Summary for the final report
Robust thin-film sensors for inline process monitoring and control of critical process pa-rameters in plastics processing (RobInPro)

In the heat contact joining of plastic films, heated tools melt the films or their sealing layer under pressure and join them in a material bond. Temperature measurement and control are based almost exclusively on resistance thermometers or encapsulated thermocouples which measure the temperature integrally and often comparatively far away from the tool surface. As a result, the high demands on quality, product safety and process stability can no longer be met, especially in fast-running processes. In addition, the trend towards low-complex (mono films), recycled and fiber-based materials reinforces the demands on process monitoring.

Novel tools with thin-film thermocouples on the surface now allow highly dynamic, sensitive temperature measurement which can carried out at many points on the surface simultaneously. In combination with innovative heating, e.g. using ceramic heating elements, real-time control of the process parameters is on the horizon. Already today, the temperature conditions, including their control-related fluctuations, can be recorded just one film thickness away from the joining zone, and seam inhomogeneities and disturbances, such as wrinkles or contamination, can be identified based on the temperature curves and thus a 100% inline quality inspection can be carried out. Products which do not meet quality standards and the resource consumption can consequently be reduced to a minimum.

Building on the proof-of-concept and the identified R&D needs in the IGF project “HePhaiStOs” (18470 BG), this project focused on increasing the lifetime of the tool coating. For this purpose, the multi-layer structure was further developed and the challenge of electrical insulation of the mostly metallic substrate was resolved. Two further focal points were 1) the reliable detection of deviations as well as 2) the development of a methodology to evaluate the anti-adhesive effect of potential protective layers.

For the investigations, a tool demonstrator consisting of two sealing bars with 8 sensors each, which were connected to a measuring amplifier via a contacting bar, was developed and utilized for the test series (Figure 1).

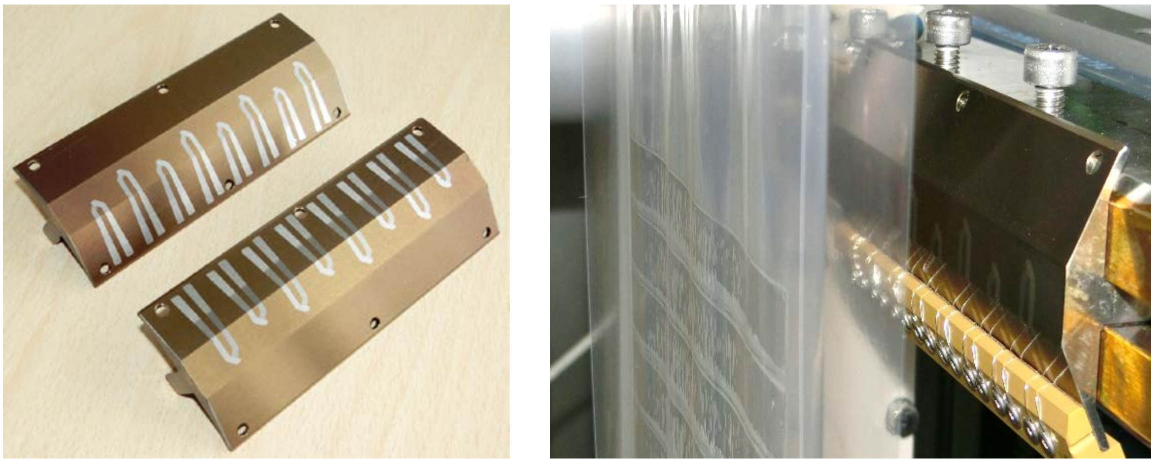


Figure 1 Tool demonstrator with thermocouples and protective coating (left); demonstrator in the lifetime test rig that based on a horizontal cross-seam sealing unit of a tubular bag machine (right)

The experimental setup utilized a horizontal cross-seam sealing unit of a tubular bag machine in which the tool demonstrator was integrated. The setup of the sealing unit includes a classic temperature measurement with a resistance thermometer in each sealing jaw. Figure 2 illustrates the measurement signal of this Pt100, as well as the temperature profile of the thin-film thermocouples S1 to S8 on the demonstrator tool surface.

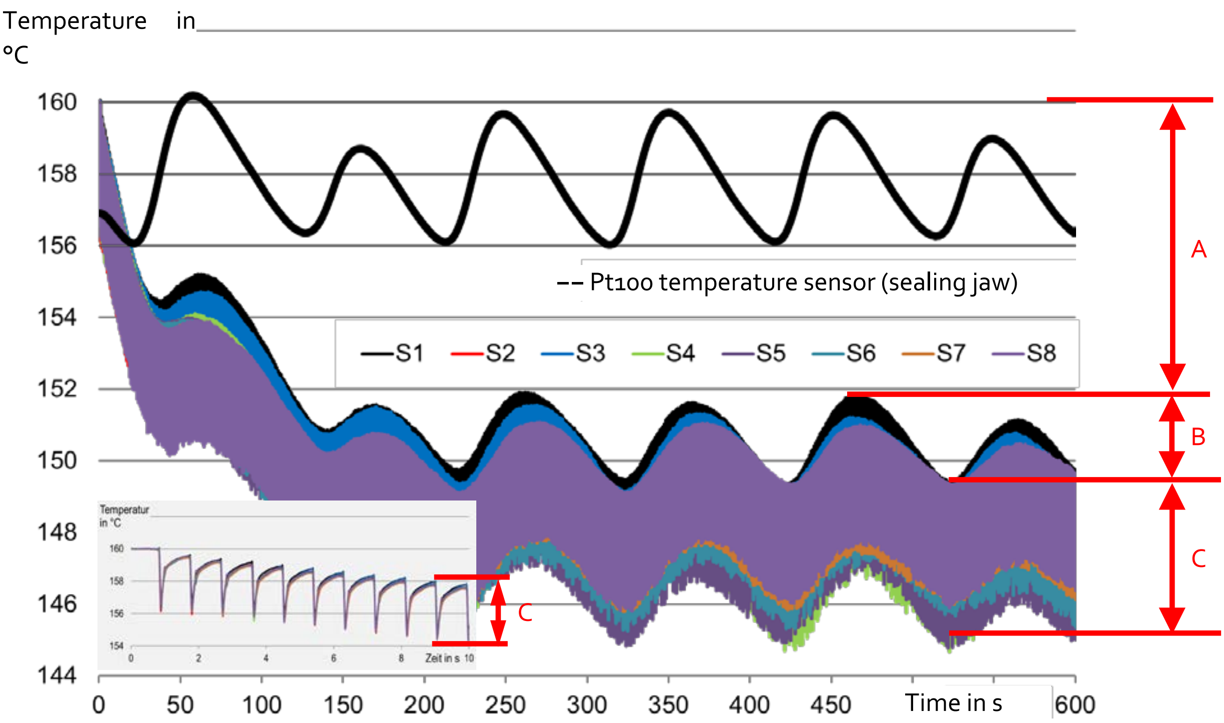
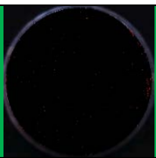
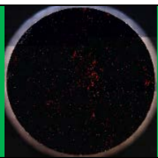
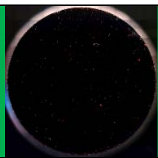
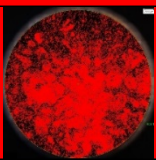
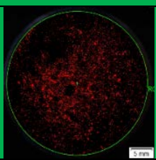
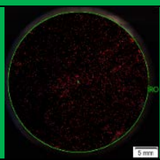
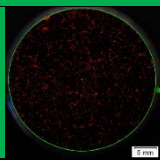
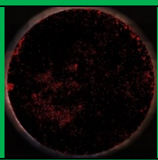


Figure 2 Exemplary temperature measurement record at 160 °C @ 150 ms @ 2 MPa after starting the test rig, 2x $BOPET_{12}$ / PE_{50}: recording over 10 min (large illustration), extract over 10 s with individual sealing cycles (below left)

It becomes clear that in the considered case there can be up to 8 K temperature difference (A) between the set temperature of 160 ° C, which is the temperature at standstill, and the maximum tool surface temperature in the operating state. Furthermore, there is a control-related difference of 3 K (B). The temperature drop due to the heat dissipation into the film during the joining process is also up to 4 K (C). In the worst case, the actual tool surface temperature is only 145 ° C. Such low temperatures may be result in quality defects especially for films with a narrow process window and short cycle times. To prevent such quality defects, the preset temperature is usually set significantly higher nowadays. But the higher temperatures can lead to a damage of the backing layer or the composite, especially in future mono-material composites.

New, more ecological film composites are also a challenge for existing processing systems, not least in terms of their adhesion to the tool. Therefore, suitable coatings are not only a necessity for the protection of the thin-film sensors, but also for tools without functionalization. For the investigations some anti-adherent coatings already used in other industries were selected for the project. Their behavior was examined against the sealing medium polyethylene (LDPE, MFR 2) and the product contaminants powdered sugar and milk powder and compared with that of a polished stainless steel surface.

Table 1 Contamination tendency of examined surfaces towards different contaminants

	Stainless steel, poliert	Tegonit®TcC	Tegonit®TdS	Tegonit®TpT
Polyethylene 140°C, 2s, 1 MPa	 10 %	 < 1 %	 1 %	 < 1 %
Powdered sugar 160°C, 2s, 1 MPa	 27 %	 2 %	 1 %	 1 %
Milk powder ‚grob' 120°C, 2s, 1 MPa	 93 %	 50 %	 5 %	 50 %
Milk powder ‚fein' 120°C, 2s, 1 MPa	 48 %	 26 %	 73 %	 42 %

As shown in Table 1, the coatings initially show clear advantages, although the type and particle size of the contaminants as well as the test parameters seem to have a decisive influence. For example, in tests with a different polyethylene hardly any significant differences were seen. Based on these results, in the future there will still not only exist one coating for all applications, and a validation of suitable coatings will be necessary for the particular contaminants.

The fact that interfering influences can be reliably detected with the help of the developed technology is illustrated by an experiment in which a strip of adhesive tape runs into the seam zone (Figure 3). The adhesive strip is representative for a fold or contamination in that case.

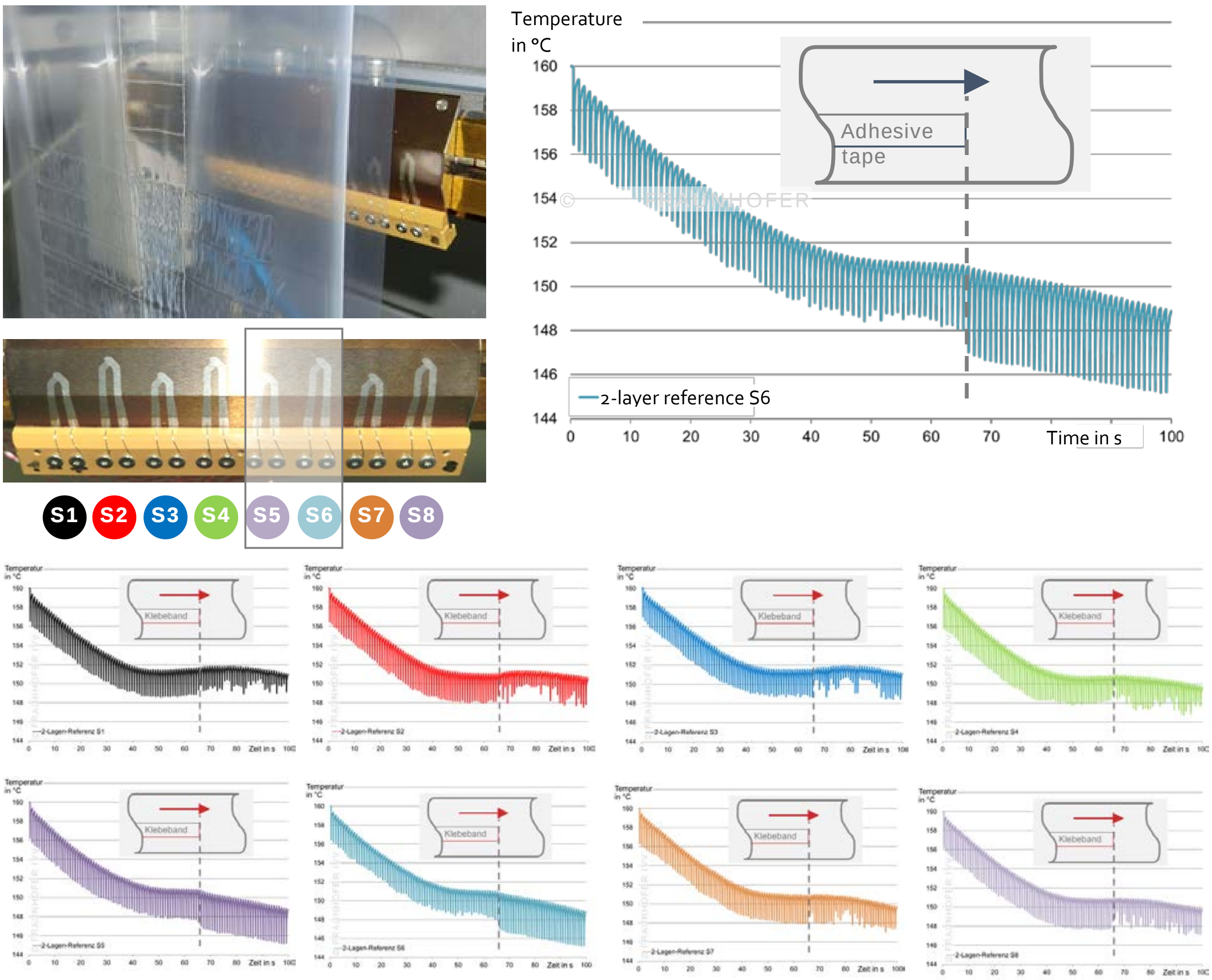


Figure 3: Effect of additional material in the seam zone on the temperature profile, here: a 46 µm thick PP-based adhesive tape between two $BOPET_{12}$ / PE_{50} layers in the area of sensors S5 and S6 of the demonstrator tool at 160 °C @ 150 ms @ 2 MPa

At the sensors S5 and S6, the temperature drops more sharply during the sealing cycles when the adhesive tape runs in. Thereby the following aspects play an essential role:

- The locally higher pressure in the range of the adhesive tape improves the contact conditions and thus the heat transfer into the film. In addition, the tape acts like a spacer so that the opposite effect occurs at the other measuring points.
- The additional material of the adhesive tape increases the heat transfer from the tool resulting in lower temperature values on the tool surface.
- The adhesive tape also generates an additional heat transfer resistance, which contributes to a lower temperature drop.

Despite the numerical simulation, due to unknown thermal characteristics, it remains necessary to determine reference temperature curves and to validate tolerances. Additional deviations are then the initiator for discharge, individual follow-up inspections or ideally real-time parameter adjustments.

Nevertheless, the validated simulation model reflects the control-side fluctuations (Figure 4) as well as disturbances and provides valuable information to support the system design.

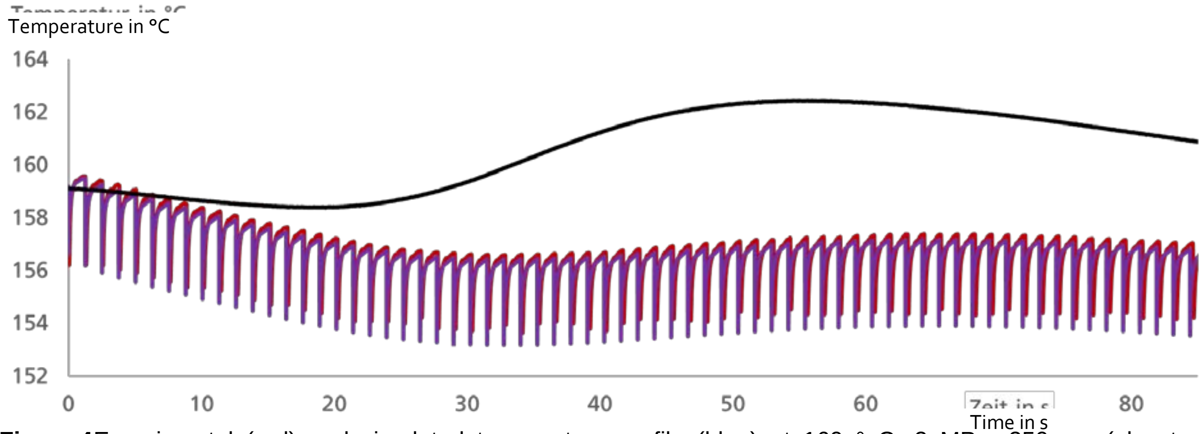


Figure 4 Experimental (red) and simulated temperature profile (blue) at 160 ° C, 2 MPa, 250 ms (plus tool movement time in each case!) considering the temperature measurement at the machine-internal sensor Pt100 (black)

With almost one million contact cycles and the reliable detection of control-related temperature fluctuations as well as provoked disturbances, significant milestones have been achieved on the way to the industrial readiness of the technology. In particular, the reproducible electrical insulation of metallic surfaces as well as the long-term stable multilayer structure provide the prerequisites for the implementation of further sensor principles and the functionalization of profiled tools in a foreseeable future. The current challenge for further R&D is setting up a contact of the conductor paths, which are only a few hundred nanometers thick, with the compensating wires, which are several hundred micrometers thick and connect the sensors with the measuring amplifier.

The development of adaptive processes, to which functionalized joining tools make an essential contribution, benefits machine and plant manufacturers, who can better align their processes to the requirements of packaging materials and package and support individualized production with small batch sizes. Sensitive temperature control is a fundamental requirement for processing the monomaterial composites demanded by legal regulations. In contrast to previous composites, they have a significantly narrower processing window that can hardly be handled with standard temperature sensors. Particularly for the pharmaceutical and medical products industries, and increasingly also in the food sector, complete traceability of production data and inline quality control are indispensable. Furthermore, there is great market potential for suppliers of sensor and analysis technique due to the widespread use of the heat conductive sealing method. Thin-film-based sensors are also of great importance in the production of technical goods and for other packaging processes, such as thermoforming, as well as for other thermal manufacturing processes, e.g. injection molding, hot embossing or extrusion. For these applications the near-surface temperature measurement helps to ensure reliable molding and high surface quality and thus to increase product quality and process reliability.

IVLV members can download the complete final project report in German from our homepage. All you need is to register in the section "My IVLV". Non-members can request the final report from the IVLV office at office@ivlv.org.

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