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Test method

Development of a novel color inhomogeneity test method for injection molded parts

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ABSTRACT

Nowadays, most research and development concerning injection molded products is focused on their mechanical properties, although visual appeal plays an even more important role on the market. There are several standards and recommendations for the testing of mechanical properties, but appearance cannot be quantified easily. The visual aspects are almost completely neglected, and there is no commonly accepted method for measuring color inhomogeneity.

The appearance and color homogeneity of injection molded parts depends on the coloring method itself, the applied technology and several other conditions. The method most used nowadays to evaluate color inhomogeneity is based on visual inspection by humans. This research focuses on developing a new and automated method that can replace visual inspection. The functionality and precision of the new method and software have been tested and compared with visual inspection to prove its applicability.

1. Introduction

To investigate color inhomogeneity in injection molded parts objectively, it is fundamentally important to have a measurement system which is fast enough, works with relatively small standard deviation and produces results which correlate with human inhomogeneity perception. Unfortunately, at least two of these criteria cannot be fulfilled by human inspections, since human decision incorporates a huge uncertainty. The only way to reduce this uncertainty is to increase the number of inspectors and average their results, which slows down the evaluation process. Due to these issues, it seemed necessary to develop an automated method, which reassuringly fulfills the criteria of being fast, working with low standard deviation and correlates well with human inhomogeneity perception.

According to ASTM, the standard measurement methods need to be precise, repeatable and reproducible [1]. These requirements also cannot be fulfilled by human visual inspections. Therefore possibilities of an evaluation algorithm executed by a computer, which works on digitalized pictures have been investigated. Commercial equipment that can digitalize pictures normally have their outputs in the RGB color space. Since the original goal was to establish a measurement method which is in line with average human color difference sensation, these color coordinates needed to be transformed to a color space where Euclidean distances, described in Eq. (1), are proportional to human color perception.

$$\Delta E = \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2}, \tag{1}$$

where ΔE is the Euclidean distance between two points in a three-dimensional space, and Δx, Δy, Δz are the coordinate differences of the three dimensions. Quite a lot of color spaces developed in recent decades fulfill this requirement, however, in most industrial applications where color is in correlation with important attributes or process parameters, CIELAB color space is used to evaluate them.

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Sometimes, CIELAB is also preferred over RGB because of its device-independency [2–4]. Transformation formulas from the RGB to the CIELAB color space can be obtained from literature dealing with color space transformations [5–11], computer graphics [12] or industrial applications [3] of color measurement systems.

The appearance of injection molded parts is very important and it does not only mean the color properties only, but in most cases the evenness of the color as well. It has been shown by many authors [13,14] that injection molding parameters have a significant effect on the color and gloss of the finished parts, and the effect is different for smooth and rough surfaces. Pisciotti et al. [13] measured the effects of injection molding parameters on color and gloss in the case of polypropylene parts, and concluded that mold temperature and packing pressure have a significant effect on the measured color and gloss. They also concluded that lower melt viscosity and higher shear rates provided a better replication of the mold surface, which had a different effect if they tested a smooth or a rough surface. In the case of rough surfaces, gloss decreased as the quality of surface replication improved, while the opposite was observed with a shiny surface. Dawkins et al. [14] measured very similar results to these. Although they did not measure color inhomogeneity, only the color coordinates themselves, it can be assumed that these parameters and the surface texture of the cavity could influence the level of visually perceived color inhomogeneity as well.

Color inhomogeneity is often caused by insufficient dispersion of the fillers or colorants, and it is also influenced by injection molding parameters, as in the case of nanofiller dispersion in extrusion, which was influenced by screw rotation speed according to S. Sathyanarayana et al. [15]. Color differences and deviations are often signs of certain processes taking place, such as various degradation processes. This was studied by Santos et al. [16], who examined the effectiveness and the durability of different stabilizers against photo-oxidation processes in ABS. Martínez-Morlanes et al. [17] found that there is a correlation between the color shade of polyethylene samples and their E vitamin content and absorbed gamma radiation.

From the inhomogeneity problem described in many publications, it is obvious that surface defects are often in a connection with chemical or physical changes during the plastic processing. Until now, there are no standards and accepted measuring methods to characterize these color inhomogeneity problems, although it is a fundamental importance to establish a widely acknowledged method. Based on this demand from the injection molding industry, the goal of this work was to establish a novel and automated measuring method for evaluating color inhomogeneity level. The new method should be fast and produce results as close as possible to the human evaluations, with better repeatability and reproducibility.

2. Materials and methods

In this study, the color inhomogeneity of specific specimens, injection molded from unfilled acrylonitrile-butadiene-styrene (ABS) with 4 wt% of masterbatch (MB) was examined. The matrix (Terluran GP-35, Styrolution Group GmbH) and the masterbatch (Renol-pink ABS143479Q, Clariant) were dry mixed, and samples were injection molded on an Arburg Allrounder Advance 370S 700-290 machine, with a screw diameter of 30 mm. The set of technological parameters were selected based on a DOE in which the most significant parameters have been identified. The range of parameters was set to be wide enough to show any differences in color inhomogeneity, but also to allow the execution of the injection molding cycle with these parameters. The injection molded samples were digitalized using a flatbed scanner with 200 dpi resolution. These pictures have been evaluated by a computer based method described in the *Mathematical method development* section. Human evaluations have been carried out on the physical samples in a conventional way, in which each sample has been evaluated by 6 trained technicians under identical circumstances. They have been instructed to score the samples from 0 to 10 based on the inhomogeneity level, where 0 is the theoretically perfect sample, with no inhomogeneity problems at all, and 10 is the worst case. These 6 scores have been averaged than correlated to the software scores.

2.1. Test mold development

For the color inhomogeneity evaluation tests, a mold was built to produce 80 × 80 mm flat specimens. The mold (Fig. 1) has exchangeable inserts to be able to produce sample parts with different gates (standard, film, and also multiple gates), with different mold surface finishes (polished, fine eroded, rough eroded) and different thicknesses (0.5–4 mm). Each parameter has a significant influence on surface quality, thus also on the color homogeneity and appearance of the parts. The mold contains a special ejector system which works on the whole surface area of the product, thus eliminating the surface defects that ejector pins would cause. For the tests, 2 mm thick samples were injection molded using fine eroded surface finished inserts and film gates.

2.2. Mathematical method development

Image analyzer software was developed in order to objectively characterize the uneven color of injection molded products by using the image of the scanned samples. Because the Lab color system approximates human vision, the RGB color coordinates of the images of the scanned samples were converted into the Lab color system ($P[L,a,b]$).

A moving window scans the picture, and at every (i,j) position of this window the mean color coordinates are calculated ($\overline{a}_{i,j,k}$), where k is the size of the window. The window size (k) could be varied from 1 to the maximum size of the picture. A matrix can be generated from the mean color coordinates as follows (Eqs. (2)–(4)):

$$\overline{\overline{A}}_{i,j,0} = \begin{bmatrix} \overline{a}_{0,0,0} & \overline{a}_{1,0,0} & \cdots & \overline{a}_{i,0,0} \\ \overline{a}_{0,1,0} & \overline{a}_{1,1,0} & & \overline{a}_{i,1,0} \\ \vdots & & \ddots & \vdots \\ \overline{a}_{0,j,0} & \overline{a}_{1,j,0} & \cdots & \overline{a}_{i,j,0} \end{bmatrix}, \tag{2}$$