Transparency in Compounding

Inline Testing Methods for Monitoring Processes

The quality of final products can be increased by using measurement technology for monitoring production processes. Interest in it is increasing especially for compounding. There are various existing methods of non-destructive testing that can also be used inline in the manufacturing process. The different methods are suitable for different applications: an overview of the current capabilities and limitations of the various inline methods.

Optimizing production processes to avoid production errors is often an important step toward achieving profitability with a new or altered product. To carry out such improvements, the first thing that has to be known is the state-of-the-art. Existing processes also profit from metrological monitoring, since it can ensure uniform product quality. Moreover, it enables quick reactions when irregularities happen to occur, and can document product quality according to objective criteria with a view to potential liability issues. In the plastics industry, the demands are rising for process monitoring especially in compounding. By applying suitable measurement methods, resources and time can be saved, and rejects or even complaints minimized.

Non-destructive testing (NDT) is ideal for process monitoring. It encompasses various procedures and makes it possible to exploit relevant parameters during decisive production steps. The measurable parameters far exceed the capabilities of established and already widely used pressure and temperature measurement and include, for example, inline detection of screw wear, filler content and particle size distributions, water content, detection of inclusions of foreign matter, characterization of the degree of melting and the downstream measurement of wall and layer thicknesses of extrudates. Depending on the application, many aspects of the challenges to a direct inline measurement of these parameters have still not been overcome. Some of the difficulties come from having to deal with the high melt temperatures and pressures, as well as abrasiveness. Even so, numerous applications could already be implemented on an industrial scale, or are currently

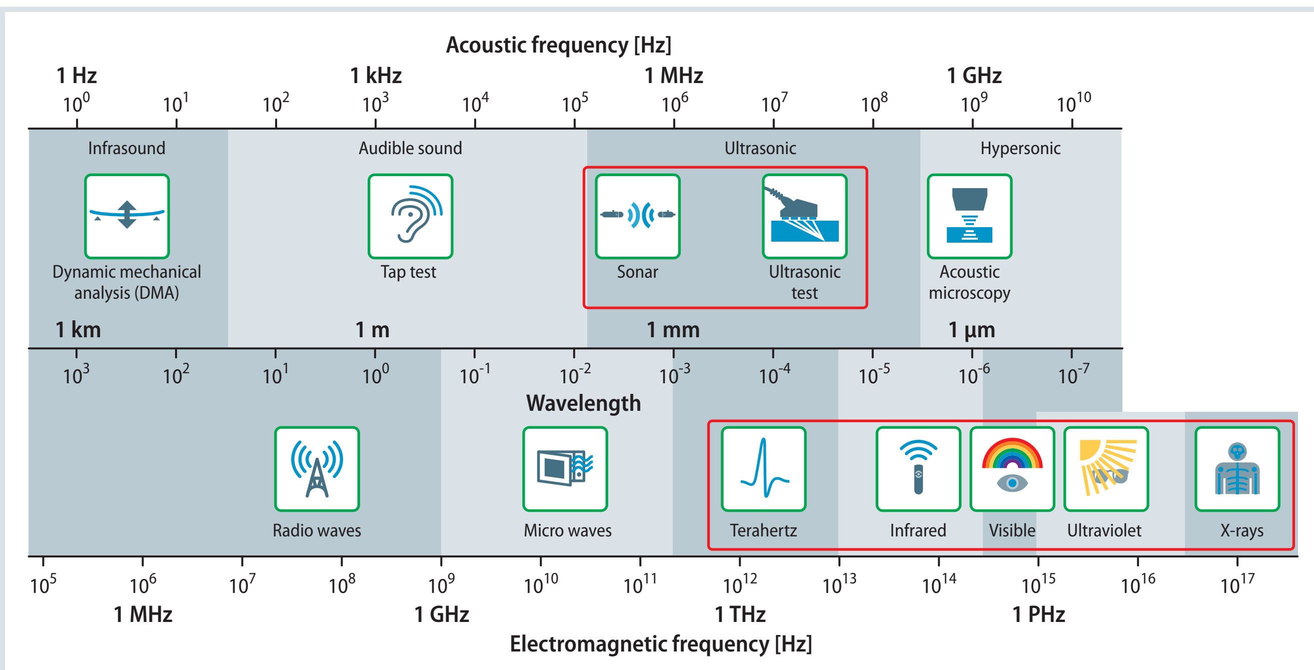

Fig. 1. An overview of electromagnetic and mechanical waves arranged in the order of frequency and wave length: The red colored areas represent the NDT methods used in plastics processing Source SKZ; graphic: © Hanser

being introduced to the market. Many of the available non-destructive testing methods are based on mechanical and electromagnetic waves (**Fig. 1**).

Ultrasonics: Proven, but Temperature-Dependent Technology

Ultrasonic waves are acoustic waves that connect to the audible sound range and cover a spectral range from approx. 20 kHz to 1 GHz. Two well-known examples are the examination of inner organs in medical technology and the natural tracking ability of bats. Ultrasonic waves, however, can also find application in the plastics industry, for example, for characterizing melts online. The technology has also been in use for such a long time, that proven signal processing and robust sensor technology are already in place.

Successful systems have already been developed that record the particle size of filler materials and their content in the melt. The calibration data banks required for this are already available for many applications (**Fig. 2**). By measuring ultrasound amplitude, they show the dependence of the extinction coefficient on filler content and the corresponding median size of particles. This technology is also capable of determining melt viscosity inline, thereby avoiding the use of expensive online rheometers. In addition to ultrasonic damping, the viscosity of the melt influences, above all, the reliably measurable speed at which ultrasonic waves propagate.

A main disadvantage of ultrasonic methods is the physically determined temperature dependence of the parameters. Its application can be limited by common temperature fluctuations during the processing of plastics. At SKZ – The Plastics Center work is proceeding on compensating them to enable wider marketability.

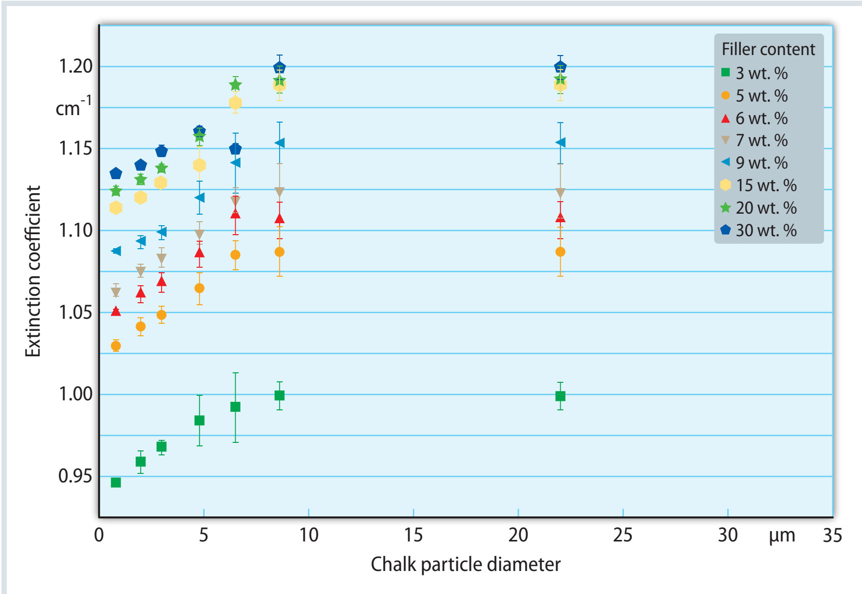

Fig. 2. Dependence of measurable ultrasonic amplitude (extinction coefficients) of filler content and the accompanying median size of chalk particles in plastics compounds: By using such databank-integrated calibration curves, both of these quality relevant features can be quantified inline by ultrasound Source SKZ; graphic: © Hanser

Optical Spectroscopy: Regulating Color Directly in Production

Optical measurement methods function mostly in the range of visible light or bordering spectral ranges. This includes ultraviolet (UV, 200 – 380 nm), visible (VIS, 380 – 800 nm) and near infrared light (NIR, 800 – 2500 nm). Optical measurement methods use the reciprocity of this electromagnetic radiation with the plas- »

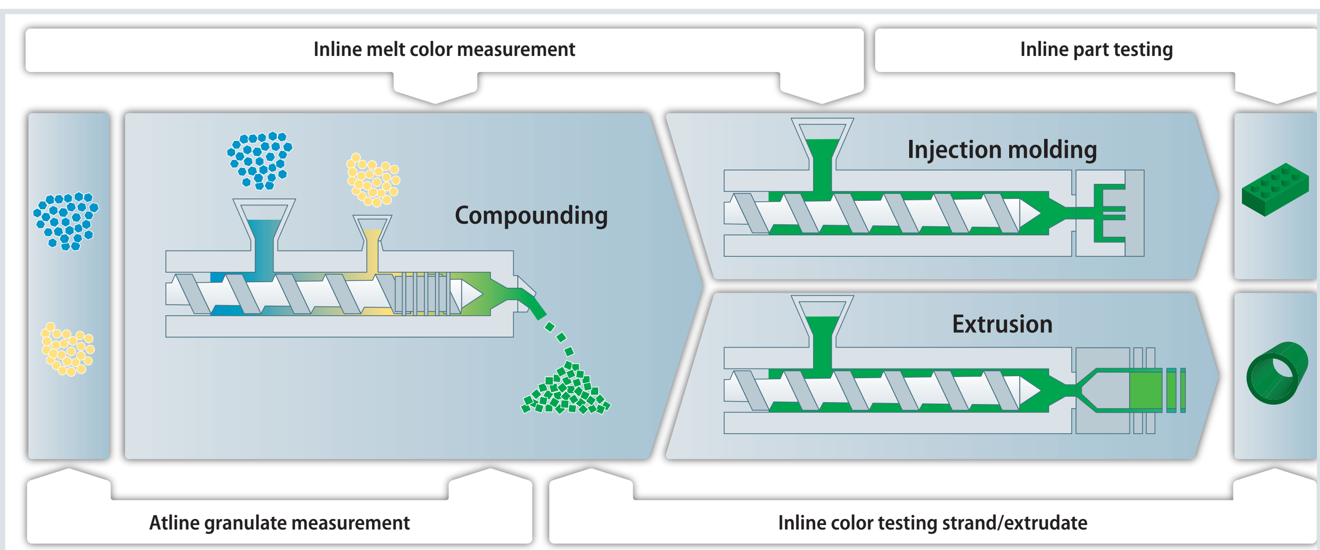

Fig. 3. Process chain exemplified by color measurement of dyed plastics products: Dyed compounds are manufactured from various raw materials and processed further, either continuously by extrusion, or discontinuously to injection molded products. All along the process chain there are various possibilities for monitoring color quality Source SKZ; graphic: © Hanser

tics melt to examine the materials properties of plastics. Fiber-optical probes are used that illuminate the plastics melt and guide the reflected or transmitted light to a spectrometer. Depending on the wave length range used, various applications are possible. In the VIS range, color measurements usually take place based on color deviations that can be quantified during the process. This enables a reduction of rejects thanks to the shorter reaction times, compared to laboratory measurements (Fig. 3). Coupling measurement with dosing can enable automatic color regulation and dwell time measurement. The challenge here is presented by thermochromism, that is, the temperature dependence of color.

Thanks to the characteristic absorption of NIR radiation in the form of molecular vibrations, spectroscopy can be used to distinguish various contents in compounds qualitatively and quantitatively. For the latter, chemometric models are generally used that combine the measured spectrum with the amount of material examined. However, calibration can prove very complicated, since it has to be created specifically for each combination of materials. That is why the recording of well-defined reference spectra has been adopted as a practical alternative for purposes of comparison.

To be sure, additives can also be quantified in the UV range, but that is utilized for practical reasons only to a small degree, since both the additives as well as the plastic reciprocate under radiation. The wide variety of measur-

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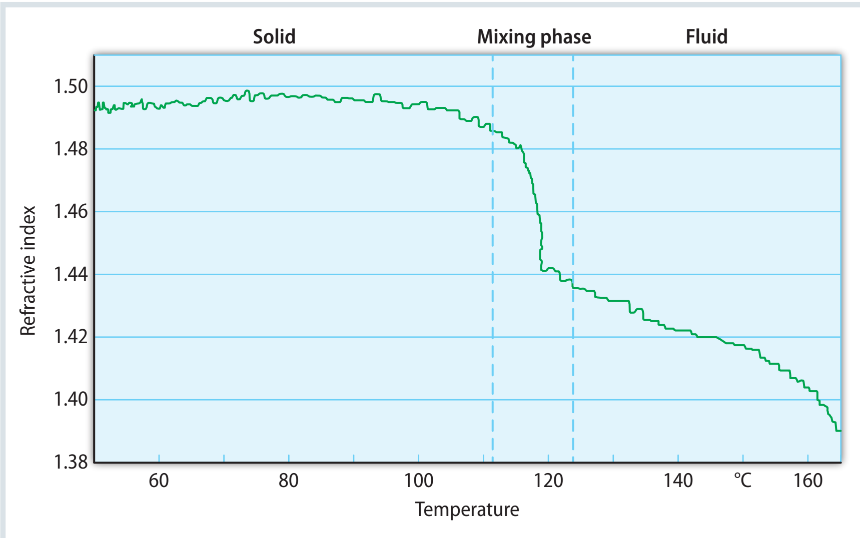

Fig. 4. Dependence of a characteristic value, the so-called refractive index determined via terahertz from the degree of melting in a compound or the melt temperature: The degree of melting can be recorded inline by consulting a databank specific to the material Source SKZ; graphic: © Hanser

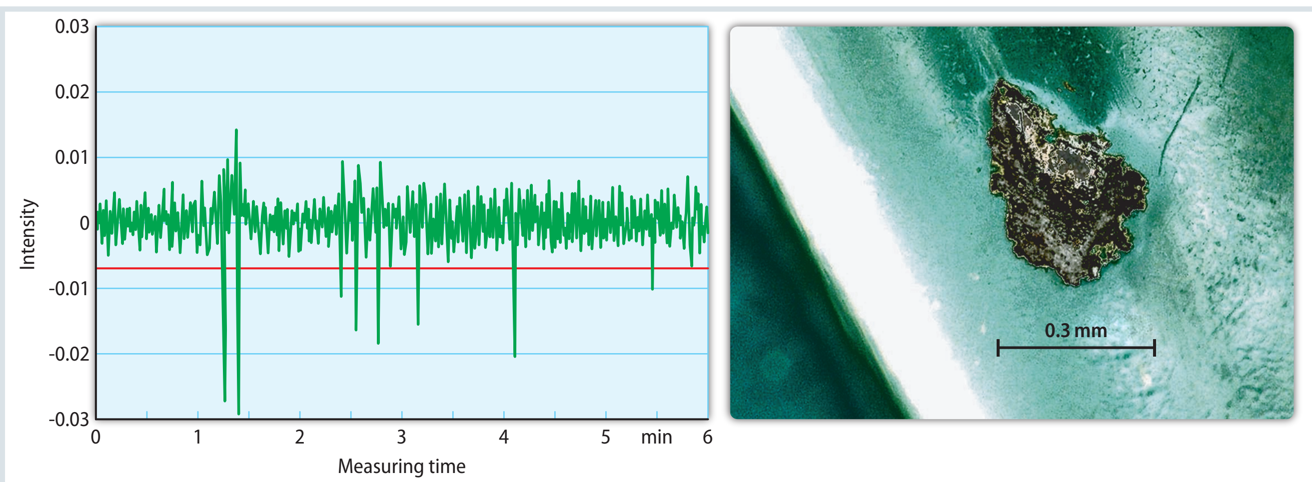

Fig. 5. The dependence of so-called intensity, a characteristic value recorded via terahertz from the stochastic appearance of foreign materials in a compound (left), as well as a microscopic image of a machine-related wear particle in the melt (right): A threshold value (red line, left) can be defined by taking a variety of processing states into consideration beyond which the measuring signal can be univocally consigned to a foreign particle

Source SKZ; graphic: © Hanser

ing capabilities of broadband and high-price all-in-one spectrometers are rarely required for compounding. That is why there are simplified solutions tailored to particular targeted parameters, such as hydrolytic materials degradation, or a color change. The SKZ has long supported companies with the selection of a suitable system.

Microwave and Terahertz: Temperature- Independent and Non-Contacting

Microwave and terahertz methods are in daily use as body scanners at airports and for distance measurement in the automotive field. They use electromagnetic waves bordering on the frequency range of radio waves and the visible range. Compared to x-rays, the frequency range is significantly lower in energy and, therefore, non-ionizing and not hazardous to health. In extrusion, wall thickness measuring systems have become established for measuring individual layers in the micrometer-to-decimeter range.

The characterization of plastics melts has, until now, not become widespread due to the rough production conditions known for the high temperatures and pressures. For more than ten years, the SKZ has been researching the transfer to industrial applications and can, for the first time, now offer a corresponding system technology and its adaptation to individual requirements. It can be applied for the inline detecting of, for example, the degree of melting in plastics (**Fig. 4**) and screw element wear. Signal amplitude and runtime are measured analogous to ultrasonic technology. Just as screw wear tends to increase the distance between it and the extruder housing, thereby lengthening the signal runtime, the degree of melting affects wave scatter and amplitude in consequence. This principle ensures that the method is fundamentally suited for detecting gel particles and foreign materials (**Fig. 5**). The method's temperature independence and non-contacting measuring technique, which considerably reduces maintenance cost, give it a considerable advantage over ultrasonic technology.

The Appropriate Method for the Particular Application

An appropriate non-destructive test and/or measurement method for recording defined quality features can be found for every application. Besides the physical principles, an important role is played by the technical framework, such as access to the product, processing speed, and production environment. Economic factors are also quite relevant. Sensor technology makes sense only if the use of measuring technology reduces rejects and complaint costs, minimizes liability risks, or offers other advantages. The SKZ can offer support with the selection of an appropriate test and measuring method by taking the stated requirements into consideration holistically. Testing methods based on ultrasonic, microwave, and terahertz radiation, as well as spectroscopic methods are at the heart of the activities at the SKZ. In addition to these, methods such as thermography, the use of thermal imaging cameras, or methods for detecting mechanical properties online are objects of development and provide very good approaches to process monitoring. ■