Non-Destructive Testing of Plastic Compound Materials

SKZ & Menlo Systems

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Introduction

Quality inspection of polymeric and plastic compound materials requires simple and reliable methods which can be easily implemented into a production chain. With a type of online surveillance, the processing of raw materials and fabrication of components can be instantaneously adapted and improved, and the reject rate can therefore be decreased.

Material testing with terahertz (THz) radiation has proved itself as a convenient method for this purpose and offers many advantages over other conventional technologies. It is safe for the user without the need for any specific precautions such as e.g. shielding off x-rays. More important, THz radiation has no influence on the object investigated since it is non-ionizing and has low photon energy. It can be applied contact-free and is a non-destructive testing (NDT) method. In comparison, testing with ultrasound waves usually requires a coupling medium such as a liquid bath. At the same time, the information obtained from THz imaging is comparable to ultrasound inspection.

A large variety of materials can be investigated with THz radiation, and in a simple experiment many aspects of their quality can be monitored, ranging from precise thickness determination to the mapping of inner variations of composition and structure. For example, the distribution of the different components in compound materials becomes visible, polymers can be distinguished, the concentration or distribution of filler media can be pictured, or internal defects such as air bubbles, delamination or contamination can be identified.

Materials and Methods

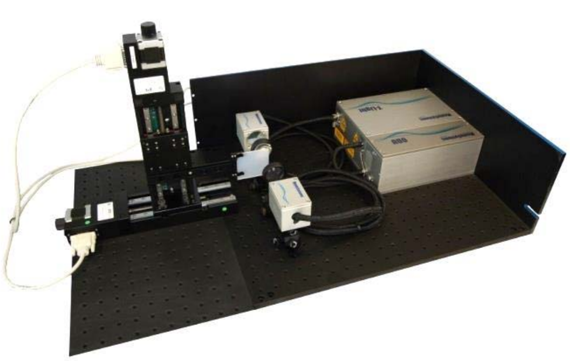

***Figure 1**: Menlo Systems TERA K15 THz-TDS system with TERA Image extension*

The SKZ is using Menlo Systems THz technology for quality inspection of polymer products and plastic compounds. The TERA K15 (Fig. 1) is a compact and fully fiber coupled turn-key THz time-domain spectrometer. It is using Menlo Systems' innovative Figure-9 fiber laser, developed for harsh industrial operations conditions. The small footprint THz emitter and detector (photoconductive antennae) operate in the far infrared spectral range between 100 GHz and approximately 4 THz, corresponding to a wavelength range λ = 3 mm to 75 µm or wavenumbers $\tilde{\nu}$ = 3 cm^{-1} to 133 cm^{-1}. The TERA K15 system with superior performance and peak signal-to-noise ratio of >65 dB is a flexible solution adapting to the requirements in plastics industry.

In combination with the TERA Image extension, Menlo's TERA K15 provides THz image reconstruction. Both, amplitude and phase information of the THz pulse transmitted through the test object are evaluated, rendering complementary information on the material thickness and density. A decrease in the peak-to-peak value of the transmitted THz pulse indicates an increased absorption in the material, e.g. due to compression or an area with higher thickness within the part. The phase, i.e. the temporal position of the pulse arriving at the THz detector, allows for precise thickness measurement. With a focused THz beam, features of about 300 to 500 µm size are resolved.

Being an expert in the plastics industry, it is SKZ major concern to satisfy quality claims and to set standards in plastic production. In the following examples we present that Menlo's THz technology proves to be the means of choice in the control process. We show how the fiber filling content in reinforced polypropylene is measured, how the humidity of wood polymer composites can be monitored, and how THz imaging helps optimizing the process of injection molding with reduced flow lines in the produced parts.

Results and Conclusion

Glass fiber reinforced plastics (GRP):

Adding glass fiber to plastics improves the mechanical properties of the raw material and the stability of the end products. The fiber reinforcement allows the use of low-cost commodities, e.g. polyolefins, instead of the more expensive technical plastics, such as polyamides, even for highly demanding applications. For example in car industry, mainly fiber reinforced thermoplastic compounds are used.

The concentration and homogeneity of the glass fibers, as well as their alignment and junction within the GRP, need to be carefully controlled in order to achieve the desired material quality. Especially in parts with a complex geometry which are often produced with molding techniques, compound decomposition and inhomogeneity formation during production need to be avoided.

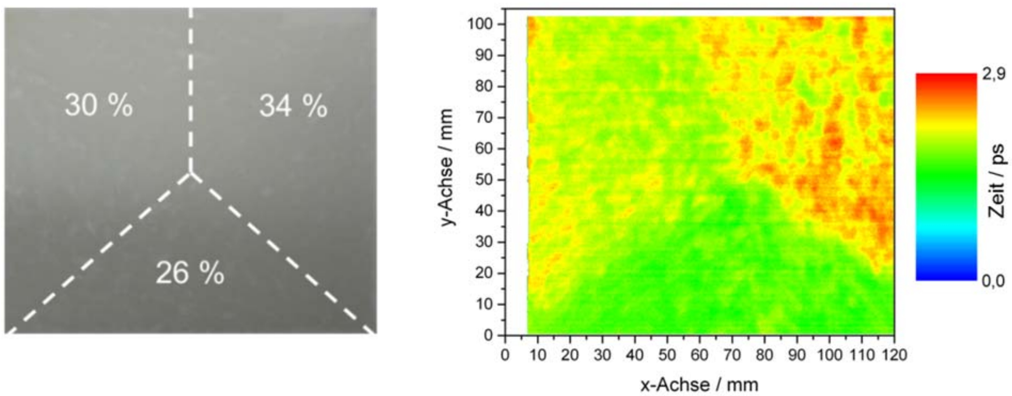

Figure 2*: Test sample from pressed polypropylene with areas of different fiber contents. Left: Photo with marked values of glass fiber weight percentage; Right: Map of the time the THz pulse maximum travels through the sample.*

With THz imaging, the filling content in polymer compounds can be determined, as demonstrated in a polypropylene specimen with areas of different contents of short glass fibers (Fig. 2). The different areas marked in the photo (left) can easily be identified in the THz image. With increasing concentration of the filling material, the THz pulse travels a longer optical path and the maximum of the transmitted THz pulse shifts towards red color (right) indicating later arrival time.

Wood polymer composites (WPC):

Wood powder mixed with thermoplastics offer an attractive alternative to solid wood. The material is easy to process and offers novel manufacture possibilities such as molding or continuous extrusion for wood products like panels, furniture, or pencils. WPC is durable and lower in price than e.g. tropical wood, and its properties can easily be adjusted according to the specific application, e.g. mechanical properties or color. Its high content of regenerative raw material puts its ecological balance in favor, and additionally, the use of tropical wood can be avoided.

Due to the high wood content, the WPC might draw humidity which would make the fabricated parts prone to deformation or biological decomposition. It is therefore important to limit the adsorption of humidity in the material. It can be monitored using THz radiation, because it is transmitted by wood and polymers and absorbed by water. With increasing humidity, the transmitted THz intensity decreases.

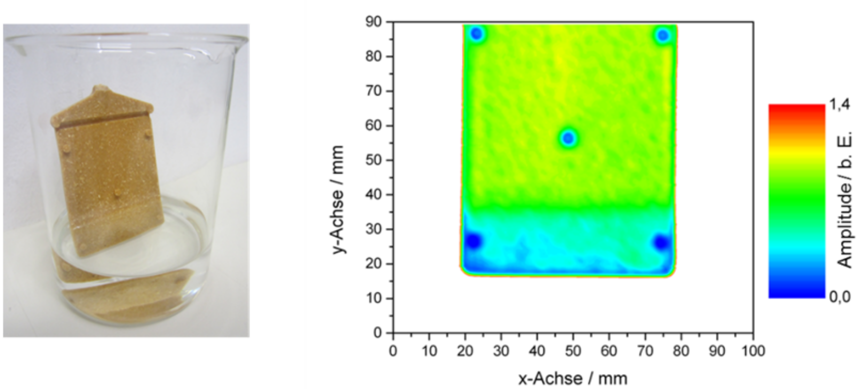

Figure 3*: Photo and THz amplitude image of a partially moistened WPC plate. Blue color indicates high THz absorption of the humid material.*

In the THz image of a WPC plate (Fig. 3), the wet areas are clearly distinguishable from the dry part. The specimen, consisting of polypropylene with 70 % wood, has been partly immersed in water. The lower wet part of the plate is highly absorbing for THz radiation and appears blue in the picture, while the upper dry part appears green because of the larger THz amplitude detected behind the sample.

Molding of functional components:

Molding of components allows to design nearly any arbitrary geometry of technical parts. However, binding lines or shrink marks might occur during production, giving rise to weak points or even failure of the component. They can be effectively prevented by optimizing the production process or molding tools, or by modifying of the part geometry.

Figure

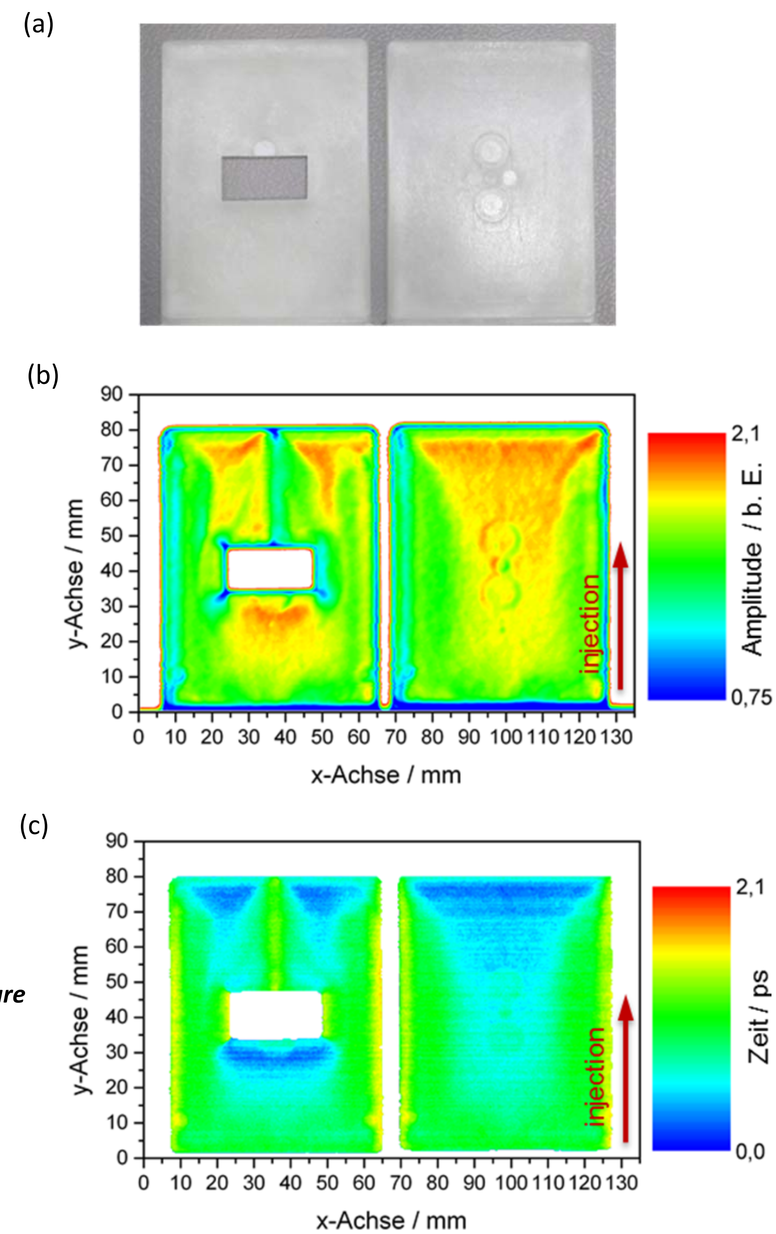

Figure4*: GPR with 30 % fiber content molded into parts with different geometry (a), material injection from the bottom side. The THz amplitude picture (b) and the phase picture (c) both show the weld line and other defects.*

For example, a flow barrier will give rise to additional unwanted variations like flow or weld lines (Fig. 4). In this case, GRP material with 30 % fiber content was injected from the bottom side of the picture. The color code in the THz picture is interpreted as a scale for the sample thickness, compactness, or the distribution of the filler medium. All these will influence the transmitted THz intensity mapped in the amplitude picture (b), while the phase picture (c) helps distinguishing them from mere thickness variations.

Together, both THz pictures shine a light on the different aspects of the internal structure. The weld line becomes visible in the sample on the left, and is missing in the homogeneous GRP plate. Shrink marks such as in the homogeneous plate are visible in both THz pictures. The ejection pin marks from the molding machine are visible in the photo (a) and in the amplitude picture (b).

SKZ' studies give an example for the high potential of THz imaging in the quality testing of plastic materials in industry. When implemented into the production chain, Menlo's compact and flexible THz imaging spectrometer TERA K15 covers manifold possibilities to address questions of process optimization and quality assurance.