Application Note

Quality Control of Plastic Joints with THz-Imaging Technique

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Introduction

Over the past 50 years, the development in polymer science and in the production of polymeric materials has overtaken the progress of metal materials. Plastics and plastic compounds have gained importance as construction material in different fields and even replace metals to a large extent, especially in the automotive industry. Polymeric materials satisfy all requirements in terms of flexibility and strength, combined with low weight and a compatibility with mass production methods. This inevitably draws attention to the various joining methods where different polymeric materials are combined. Welding, adhesive bonding, mechanical joining, or gluing, have become established techniques in industrial use. Since all methods, especially welding techniques, have different vulnerabilities, quality control at the end of the welding process is mandatory.

During the welding process, the surface of the polymeric material is softened or melted at the interface to be joined. New molecular chains are developed such that the components stick together. This method provides a durable junction, but defects like contamination, blowholes, or impurities might reduce the strength of the weld dramatically and can lead to a loss of structural integrity.

Until recently, there has been no general non-destructive, harmless and easy method which can characterize the quality of various glued or welded plastic materials. All commonly used techniques are application specific and depend on the chosen welding method and joint design. Popular standard testing methods such as tensile or bend tests are limited to specific geometries and require a preparation of the tested material. Above all, those tests destroy the specimen and therefore allow only for random sampling. Non-destructive techniques like visual inspection or testing with x-rays require an experienced inspector or special safety regulations and are not suited for mass production.
Ultrasonic testing is an established method for the detection of air bubbles and contamination, but it imposes restriction on the material thickness. Attenuation of ultrasound waves is relatively high in thermoplastics, particularly in polymeric materials with additives, and the application is therefore limited to very thin layers.
We are presenting an imaging technique based on terahertz (THz) waves which combines the advantages of ultrasonic testing with a high compatibility of different polymer materials [1,2]. It shows an enormous potential for quality control in industrial applications.

Materials and Measurement Methods

Most polymeric materials are transparent for THz radiation. Therefore, it is possible to examine the quality of welded joints in a THz imaging setup operating in transmission or reflection geometry. For plastic materials, a THz spectrometer system with a spectral range of >2 THz is required. For easy handling and high flexibility, a fiber coupled system is preferred, such as the Menlo Systems TERA K15 THz time-domain spectroscopy (TDS) system.

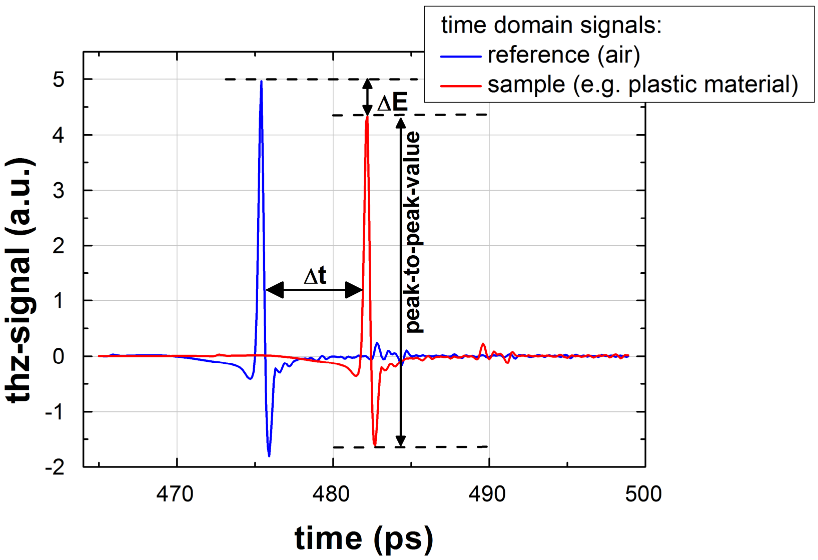

Fig.1: *Time traces of THz pulses measured in air (reference, blue line) and after transmission through a 2 mm thick polypropylene (PP) slab (sample, red line).The amplitude of the sample pulse is decreased by ΔE due to absorption in the material and the temporal position of the THz pulse is shifted due to dispersion (Δt).*

In order to obtain a THz image, the sample is placed into the focal plane of the THz-path. An automated mechanical motion element scans the sample through the focus and a THz pulse trace is recorded at each position. The material parameters are then determined by comparing the THz pulse measured with the sample in the THz path (figure 1, red pulse) to the reference THz pulse measured in air (figure 1, blue).
So figure one shows the THz trace for one pixel, recorded in transmission.
The absorption coefficient α is calculated by evaluating the difference ΔE of amplitudes, for simplicity the peak-to-peak value is considered. The thickness of the sample is calculated by evaluating the time shift Δt of the transmitted pulse in comparison to a reference pulse. With these values a false colour THz image (figure 2) of the investigated sample is created. For measurements in a reflection-setup a modified algorithm is used.

The duration of the entire image acquisition depends on the dimensions of the investigated sample and the desired image resolution. With a slow measurement high resolution is achieved, ensuring high accuracy in the detection of small impurities or air bubbles. Physically, the spatial resolution is limited by the THz wavelength, resulting in approx. 500 µm for broadband THz radiation.

Results and Conclusion

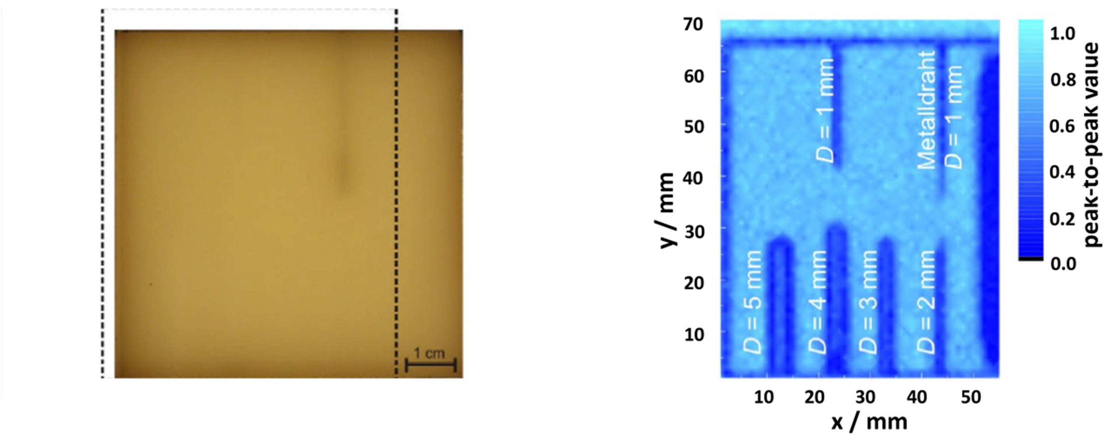

Fig. 2: *Left part: Backlight picture of two welded plastic slabs (PE) with simulated delamination. Right part: THz transmission image where darker areas indicate delamination defects, e.g. metal impurities, here represented by a wire („Metalldraht“).*

The peak-to-peak value of the signal amplitude depends on the absorption and the thickness of the welded materials. For areas with good welding results this value is nearly constant over the surface. Impurities or defects change the material parameters and the peak-to-peak value decreases, as seen in the example of the two welded polyethylene (PE) slabs (figure 2) with artificial defects inserted into the welded joint layer (left part: photo). Each slab has a thickness of 4 mm so the welded material has a resulting thickness of 8 mm. Air inserts have been simulated by drilling holes of different diameters D, while the metallic wire in the upper part of the sample represents impurities. In the THz transmission image (figure 2, right part) all types of defects are clearly resolved. The defects like drill holes or metal wire appear darker than the good welded areas, the signature of the metal wire is darkest at its thickest part. As a first conclusion, the results are suggesting that THz imaging is a suitable tool for quality assessment of plastics welding.

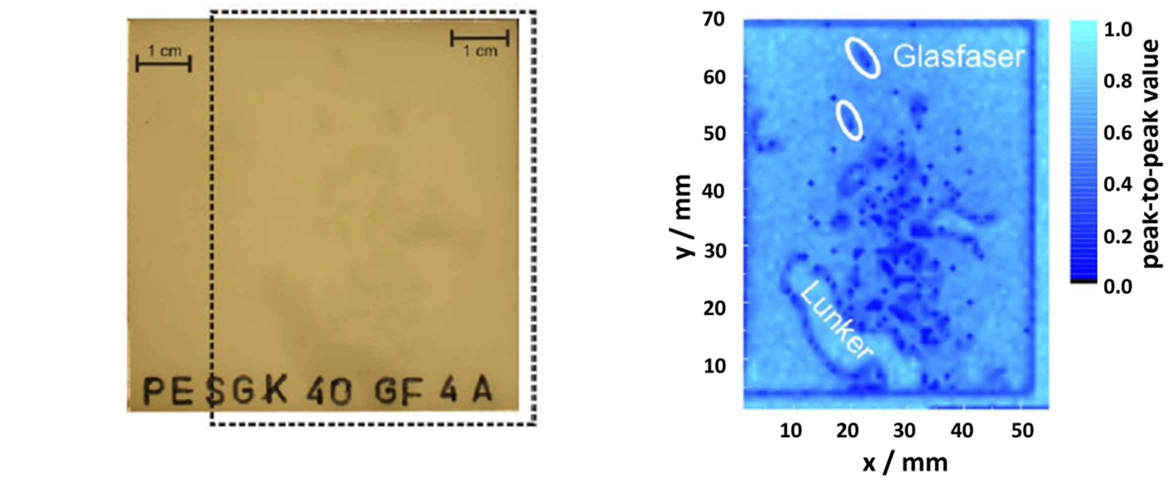

Fig. 3: *Two plastic slabs (PE) glued together. Left part: The black frame on the photo defines the imaged area. Right part: THz transmission image with darker areas showing impurities such as a blowhole ("Lunker") or pieces of glass fiber (''Glasfaser'').*

Similarly, glued materials can be inspected with the THz imaging technique described, such as in the example of two slabs of PE joined by gluing (figure 3). The black frame in the photo (left part) indicates the characterized part. The sample impurities within the glued joint are blowholes (technical term for air bubbles, German: Lunker) and pieces of glass fiber. The backlight photo (figure 3, left part) gives only a rough impression of the location of the defects. The THz image recorded in a transmission setup resolves all particles and blowholes, even the small glass fiber pieces with an average length of 2.5 mm which appears as darker dots in the THz image. Furthermore, the THz image resolves the particular feature of blowholes: lighter interior (smaller optical thickness of air compared to polymeric material) and sharp dark fringe zone (diffraction losses).

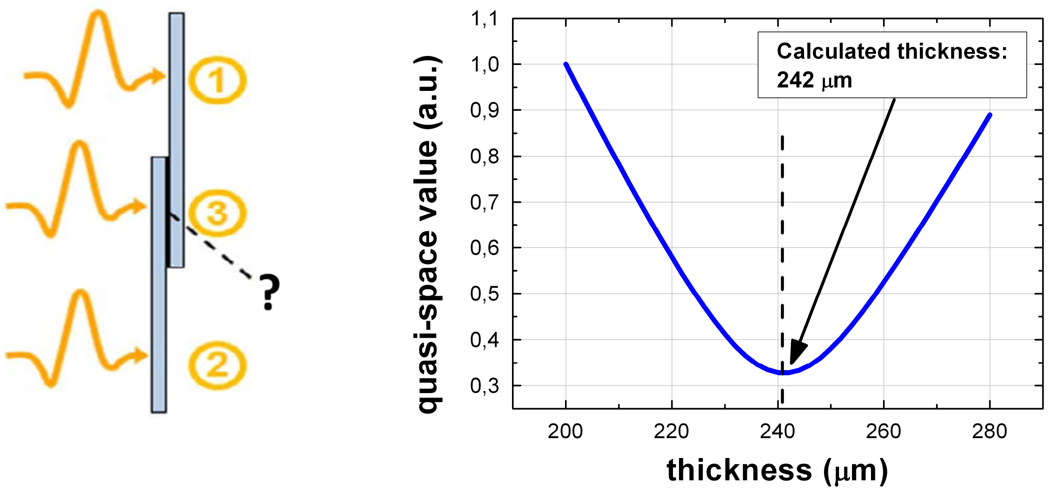

Fig. 4: *Left part: Method for the determination of the glue layer thickness. Right part: Optimized values of the "Quasi-Space"-method [3] for a polyamide (PA) sample with a thickness of 0.232 mm.*

Besides the search for impurities, THz spectroscopy offers a tool to further characterize the glued connection. If the exact material parameters (thickness *d*, refractive index *n*, absorption coefficient *α*) of the adhered polymers are known it is possible to calculate the thickness of the glue layer with only one measurement, independently of the chemical composition of the glue. Even if the material parameters of the polymer itself are not known it is still possible to calculate the thickness of the glue in three steps (figure 4, left part).
First, the two polymer layers are characterized in a spectroscopic measurement using a THz-TDS system in transmission geometry (points 1 and 2 in figure 4, left part) in order to determine *d*, *n* and *α* of the two layers. Then, the thickness of the glue layer can be accurately extracted from one further measurement (point 3).
The evaluation algorithm for the spectroscopic data is based on the optimization of the "quasi-space"-values [3] in the theoretical transfer function of the transmitted THz pulse. It is implemented in the Lytera's TeraLyzer software which is exclusively distributed by Menlo Systems. The minimum optimization value provides the exact layer thickness of the glue (figure 4, right part).

In conclusion, THz time-domain spectroscopy and imaging are powerful methods of quality inspection of welded or glued joints between plastic materials. The resolution of the THz images is high enough to identify even small impurities which typically deteriorate the strength of the joint. Moreover, with a suitable algorithm for the spectroscopy data, the exact thickness of the glue layer can be determined. THz imaging as a novel method for non-destructive testing of welded or glued plastic materials can be implemented into the final manufacturing process to ensure the product quality.

Further Reading

[1] S. Wietzke et al.: Terahertz imaging: a new non-destructive technique for the quality control of plastic weld joints; Journal of the European Optical Science – Rapid Publications 2, 07013 (2007)

[2] C. Jansen et al.: Terahertz spectroscopy on adhesive bonds; Polymer Testing 30, 150-154 (2011)

[3] M. Scheller et al.: Analyzing sub-100-µm samples with transmission terahertz time domain spectroscopy; Opt. Commun. 282, 1304 (2009)

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