SPE Plastics Research Online
10.2417/spepro.006936

A simple, versatile imaging technique for quantifying the haze of materials

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An alternative imaging-based technique quantifies the haze of materials in practically useful terms, and allows more sophisticated optical data to be extracted compared with the commonly used ASTM standard.

The cloudy appearance of materials (e.g., semicrystalline polymers used in the packaging industry) is quantified by an optical property called haze.[1–3] This property is typically measured using a dedicated hazemeter instrument adhering to the ASTM D1003 standard.[2] The latter defines haze as the percentage of the total transmitted light that is scattered by more than 2.5° from the direction of the incident beam. This standard features certain drawbacks, however, principal among which is its non-practical definition of haze (i.e., based on an arbitrary minimum scattering angle).[3] Additionally, a typical hazemeter requires large ($\sim$5cm^2) and maximally homogeneous samples (because the output is a single spatially averaged value), rendering the instrument unsuitable for obtaining locally well-resolved data.

Haze arises from light scattering that occurs due to refractive-index inhomogeneities present in the material.[1] In practice, an increase in the haze of a material corresponds to a reduction of contrast for an object viewed through it. This effect justifies the search for low haze in the development and production of, for instance, packaging materials.

Using this correlation, and motivated by the emergence of new applications requiring spatially resolved measurements of haze, we have developed an improved imaging-based technique wherein haze is unambiguously defined in practically useful terms, i.e., as the reduction of the perceived image quality of an object viewed through a material specimen.[4] Our technique furthermore allows local (sub-millimeter spatial resolution) measurements and, if required, outputs the distribution of haze values for a given specimen area.

The principle as well as the instrumentation of our technique is illustrated in Figure 1. Samples are placed in direct contact with—and backlit through—a 'knife-edge' array mask, and are photographically imaged. The knife-edge array mask (essentially a thin, perforated sheet) functions as the viewed object, creating a spatially defined pattern of light intensities with maximally sharp transitions between backlit and masked areas. Subsequent image analysis and calculation of the haze involves quantifying the reduction of the sharpness of backlit-to-masked (i.e., bright-to-dark) transitions for the knife-edge mask when imaged through a given material sample. A detailed illustration of this method—see Figure 2—shows the principal elements of image analysis for a series of injection-molded disk-shaped plaques of polyethylene (PE) containing varied fractions of the clarifying agent 1,2,3-trideoxy-4,6:5,7-bis-O-[(4-propylphenyl)methylene]-nonitol (TBPMN, *Millad®NX™ 8000*, Milliken Chemical, USA).[4]

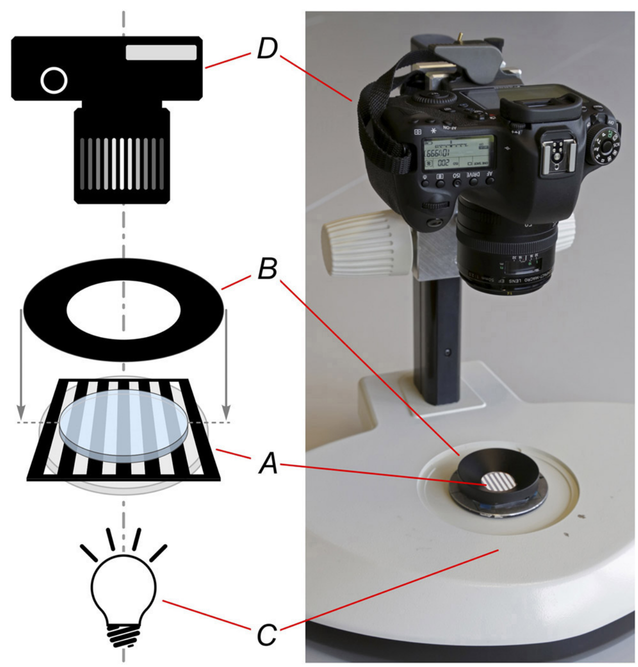

Figure 1. *Schematic illustration of the operating principle and actual photo of the instrumentation.[4] A: The material sample positioned flat on the knife-edge mask and light diffuser. B: A means of obscuring stray light around the sample. C: The light source. D: Digital camera.*

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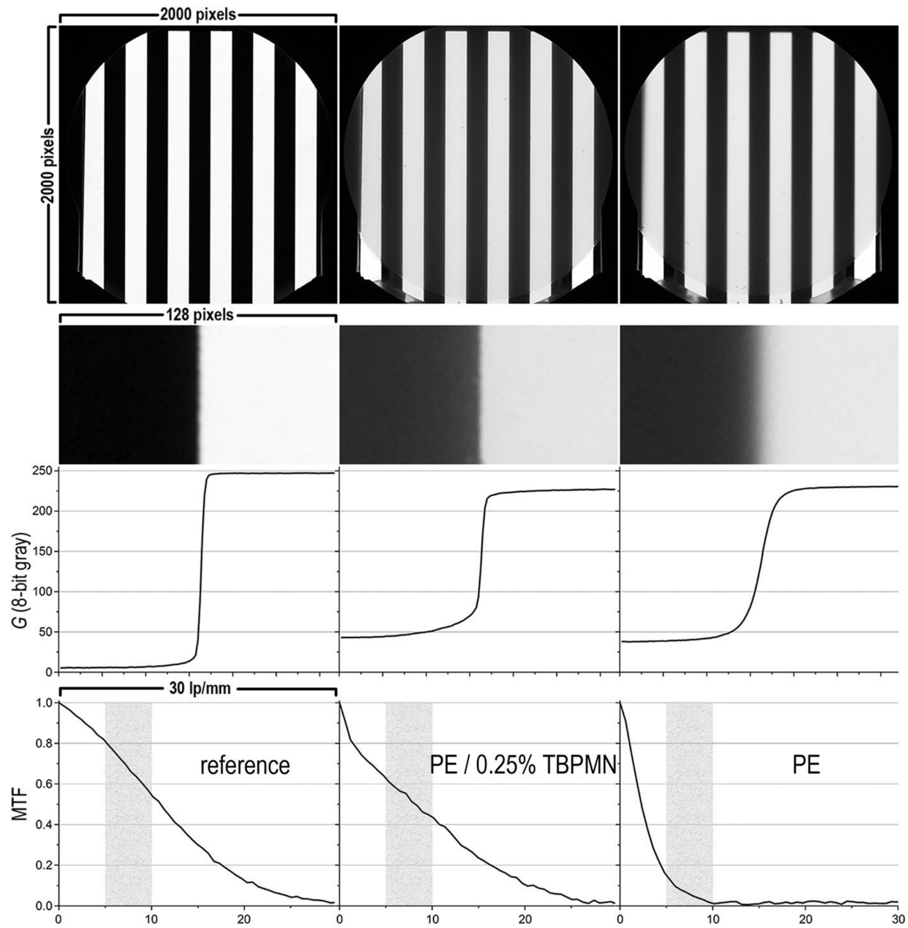

Figure 2. *Left to right: Image analysis for the mask ('reference') and two polyethylene (PE) samples containing a clarifying agent—1,2,3-trideoxy-4,6:5,7-bis-O-[(4-propylphenyl) methylene]-nonitol (TBPMN Millad®NX^{TM} 8000, Milliken Chemical, USA)—at weights of 0.25 and 0%, respectively, placed on top of it. Top row: Actual photographs. Second row: Close-up views of selected dark-to-bright transitions. Third row: Light intensity (gray value, G) profiles for the dark-to-bright transitions shown above. Bottom row: Modulation transfer functions (MTF) for the selected dark-to-bright transitions (shaded regions indicate the spatial frequency range, in units of line pairs/mm, used to extract single haze values).*[4]

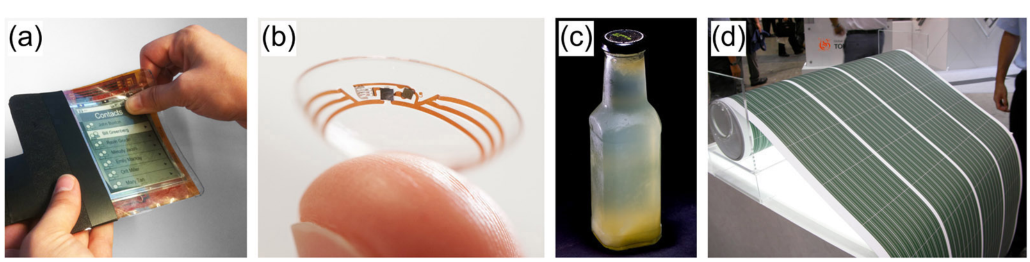

Figure 3. *Examples of emerging and existing technologies that require spatially resolved measurements of haze: (a) plastic electronics, (b) smart contact lenses, (c) the food and beverage industry, and (d) flexible photovoltaics. Images (a), (c), and (d) subject to Creative Commons CC BY 2.0 license, and image (b) shows an investigational device currently in co-development by Verily and Alcon (reproduced with permission).*[5]

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Table 1. Haze values measured using our imaging-based technique and a conventional ASTM hazemeter (in brackets).[4] Haze standards are labeled by their nominal haze values.

Sample	Haze [%]	
PE / clarifying agent (TBPMN)		
PE / 0.25% TBPMN	23.6 ± 4.3	(34.5)
PE / 2% TBPMN *	39.7 ± 4.6	(56.3)
PE	90.6 ± 1.6	(91.4)
ASTM haze standards		
'4.79%'	4.9	(4.82)
'10.3%'	10.2	(10.3)
'20.2%'	22.0	(20.3)
'30.4%'	32.9	(30.5)

* Imaging data not shown in Figure 2.

Such image analysis can be performed simply, using widely available software (e.g., ImageJ[6]).

The use of a knife-edge mask—here, a simple 'stripe and gap' grid pattern—allows the modulation transfer functions (MTF) to be calculated for the backlit-to-masked transitions, with MTF quantifying the contrast between bright and dark image regions as a function of spatial frequency.[7] The haze value for a given material sample is then calculated, based on the ratio of the sample MTF to a 'reference' MTF (i.e., the mask alone, without a sample, representing a 0% haze standard) in a chosen spatial frequency range.[4] In our analysis, we determined the optimal spatial frequency range for calculating haze to be 5–10 line pairs/mm (lp/mm). It is worth noting that this range of values closely matches the typical resolution of the human eye at a viewing distance of 20cm (∼6 lp/mm),[8] reaffirming the practicality of our technique for carrying out research and development, as well as optical quality control, of materials intended for packaging and display applications.

The extracted haze values for the PE/clarifying agent plaques (see Figure 2), as well as commercially available ASTM haze standards (BYK-Gardner GmbH, Germany), are presented in Table 1 alongside the corresponding values obtained using a conventional hazemeter. Complete qualitative agreement and excellent quantitative correlation is observed throughout, particularly for the ASTM haze standards (within 1%). Any discrepancies in the extracted haze values are primarily due to the different definition of haze used in our method which, if necessary, can be corrected by calibration.

In summary, we have developed a simple and versatile imaging-based technique for quantifying the haze of materials and have applied this technique for two distinct material systems. Our method employs an alternative, application-centered definition of haze based on the reduction of perceived image quality, and can be used to extract more sophisticated optical data compared with an ASTM hazemeter (e.g., probing haze with sub-millimeter resolution and outputting a distribution of haze values for a given specimen area). As such, we expect our approach to be more suited for materials development and optical quality control in emerging technologies (e.g., plastic electronics and smart wearable devices) as well as in existing fields (e.g., the food and beverage industry): see Figure 3. The micropatterned features, inhomogeneities, and complex specimen geometries inherent in these applications make the use of an ASTM hazemeter highly problematic. In subsequent work, we will explore the variation of haze as a function of distance between the knife-edge mask and material samples, given that both contact and out-of-contact haze are highly relevant for the commodity plastics industry.

The authors wish to thank professor emeritus Paul Smith (ETH Zurich) for supporting this work and Peter Schwarz (BYK-Gardner/ALTANA) for stimulating discussions. Ron Gallo (Vanderbilt University) is gratefully acknowledged for his encouraging presence during the preparation of this manuscript.

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References

1. G. H. Meeten, **Optical Properties of Polymers**, Elsevier Applied Science Publishers, London, 1986.
2. **ASTM D 1003–13: Standard Test Method for Haze and Luminous Transmittance of Transparent Plastics**, ASTM International, 2013.
3. F. W. Billmeyer Jr. and Y. Chen, *On the measurement of haze*, **Color Res. Appl. 10**, pp. 219–224, 1985.
4. S. Busato and A. Perevedentsev, *A simple imaging-based technique for quantifying haze and transmittance of materials*, **Polym. Eng. Sci.**, 2017. Patent application EP16191416.3, 2016, doi:10.1002/pen24580
5. http://verily.com/projects/sensors/smart-lens-program/ Verily Life Sciences, Smart Lens Program. Accessed 7 July 2017.

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6. http://imagej.nih.gov/ij/ ImageJ: Image Processing and Analysis in Java, public domain software. Accessed 7 July 2017.
7. G. D. Boreman, **Modulation Transfer Function in Optical and Electro-Optical Systems**, SPIE Press, Bellingham, WA, 2001.
8. H. Weber, **Digitale Farben in der Medienproduktion und Druckvorstufe**, MITP, Heidelberg, Germany, 2006.