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The Evolution of Thermo-Wet – the Computerized System for Measurements of Surface Properties

1. Introduction

In many industrial processes, an important and sometimes a predominant role is played by the phenomena occurring at the interfaces of the liquid and the solid state. These phenomena occurs in welding, making of composite materials with the participation of the liquid phase, sintering of powders, saturation of porous structures, coating, refining of metals to eliminate non-metallic inclusions, foundry or processes of crystallization from the liquid phase. Thus, the knowledge of physical-chemical processes occurring between a liquid and a solid is a significant technological problem.

Among the basic measurable quantities characterizing interactions between solid and liquid are the surface energy (surface tension) of the liquid phase and the extreme angle of wetting of the base by a liquid. Once the above quantities have been measured, it is possible to measure the remaining important quantities of the system, such as the adhesion energy, interfacial tension and, possibly, adsorption. The background information about surface tension and wettability can be found in the fundamental work [1].

2. The past

Within the framework of the research sponsored by the Polish National Research Committee, carried through from February 1998 until June 2000, The Computer Engineering Department of Technical University of Lodz with co-operation of Warsaw University of Technology and Industrial Electronic Institute (PIE) in Warsaw built a computerized device for the automated measurement of surface phenomena occurring in contact of liquid and solid phases [15, 19] (Fig. 1). The system was named Thermo-Wet. It is capable of measuring the surface tension of a liquid and the wetting angle of a solid by a liquid over a wide range of temperatures (up to 1800 ^{o}C).

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Fig. 1. The main view of computerized device for the automated measurement of the surface tension and the wetting angle (1 – the heating chamber of the furnace; 2 – the temperature controllers; 3 – the system of technological gas supply; 4 – the specimen insertion mechanism; 5 – the vision subsystem including CCD camera and infrared filters changer; 6 – the computer controlling measurement process and processing measurement data)

Within the project, the task of Computer Engineering Department was to develop and to implement of the algorithms responsible for every aspect of measurement process. The software pack composed of two programs performing separate functions. The first one was responsible for the acquisition of an image, its preliminary processing and analysis as well as for the determination of physical-chemical properties of the material studied (Fig. 2). The second program was used for the archiving and visualization of the results (Fig. 3).

Image processing, segmentation and analysis algorithms developed during project and implemented in the measurement system were described in [16, 17, 20, 21].

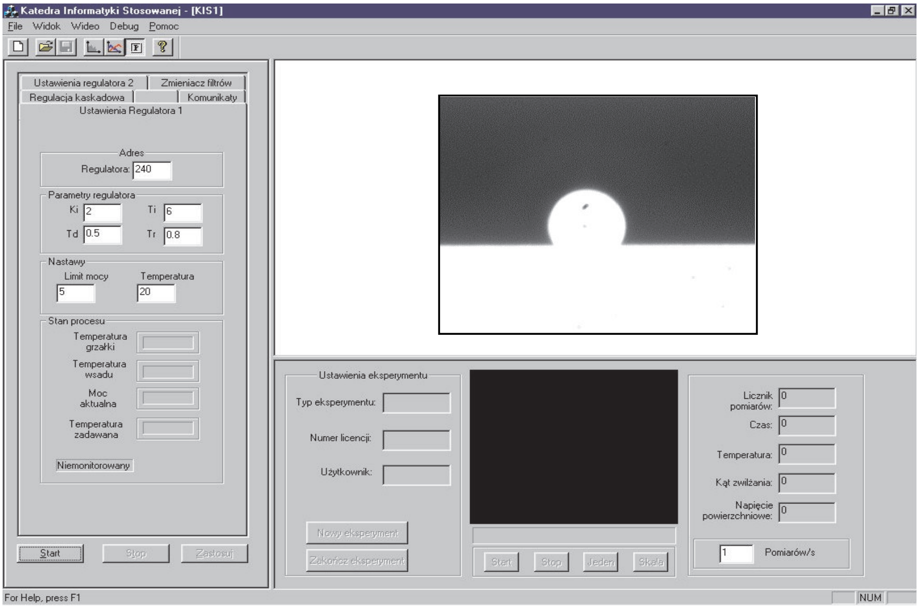

Fig. 2. The user interface of the first version of the measurement application

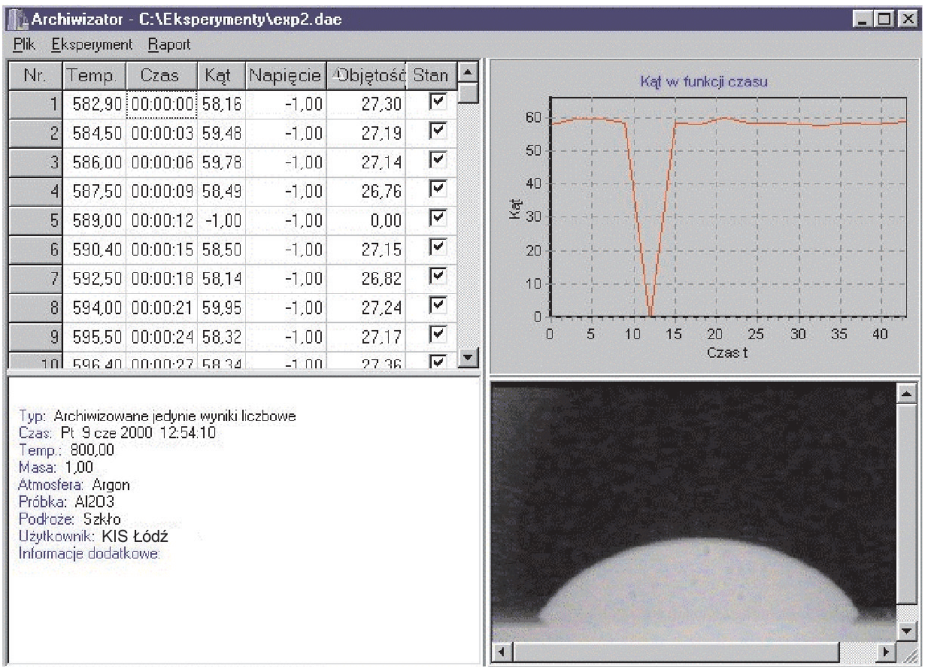

Fig. 3. The user interface of application for archiving and visualization of the measurement results

The developed measurement system has introduced an objective, automatic measuring method, although we shortly found it has some limitation. The most important of them are:

– pure software architecture resulting in software maintenance difficulties;
– pure software stability;
– incompatibility with modern video acquisition hardware;
– incompatibility with modern operating systems.

Despite of some drawbacks, Thermo-Wet became not only unique measurement device but also the excellent platform for developing and testing new image processing, segmentation and analysis methods for wide range of quantity image analysis systems.

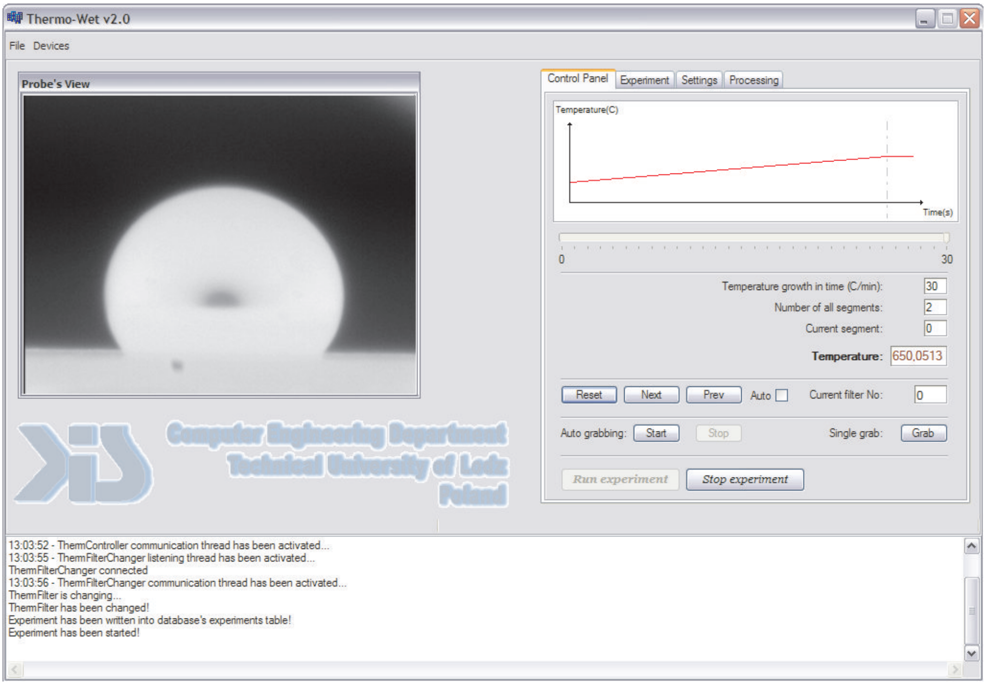

Fig. 4. The user interface of the second version of the measurement application

3. The present

Knowing the disadvantages of Thermo-Wet system listed in previous section, shortly after finishing project we decided to eliminate most of them. In the effect, during last few years, a lot of changes have been done to measurement stand.

Most significant of them are:
- the software of measurement system was completely rewritten, its architecture was carefully designed, main project's structural and functional requirements were oriented to application stability, flexibility, functionality, separate modules re-usability and high measurements accuracy [18, 27];
- new, much more accurate and stable algorithms of image processing and analysis were developed and implemented [3, 5, 6, 9–11, 13, 23–26];
- the user interface of the measurement application was newly designed to provide much better control on measurement process (Fig. 4);
- the application for archiving and visualization of experiments results was abandoned, in place of it SQL database system was introduced;
- temperature controllers were replaced with one fully compatible with MODBUS protocol, what allowed us to unify communication with every piece of hardware of the measurement device;
- the hardware and software of the measurement stand embedded computer were completely redesigned and reimplemented to support unified communication with temperature controller and infrared filters changer. Its present architecture gives us possibility to add new hardware modules without any significant changes to its hardware or software.

In 2008, as the result of changes mentioned above, we finally obtained the measurement environment which is stable and easy expandable.

4. The future

During both, development and usage of Thermo-Wet we found many new possible ways of its improvement [22]. As we wanted to have working device as soon as it is possible, we have decided to first implement only basic, crucial features. Now, when we have fully working and stable measurement environment we are able to fully test and eventually implement the most of our new ideas. The main goals of the improvements we are working currently on are:
- extending device usability by making possible measurements below 700 ^{o}C;
- further automation of measurement process by fully automation of the specimen insertion device and the vision system;
- improving accuracy and repeatability of obtained results by eliminating or correcting inaccuracies introduced by components of the vision subsystem of the device.

To be achieved, all of them need both, software and hardware changes to the device.

4.1. New ideas and solutions in hardware

A lot of improvements to hardware of the measurement system were considered. Regarding limited funds we decided to implement only some of them, which we regard as the most important ones.

The stand of vision subsystem

The stand of the vision subsystem was developed from the scratch. The project of the new construction is shown on Figure 5. It's new the most significant feature is the possibility of precise positioning of CCD camera. Its position will be controlled by three step motors supervised by the main computer of the measurement device. For communication with step motors controllers MODBUS protocol will be used.

The specimen insertion mechanism

The specimen insertion mechanism will be improved to allow smooth placing of the specimen in the furnace chamber. The position of the specimen inside the furnace will be controlled with the high precision using two step motors supervised by the main computer of the measurement device. For communication with the insertion mechanism MODBUS protocol will be used. The project of the new construction is shown on Figure 6. Additionally the new specimen insertion mechanism will be highly resistant to the floor vibrations.

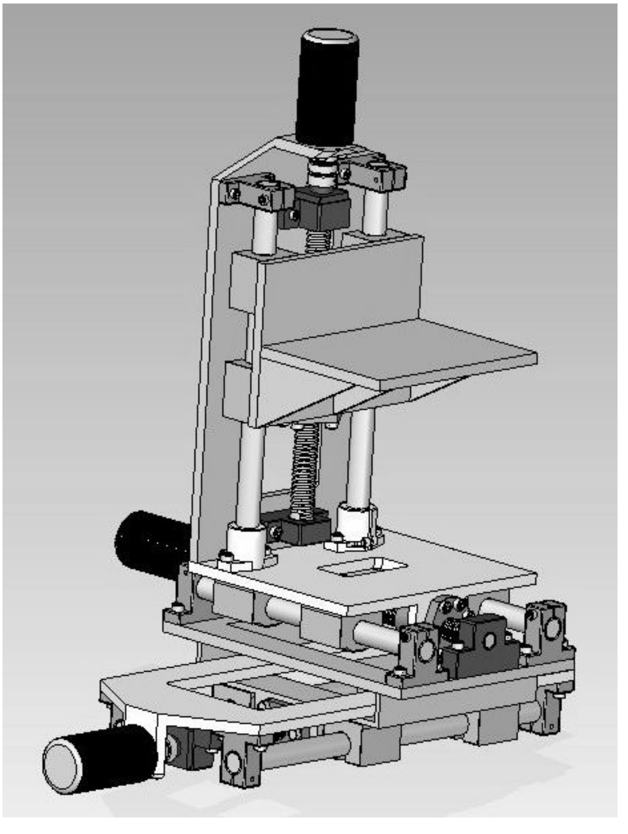

Fig. 5. The project of the new construction of the stand of the vision subsystem

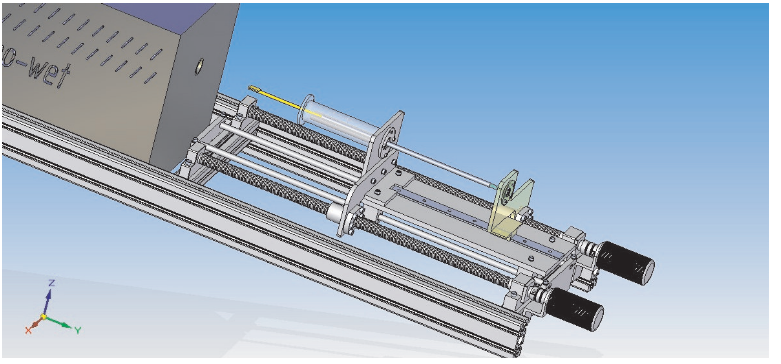

Fig. 6. The project of the new construction of the specimen insertion mechanism

We hope that possibility of precise relative positioning of the CCD camera and the specimen will allow us to highly improve accuracy and repeatability of measurement results. We expect similar impact from the lower sensitivity of the device to floor vibrations.

Additionally possibility of automate positioning of CCD camera during measurement experiments will allow as to implement auto-focus algorithm. Its necessity is discussed later in this paper.

Infrared cameras

CCD cameras presently used in Thermo-Wet are introducing some limitations to the measurement process. Replacing them with infrared ones should help to eliminate most of them.

The proper selection of infrared cameras should allow us to:

– eliminate of the infrared filters and thus to eliminate distortions they introducing;
– precise measure of the specimen temperature;
– at least partial eliminate of "aura" phenomenon by using narrowband (0.8–1.1 mm) infrared cameras, and thus to much more accurate localization of specimen edges;
– expand temperature range of measurements below 700 ^{o}C.

4.2. New ideas and solutions in software

Software changes described below are necessary for more complete automation of the measurement process and for improving accuracy and repeatability of the obtained results.

Algorithms for controlling new hardware

All hardware improvements described in the previous section need suitable control algorithms. These algorithms should be implemented and embedded to the existing software. As the effect both the camera and the specimen positioning became integral part of automated measurement process.

Correction of the vision subsystem distortions

This group of algorithms is dedicated to the correction of distortions arising from individual components of the vision subsystem of the measurement device. CCD camera electronic components influence image quality especially by:

- instrumental background presence;
- non-uniform pixel sensitivity.

There are also distortion factors of other components of the vision subsystem which should be considered, including:

- nonlinear characteristics of infrared filters;
- optical aberrations (spherical, chromatic, comatic) of camera lens.

During the last few years our team developed some algorithms to eliminate influence of these factors. They were described in [4, 7, 8, 14]. However they haven't been fully implemented and tested in software of the measurement device yet. There are also possible ways to improve them on the basis of the detailed analysis of the vision subsystems components.

Auto-focus algorithm

For most of materials measurements of surface tension and wetting angle are carried out in the protective atmosphere. The flow of protective gas introduces significant distortions to acquisitioned images. Gas is introduced to the furnace chamber form the side of CCD camera having temperature about 280 K, and then on the way to the specimen it is heated to the current working temperature, 1500 K for example.

The absolute index of the light refraction n in gas depends on its density and temperature. For the temperature above 280 K and for atmospheric pressure it is given by equation:

$$\Delta n = \frac{k_1 \gamma}{T} \tag{1}$$

where:

γ – density of gas,
T – absolute temperature,
k_1 – constant value.

Boyle-Mariotte law states that for constant pressure gas density is inversely proportional to its absolute temperature:

$$\Delta n = \frac{k_2}{T^2} \tag{2}$$

where k_2 – constant value.

Following formula (2), in example given above, where temperature of gas is raising from 280 K to 1800 K on its way through the furnace chamber, the value of Δn is decreasing nearly 40 times.

As the result we can assume that gas introduced to the furnace should be considered as the optical lens, which index of light refraction is smoothly changing between camera and specimen.

It should be said, that presented model of "gas lens" is very simplified. In fact, parameters of this lens depend on many different factors, including: parameters of the gas flow, composition of gas mixture and distribution of temperature in furnace chamber. Additionally these parameters usually change during measurement experiments.

It seems that the simplest and the best way to correct distortions inducted by "gas lens" is to develop and to implement real-time auto-focus algorithm.

Sub-pixel specimen localization

Precision of specimen localization and determination of its geometrical parameters has critical weightiness for accuracy of surface tension and wetting angle measurements. Traditional image processing and analysis methods seem to give insufficient results. The accuracy of edge-detectors is limited by the discrete structure of a digital raster. Moreover, the detected edge is approximate and ambiguous as different methods often produce different results for one image. It causes problems, especially when object dimensions are measured [2, 12]. To meet the demands of today's industrial applications, edge detection and objects geometrical parameters determination should be carried out with subpixel accuracy [28].

This group of algorithms is usually used in the case of images with strongly elongated edges or containing well defined, known objects. In such cases they allow to localize edges with resolution exceeding nominal resolution of analyzed image. As a consequence of implementation of these methods we should be allowed to much more accurate localization and geometrical parameters determination of specimen under investigation.

It should be mentioned, that subpixel methods are commonly used in geodesy and cartography, although there are no any significant applications of them in industrial measurement systems.

5. Conclusions

The evolution of Thermo-Wet measurement system was presented. Its history and current state were described. The paper focused mainly on the new ideas in the high temperature computerized measurements of wetting angle and surface tension. The main goals of given ideas are to expand the usability of measurement stand and to improve the accuracy and repeatability of the measurement results.

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