Polymer Testing 39 (2014) 12–19

Contents lists available at ScienceDirect

Polymer Testing

journal homepage: www.elsevier.com/locate/polytest

Test method

A novel sink mark model for high gloss injection molded parts – Correlation of deflectometric and topographic measurements

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ARTICLE INFO

Article history:
Received 23 May 2014
Accepted 1 July 2014
Available online 10 July 2014

Keywords:
Quality inspection
Injection molding
Sink mark
Deflectometry
Sink mark model
Topographic measurement

ABSTRACT

This paper introduces a mathematical model which approximates the topographic shape of punctiform sink marks to a Gaussian-bell-like function. Such a model enables the description of sink mark shapes with few parameters, and the calculation of features which can be used to describe the visibility of the sink marks. The topography of test series of sink marks on black high-gloss plastic parts was measured with a chromatic coding confocal microscope. The obtained data was fitted to the model which enables calculation of a sink mark's amplitude and volume. These two parameters are proposed to feature a sink mark's intensity. The results were compared to deflectometric measurements of the sink marks. Despite the fact that the two measurement methods are based on different principles, the results show high correlation. Especially, the behavior of sink mark volumes agreed well with the behavior of sink mark intensity which was measured using deflectometry. Therefore, the model also represents a viable option for the calibration of deflectometric applications. Additionally, the model can be used in future to simulate sink mark properties such as visual perceptibility.

1. Introduction

Besides functionality, the appearance of plastic products has become one of the major factors for the buying decision of customers. Especially, high-gloss plastics front panels, which have become complexly shaped in recent times, enhance the look of products. Fast and reproducible production of such parts is facilitated by injection molding. After the investment in a mold, even complex parts can be produced rapidly and cheaply. However, due to properties of plastics such as their low hardness compared to inorganic materials, their low thermal conductivity or their relatively high thermal expansion coefficient, plastics engineers have to consider specific rules for the conception and production of injection molded parts [1].

Nevertheless, because of the need to ensure the functionality of the parts and their aesthetic appearance as well as to reduce costs, designers have to violate the rules of plastics manufacture [1]. For this reason, such parts are prone to surface defects. Sink marks, which are caused by characteristic thermal shrinkage of polymers and local

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http://dx.doi.org/10.1016/j.polymertesting.2014.07.001
0142-9418/

geometry of the part, are one common type of surface defect related to injection molding. Especially on high-gloss surfaces, this defect type can considerably influence the appearance, due to distorted reflections of the surroundings on the defective surface area.

Traditionally, quality inspection on high-gloss injection molded parts is performed manually, despite the fact that sink marks are especially hard to evaluate reproducibly by human observers when the visibility of defects is close to the threshold of perceptibility [2]. Also, human observers are prone to fatigue and boredom which prevents objective part evaluation [3,4]. For these reasons, machine vision methods have become increasingly important for quality inspection. Extensive reviews [5,6] describe texture analysis methods. These methods detect surface defects in surface textures which result from the interaction between surface structure and shadowing, which in turn is caused by the setup of the lighting. Methods were found for surface inspection that are based on analysis of texture or distinctness of image. Such methods facilitate the detection of defects [7,8] or the evaluation of gloss [9,10] on plane surfaces in correlation to human perception.

For curved surfaces, the mentioned methods have to be adapted, since the direction of light incidence in relation to the surface normals changes with the position on the surface [11]. On plane or slightly curved surfaces the direction of light incidence is approximately constant for a suitably small region of interest whose size is dependent on the distinctness of surface curvature. In the respective regions of interest the morphology of surface texture can be evaluated similar to plane surfaces [11,12].

If either the surface curvature is too pronounced or if larger regions of a surface have to be evaluated at once, machine vision methods have to be applied, which are explicitly developed for quality inspection or metrological reconstruction of curved surfaces. Comprehensive reviews concerning the most common methods for reconstruction and inspection of curved surfaces are given [13–17]. Many of these methods, for example photogrammetry or photometric stereo, are based on image fusion where the shape of the inspected object is calculated from several images of the object. However, most of these methods have in common that they were developed for diffusely reflecting surfaces. Such methods tend to be unreliable for specularly reflecting surfaces.

Deflectometric methods on the other hand are well-suited for the measurement of specularly reflecting surfaces, since they relate the diffractions in surface reflections of known patterns to the shape of the respective surfaces. The method is based on the Moiré diffraction method where a coherent light beam, usually a laser, is deflected by successively arranged lattices [18]. The resulting interference patterns are projected onto the inspected surface and the pattern changes with different surface shapes. Ritter and Hahn enhanced this approach with their reflecting grating method where only one lattice is used [19]. Horneber et al. introduced phase measuring deflectometry [20]. They used a projector to project a light pattern on a screen which was reflected by a surface into a camera. By application of phase-shifting algorithms, they were able to calculate a relationship between the light pattern on the screen and the image of the camera. Since this relationship is proportional to the normal vector sets of the surface, it contains information about the first derivative of the surface.

Based on their work, Kammel and León proposed this method for the quality inspection of high gloss surfaces [21–23]. They exploited the fact that deflectometry measurements contain direct information about the surface slope and postulated that the derivatives of the measurements correspond to the directional curvatures of the inspected surface. A mathematical model which was introduced in a previous paper [24] can be used to calculate sink mark intensities for high gloss parts from deflectometric measurements. However, the implementation of such an inspection system in an injection molding process requires the definition of a threshold to define whether a given part is faultless or has to be rejected. Such a threshold is chosen subjectively by the engineers responsible. In most cases, a better solution is to base threshold definition on objective measurements to increase comparability of sink mark inspection. Additionally, such measurements can be used to calibrate and evaluate the deflectometric measurements of the sink marks.

In this paper, topographic methods are used to evaluate deflectometric measurements of test series of injection molded parts. The comparison of the results from topographic measurements with the results from deflectometric measurements was done by fitting the topographic measurements with a Gaussian-like bell model. This facilitated the extraction of two features: The amplitude and the volume of the sink marks. The applied fitting model which was motivated by previous approaches to model sink mark shapes with distribution functions [25,26] will be also introduced in this paper.

2. Principles of deflectometry

In this paper, deflectometric measurements carried out in a previous paper [24] are compared to topographic measurements. The principle ideas which allowed for the calculation of the sink mark intensities from deflectometric measurements are shown in this section.

The basic deflectometric measurement setup consists of a screen which provides a structured light source, a highly reflective surface sample and a camera. Thereby, the sample can be considered to be part of the optical setup. The camera is not focused on the surface of the sample but on the image of the light source reflected by the surface, because the reflection of the screen contains the information which is required for the deflectometric measurement.

The evaluation of a sample's influence on the reflection is accomplished by tracing the light paths from the light source to the camera sensor. By encoding the screen, the starting and end points of the respective light paths can be expressed in the intrinsic pixel coordinate systems of screen and camera. This information is stored in a mapping function m [22,23,27]. Because the light paths are dependent on the surface of the sample, the mapping function also includes information about the normal vector field of the inspected surface.