Rise Profile and Temperature Measurement of Strong Heat Producing PU Foams

BERND H. W. HOFMANN
Format Messtechnik GmbH
GERMANY

ERNEST J. FOLDVARI
Weidmuller Sensor Systems
USA

and BODO RUCK
Universität Karlsruhe
GERMANY

ABSTRACT

Foam rise time and rise profile measurement data have been accepted as key measurement parameters for polyurethane (PU) foam development and quality control. The implementation of precise measurement interpretation and recording of rise time and profile data requires a reliable, accurate and fast measurement and data acquisition system.

For standard applications the ultrasonic pulse-echo method has proved to be a reliable testing method because it is independent of structure and shape of the foam surface.

Measurement problems arise for rigid and integral PU foams which react with strong heat release especially in the polymerization phase after the rise time. The exothermal reaction heats up the foam over 200°C. The heating of the surrounding air and the release of hot blowing agents generate an inhomogeneous gas mixture above the PU sample. These conditions alter the travelling ultrasonic wave propagation to the foam surface. No clear signal is detected in the pulse-echo measurement. The different velocities of sound depending on temperature and chemical composition of the gas cause scattering, diffraction and total reflection of the ultrasonic wave.

This effect was recognized at German laboratories of suppliers of PU-components, such as AirProducts, BUFA Industrie, Bayer, Sonderhoff and others: The rise curve measurement of strong heat producing samples were effected and invalid data was registered by the ultrasonic distance measurement device. First attempts to solve the problem were made by cross-venting the air above the PU sample using a normal room ventilator. Statisfactions caused by heat and driving gases, e.g. CO₂ were simply blown away.

This venting method was improved by Format Messtechnik, Germany, in developing the patented fan-sensor LR 2-40 PF. It contains a small coaxial ventilator generating an air stream directed towards the surface to be measured. The fan-sensor homogenizes the gas volume in front of the sensor by suppressing natural convection driven by the exothermal heat release of the PU sample.

As a result, smooth rise curves are recorded during the entire foaming process and valid data is recorded. Measured data are presented.

Another improvement of the new sensor is venting the test cup at the beginning of the rise test. Volatile organic gas fractions that evaporate from the A-component before the reaction has started are blown out of the cup. This avoids any measurement errors concerning the fill level and the start time indicating the beginning of the foaming reaction.

The temperature of the venting air is continuously measured with a high resolution temperature sensor PT 500. From its output the velocity of sound is computed by a microcontroller resulting in permanent temperature compensation with a high resolution of the ultrasonic device.

Synchronized with the foam rise, the temperature within the foam sample is recorded by a supplementary thermocouple which is merged into the foam.

The new sensor hardware and an improved software package make the ultrasonic measurement system of Format a versatile testing equipment for rise profile and temperature measurement for a variety of PU foams.

INTRODUCTION

Consistent quality in all phases of the production process is a key concern in manufacturing. This is especially true for chemical products such as PU foams and their wide range of applications that range from flexible foams for furniture and automotive products to rigid foams used in construction and thermal insulation. Quality control must be implemented for all phases in production of chemical components, i.e. polyols, additives and isocyanates, the mixing and extrusion process and the final manufacture of foam products.

Due to the variety of different foams to be tested, Format Messtechnik has improved the LRS 3V3 Foam Qualification System introduced to the market by Weidmuller Sensorik, Germany.
SYSTEM CONFIGURATION OF LRS 3V3 FOMAT

The LRS 3V3 FOMAT is a powerful tool for PU foam development and foam production quality control. It was used for the tests described in this paper. The system comprises the following components (Fig. 1):
- measurement stand with patented ultrasonic sensor head /1/, ambient temperature sensor and cup positioning mechanics including photo switch;
- microprocessor based controller unit with LED display and thermocouple for foam temperature measurement;
- PC based menu driven software FOAM.

For rise height measurements of flexible and semi rigid foams, the standard ultrasonic sensors using the pulse-echo method have proved to be a reliable testing equipment. The pulse-echo method (Fig. 2) enables precise and repeatable foam rise measurement, independent of shape and foam surface variations.

THERMAL EMISSION DISTURBANCE EFFECTING CONVENTIONAL PU TEST EQUIPMENT

Measurement problems with conventional test equipment arise for rigid PU foams of high density. They are used for thermal insulation and structural applications. Special systems are even used for strata consolidation in mines. Thermal and chemical effects may disturb the ultrasonic distance measurement for those systems:

PU rigid foams react with strong heat release due to the exothermic polymerization reaction that forms the rigid PU structure. This reaction is predominant at the end of the expansion phase which is recorded as rise time. The exothermal heating increases the foam core temperature to about 200°C. This can be measured by a thermocouple inserted into the test cup. The top surface of the foam is also heated. Fig. 3 shows the foam surface at approx. half maximum rise height (50% criterion) recorded by a IR sensitive pyroelectric video-camera.

The surface temperature is 65°C when the foam under test (Fig. 8) reaches the edge of the test cup.

The heating of the surrounding air and the release of hot blowing agents generate an inhomogeneous gas mixture above the PU sample. Thermal stratification and air vortices could be visualized in the beam of an Argon-Ion laser using propandiol mist for light scattering (Fig. 4). The visualization of tracer tracks delivers both, a stream-line-equivalent flow field information and an identification of hot and cold zones. At the interface between hot and cold areas the propagating sound waves emitted from the sensor head are reflected and scattered in different directions. The echoes detected by the sensor depend on the local physical and chemical gas condition in the space between sensor head and foam. Due to thermal fluctuations and the moving foam surface, this situation is always changing. Local temperature changes cause different velocities of sound (0.2%/°C). From the displacement values recorded, we know that some sound pulses do not reach the foam surface but are reflected at the hot air layers: The measured distances are too short; the rise height exceeds the true rise curve and shows erroneous spikes (Fig. 5a).

In other cases, multiple reflections between the foam surface and a hot/cold interface occur that give a dip in the rise curve. This results in measurement errors between sensor head and
foam bun, by registering increased distance (Fig. 5b). This effect may also be caused by "heavy" blowing agents with low velocity of sound. In worst cases the sound pulses are scattered diffused and no echo is detected at all. The rise curve is then interrupted or deformed and no longer represents the true geometrical changes, i.e. rise of the foam sample. These effects were first recognised at German laboratories of suppliers of PU-components, such as AirProducts, BUFA Industrie, Bayer, Sonderhoff and others.

THE FAN-SENSOR LR 2-40 PF

The problem was solved by Format Messtechnik in developing the ultrasonic fan-sensor LR 2-40 PF. In addition to the ultrasonic emitter/receiver sensor it contains a coaxial ventilator generating a stream of air directed towards the surface to be measured (Fig. 6). The fan-sensor homogenizes the gas volume in front of the sensor by ventilating thermal stratifications and blowing off agents released by the PU sample (Fig. 7). As a result smooth rise curves are recorded during the whole foaming process including the hot phase. A typical rise curve of a strata consolidation foam (BEVEDOL S/BEVEDAN) is shown in Fig. 8. Another improvement of the new sensor is ventilating the test cup at the beginning of the rise test: Volatile organic gas fractions that evaporate from the A-component after mixing are blown out of the cup. This avoids any measurement errors concerning the fill level and the start time indicating the beginning of the foaming reaction. The temperature of the ventilating air is continuously measured by a high resolution temperature sensor PT 500. From its output, the velocity of sound is computed by the firmware of the controller unit. Permanent temperature compensation results in a high displacement measurement resolution of the ultrasonic sensor.

Synchronized with the foam rise, the core temperature of the foam sample is recorded by a supplementary thermocouple merged into the foam. The foam rise height curve, the rise site and the foam temperature are displayed superimposed in one graph by means of the software FOAM (Fig. 8).

Figure 6. Ultrasonic fan-sensor LR 2-40 PF and temperature compensation sensor (PT 500) mounted to the stand facing the foam sample to be tested.

Figure 7. The surface of the foam is effectively ventilated by the built-in fan of the sensor head LR 2-40 PF. Thermal inhomogeneities between sensor and foam surface are blown away by the vent air being visible in the light of an Argon ion laser using artificial aerosols for light scattering.

The new sensor hardware and the improved software package FOAM make the ultrasonic measurement system LRS 3V3 FOMAT of the Format Messtechnik a versatile testing equipment for rise profile and temperature measurement of various
PU foams (Fig. 9). The LRS 3V3 FOMAT enables the user to generate, record and store data concerning flexible and rigid PU foams during the foaming process. The height of the rising foam bun and the temperature in the core of the foam sample are continuously measured and recorded. The start time, which marks the beginning of the polymerisation reaction, the rise time, i.e. the moment of maximum rise height and the shrinkage behavior provide information concerning the foam quality. The calculated rise rate and the measured exothermal temperature increase provide reliable data to analyse the effects of catalysts, water and other system components (Table 1).

The recorded rise curves are handled in application specific subroutines of the FOAM program. Generation of a master curve with absolute height and time tolerances enable the producer of PU systems to establish quality standards for a specific foam article. The printout of the master curve may be used as a quality certificate.

**HOW TO USE THE LRS 3V3 FOMAT SYSTEM**

A measurement is started by activating the foot switch supplied with the system (Fig. 1). This marks zero on the time scale for the rise curve and starts an electric mixer operated by the controller unit. The A and B components are mixed for a preselected software controlled mixing time. After the mixing, the user inserts the thermocouple wire supplied with the system through the side of the test cup, then, the test cup is placed on the measuring stand aligned under the ultrasonic fan sensor. The test cup activates a photo switch and data acquisition begins for foam height-profile measurement cycle.

The cup is continuously ventilated so that no evaporation of the A component or release of blowing agents can change the velocity of sound. The distance between sensor head and a foam surface is measured with an accuracy of 0.1 mm. The first distance reading is taken as full level of the liquid components. The height of the foam rise is registered in millimeter (mm) referenced to the bottom of the cup and in percentage of the total foam rise height (Fig. 2). During the foam height measurement the core temperature within the foam sample is logged by the thermocouple inserted in the cup.

All data are transmitted to the PC via a serial interface cable connected to the controller unit. The curves of foam rise, rise rate, and foam temperature are evaluated by the FOAM software using special mathematical subroutines, i.e. spline functions, and then displayed on the PC monitor. Foam data can be printed out showing foam rise profile, rate of rise and temperature or may be exported to a data bank file for further evaluation and stored for quality control records.

**CONCLUSION**

The introduction of the fan sensor LR 2-40 PF has significantly improved the ultrasonic pulse-echo method for foam rise measurements. Even strong heat producing rigid foams can be tested giving smooth rise curves. The LRS 3V3 FOMAT Foam Qualification System and its software FOAM represent a versatile tool for quality control in the production of all kinds of PU foams.

**ACKNOWLEDGEMENTS**

The authors wish to thank Erland Hofmann for his assistance in preparing the figures for this paper. The permission of Ernst Sonderhoff GmbH to present photographs made in their laboratories is gratefully acknowledged.
REFERENCES

/1 Bundesrepublik Deutschland, Deutsches Patentamt, Patentschrift DE 3621819 C2 (1995).

BIOGRAPHIES

Bernd H. W. Hofmann
Dr. Hofmann received his Ph.D. in solid state physics from the Technical University of Karlsruhe, Germany, in 1976. He has worked in the field of conventional and nuclear physical engineering at different institutions and companies including the Karlsruhe Nuclear Research Center, ABB Reactor and others. In 1992, he became sales manager of the Weidmüller ultrasonic group and product manager for foam testing equipments. Since 1994, Dr. Hofmann is director of Format Messtechnik GmbH.

Ernest J. Foldvari
Ernest J. Foldvari joined Weidmüller, Inc. in 1988 as national sales manager to oversee the company's newly formed sensor division. Previously Mr. Foldvari held a variety of positions in Europe and the USA as sales and marketing manager for Valenite and Kennametal sensors divisions. Mr. Foldvari received a BS in electrical engineering from the Technical University of Budapest.

Bodo Ruck
Dr. Ruck received his Ph.D. in experimental fluid mechanics from the Technical University of Karlsruhe, Germany, in 1981. He has worked in the field of laser measuring techniques applied to flow analyses. In 1982 he became head of a research group for experimental fluid mechanics at the Institute of Hydromechanics/University of Karlsruhe. Since 1991, Dr. Ruck is President of the German Association for Laser Anemometry, a German scientific society representing researchers from 46 institutions. In 1992, he became Vice-President of the European Association for Laser Anemometry/Manchester U.K.