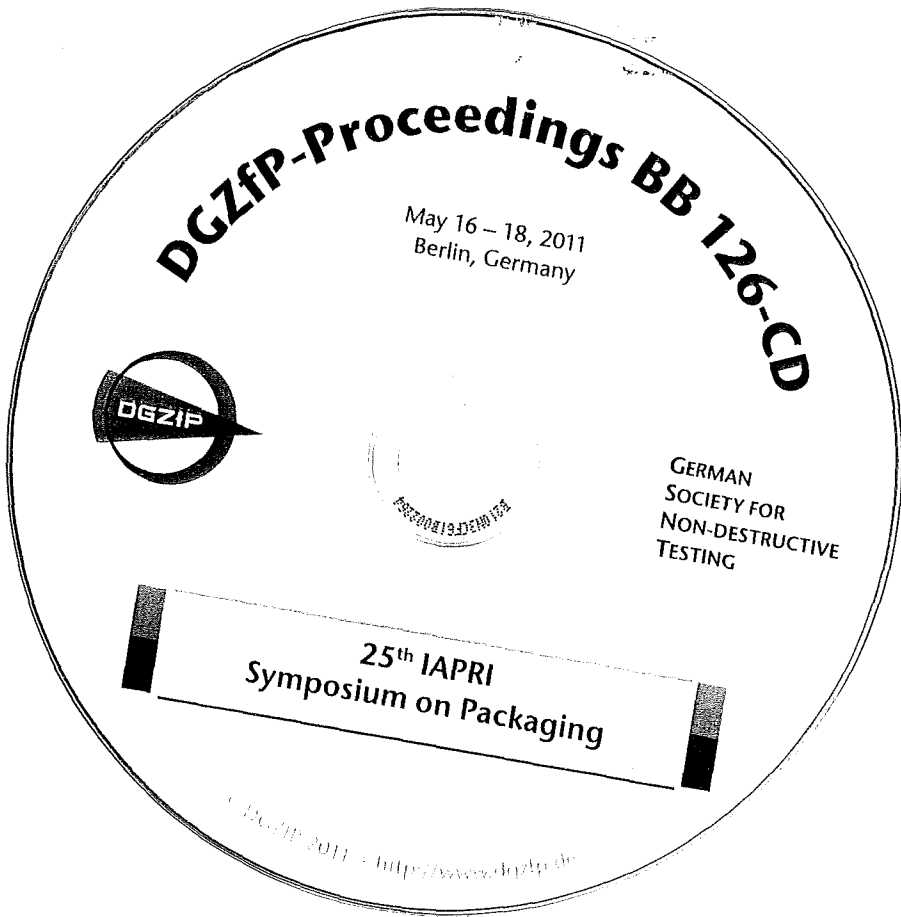
The wall thickness measured with CT e.g.  versus the thickness measured through magneto static e.g. **2,09** is plotted for selected areas. The correlation between both techniques is very good. Both techniques deliver the minimum wall thickness in areas with abrupt geometry changes. These are the critical parts of the jerrycans. For the verification of this statement the hydraulic pressure tests were carried out in the laboratories.

becomes higher. Therefore, an overview of the wall thickness distribution as measured using CT is also a good tool for the optimization of the production process.

Simulations using the Finite Element Model (FEM) support the experiments. Basis of FEM are, as well known, the material properties. These properties are collected from experiments. The future goal is, that the experimental determined material properties are confident enough, so that the mechanical behavior of products, made of HDPE, can be predicted using FEM.

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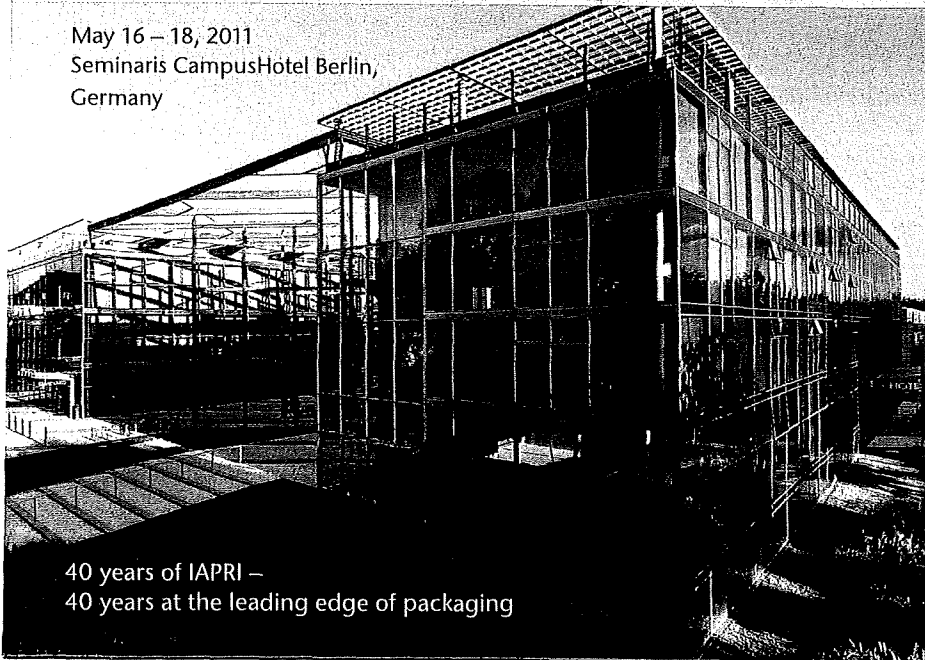
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