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MODIFICATIONS OF THE SURDAT DATABASE OF THE PHYSICOCHEMICAL PROPERTIES OF METALS AND ALLOYS

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Abstract

Experimental studies of the surface tension and the density were carried out by means of the maximum bubble pressure method and the dilatometric technique and next, they were compiled with the results of over 12 years of research of the liquid pure components, binary and multicomponent alloys, with the aim to create the SURDAT database of the Pb-free soldering materials. In the last years, a modification of SURDAT has been conducted. The new version, beside the earlier data of the physical properties, also contains such data as: the viscosity data, selected data of the mechanical and electrical properties, the DTA data and the meniscographic study results (contact angle, wetting time, wetting force and interfacial tension). Additionally, the data base of the heat properties, worked out at NIST (National Institute of Standard and Technology from Boulder in Colorado) has been implemented.

Keywords: *Surface tension; Density; Viscosity; Wettability; Electric al properties; Mechanical properties; Lead-free solders; SURDAT; Database.*

1. Introduction

For over 12 years, the studies on the surface tension by means of the maximum bubble pressure method and of the density with the use of the dilatometric technique have been carried out and developed for metals and their two-and multicomponent alloys, in the course of research programs aimed at identifying new lead-free solders for electronics and electrical engineering. The results and the data from the modelling of the surface tension have been used to create a database of the lead-free solders' physicochemical properties, that is SURDAT [1]. This database was released in 2007. It is a freely available database which can be downloaded from the website of the Alexander Krupkowski Institute of Metallurgy and Materials Science of Polish Academy of Sciences in Krakow: http:// www.imim.pl. In the last 4 years, the research conducted at the institute has been greatly expanded by new lead-free solder physicochemical values, such as the contact angle, the wetting force, the wetting time, the interfacial tension, and the results of the thermal analysis, and they have been implemented in the database. Broadening the scope of this study was stimulated by the cooperation with the institutes pursuing research for the industry. In addition, new programs were created to predict the viscosity based on the models proposed in the past by Moelwin-Hughes [2], Iida, Ueda and Morita [3, 4], Sichen, Boygen and Seetharaman [5, 6], Kozlov, Romanov and Petrov [7] and Kaptay [8]. In 2008, this led to a collaboration with the University of Alberta in Edmonton, Canada, in the field of the viscosity, the density and the surface tension by the outflow from the hole in the bottom of the container (crucible), which allows a simultaneous measurement of these three physical quantities. The test performed for the Ag-Sn alloys has been introduced to the new SURDAT database version. In addition, the latter contains the database of the thermal properties - with the consent of the National Institute of Standard and Technology from Colorado. The Polish version of the SURDAT 2 database was printed in 2012 and, like the previous edition, it is free and can be downloaded from the website of the Institute of Metallurgy and Materials Science of Polish Academy of Sciences (IMMS PAS). The English version of the SURDAT 2 database is being currently prepared and it will be also free and available for download from the website of the Institute.

2. Database SURDAT 2

Modifying the SURDAT database has had a multidirectional nature. First, it contains an extended number of systems and secondly, the range of the physicochemical properties of metal alloys has been much expanded by the experimental data and the data calculated by different models, with the application of the alloy's thermodynamic as well as other physical

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Dedicated to the memory of Professor Zbigniew Moser properties. Table 1 presents the metals and alloys subjected to experimental research, which are included in the database (marked in red), while Figure 1 shows a diagram of some new physicochemical properties possible to be included in the SURDAT 2 database, as well as some new components of the database which were not part of the SURDAT database, also marked in red. Compared to the original version, the SURDAT 2 database includes 41 new systems (mostly two-and three-component ones four quaternary ones and a quinary one). On a pooled basis, SURDAT 2 is available for different physicochemical properties of 56 systems. As shown by the diagram in Fig. 2, the number of the presented experimental and modeled properties has increased significantly. Since the Institute of Metallurgy and Materials Science, Polish Academy of Sciences was one of the cooperators in the COST Action 531 and COST MP0602, the phase diagrams developed within these projects have also been introduced (Fig. 3).

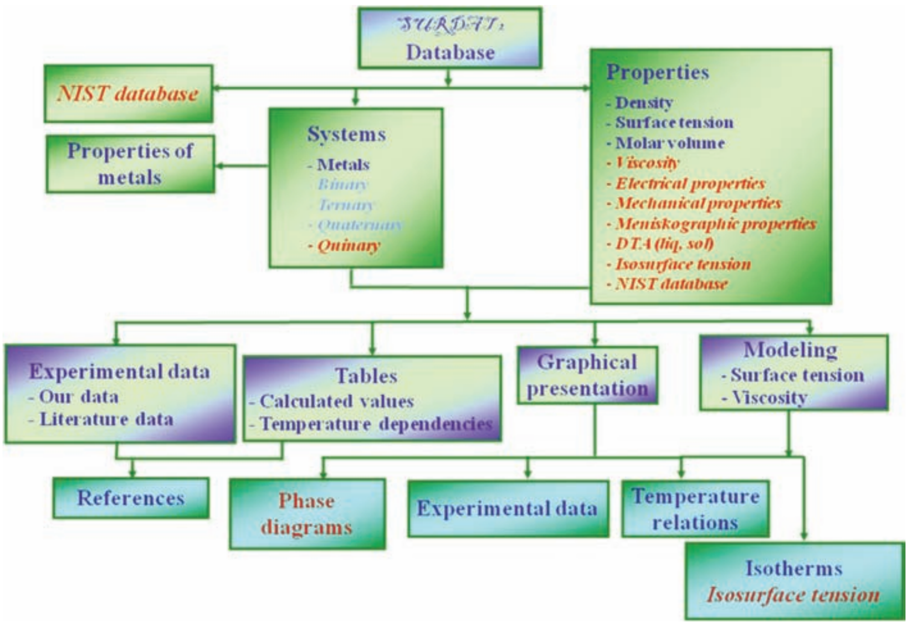
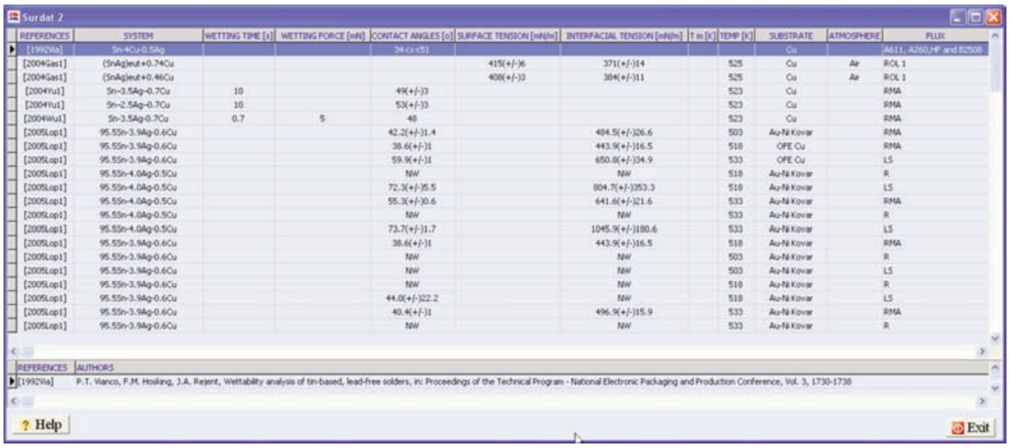


Figure 1. *Scheme of SURDAT 2 possibilities.*

Table 1. *Systems in SURDAT 2 database.*

Metals (10)	Binary Systems 29 (11/18)		Ternary Systems 22 (4/18)		Quaternary & Quinary Systems 7 (2/5)
Metals and Systems in SURDAT Database					
Ag, Al Au, Bi Cu, In Pb, Sb Sn, Zn	Ag – Bi	Ag – In	$(Sn\text{-}Ag)_{eut}$ +In	$(Sn\text{-}Ag)_{eut}$ +Bi	$(Sn\text{-}Ag)_{eut}$+Cu+Sb
	Ag – Sb	Ag – Sn	$(Sn\text{-}Ag)_{eut}$ +Cu	$(Sn\text{-}Ag)_{eut}$ +Sb	$(Sn\text{-}Ag)_{eut}$+Cu+Bi
	Bi – Sn	Cu – Sb			
	Cu – Sn	In – Sn			
	Pb – Sn	Sb – Sn			
	Sn – Zn				
New Systems in SURDAT 2 Database					
	Ag–Au	Ag–Cu	Ag–Bi–In	Ag–Cu–In	Ag–Cu–In–Sn
	Al–In	Al–Sn	Ag–Sn–Zn	Au–In–Sn	Bi–In–Sn–Zn
	Al–Zn	Au–Cu	Al–Sn–Zn	Bi–Cu–Sn	Bi–Cu–Sn–Zn
	Au–In	Au–Sn	Au–Sn–Zn	Bi–Cu–Sn	Bi–Sb–Sn–Zn
	Bi–Cu	Bi–In	Ag–Bi–In	Ag–Cu–In	$(Sn\text{-}Ag)_{eut}$+Cu+Bi+Sb
	Bi–Zn	Cu–In	Bi–In–Sn	Bi–In–Zn	
	Cu–Ti	Ga–In	Bi–Sn–Zn	Cu–Sn–Ti	
	Ga–Sn	In–Sb	Cu–Sn–Zn	Ga–In–Sn	
	In–Zn	Sn–Ti	In–Sb–Sn	In–Sn–Zn	



REFERENCES	SYSTEM	WETTING TIME [s]	WETTING FORCE [mN]	CONTACT ANGLES [o]	SURFACE TENSION [mN/m]	INTERFACIAL TENSION [mN/m]	T m [K]	TEMP [K]	SUBSTRATE	ATMOSPHERE	FLUX
[1992Via]	Sn-4Cu-0.5Ag			34<x<51					Cu		A611, A260,HF and B2508
[2004Gas1]	(SnAg)eut+0.74Cu				415(+/-)6	371(+/-)14		525	Cu	Air	ROL 1
[2004Gas1]	(SnAg)eut+0.46Cu				408(+/-)3	384(+/-)11		525	Cu	Air	ROL 1
[2004Yu1]	Sn-3.5Ag-0.7Cu	10		49(+/-)3				523	Cu		RMA
[2004Yu1]	Sn-2.5Ag-0.7Cu	10		53(+/-)3				523	Cu		RMA
[2004Wu1]	Sn-3.5Ag-0.7Cu	0.7	5	48				523	Cu		RMA
[2005Lop1]	95.5Sn-3.9Ag-0.6Cu			42.2(+/-)1.4		484.5(+/-)26.6		503	Au-Ni Kovar		RMA
[2005Lop1]	95.5Sn-3.9Ag-0.6Cu			38.6(+/-)1		443.9(+/-)16.5		518	OFE Cu		RMA
[2005Lop1]	95.5Sn-3.9Ag-0.6Cu			59.9(+/-)1		650.8(+/-)34.9		533	OFE Cu		LS
[2005Lop1]	95.5Sn-4.0Ag-0.5Cu			NW		NW		518	Au-Ni Kovar		R
[2005Lop1]	95.5Sn-4.0Ag-0.5Cu			72.3(+/-)5.5		804.7(+/-)353.3		518	Au-Ni Kovar		LS
[2005Lop1]	95.5Sn-4.0Ag-0.5Cu			55.3(+/-)0.6		641.6(+/-)21.6		533	Au-Ni Kovar		RMA
[2005Lop1]	95.5Sn-4.0Ag-0.5Cu			NW		NW		533	Au-Ni Kovar		R
[2005Lop1]	95.5Sn-4.0Ag-0.5Cu			73.7(+/-)1.7		1045.9(+/-)180.6		533	Au-Ni Kovar		LS
[2005Lop1]	95.5Sn-3.9Ag-0.6Cu			38.6(+/-)1		443.9(+/-)16.5		518	Au-Ni Kovar		RMA
[2005Lop1]	95.5Sn-3.9Ag-0.6Cu			NW		NW		503	Au-Ni Kovar		R
[2005Lop1]	95.5Sn-3.9Ag-0.6Cu			NW		NW		503	Au-Ni Kovar		LS
[2005Lop1]	95.5Sn-3.9Ag-0.6Cu			NW		NW		518	Au-Ni Kovar		R
[2005Lop1]	95.5Sn-3.9Ag-0.6Cu			44.0(+/-)22.2		NW		518	Au-Ni Kovar		LS
[2005Lop1]	95.5Sn-3.9Ag-0.6Cu			40.4(+/-)1		496.9(+/-)15.9		533	Au-Ni Kovar		RMA
[2005Lop1]	95.5Sn-3.9Ag-0.6Cu			NW		NW		533	Au-Ni Kovar		R

REFERENCES	AUTHORS
[1992Via]	P.T. Vianco, F.M. Hosking, J.A. Rejent, Wettability analysis of tin-based, lead-free solders, in: Proceedings of the Technical Program - National Electronic Packaging and Production Conference, Vol. 3, 1730-1738

Figure 2. *Meniscographic measurement results for the Ag – Cu – Sn system.*

From the perspective of future applications, the electrical properties of solders and solder joints, as well as their mechanical and wettability properties, are very important, and so they were implemented in the new SURDAT in the form of figures and tables. They are shown in a block of properties under the name of 'meniscographic properties'. They appear to be extremely important and decisive for the use of brazing materials, an they include the contact angle, the wetting time, the interfacial tension between the solder and the solder material and the wetting force. As regards the interfacial tension, also the information on the flux applied is given. These quantities are presented in a tabular form (Fig. 2) for several solders, together with the applied fluxes (flux) and the material on which the wettability test was carried out. Another interesting figure for the potential users of lead-free solders is the melting and solidification of the soldering material (DTA, DSC), which is presented in the SURDAT 2 database, also in a tabular form, as it is seen in Fig. 4.

For the sake of a continuous development of the SURDAT database through the enhancement of its other properties, we have established a cooperation with NIST, Boulder, Colorado, which led to the approval of the NIST database of the thermal, mechanical and electrical lead-free solder properties for the inclusion in the SURDAT database (Fig.5).

The electrical and mechanical properties of the lead-free solders belonging to the quinary (Ag-Sn-Cu)$_{eut}$+Bi+Sb system investigated at our institute have been added in the form of graphs, as it is shown in Figs 6 and 7.

The presentation of the viscosity, density and surface tension data of binary alloys in SURDAT was possible in the form of temperature dependences or isotherms. In the discussed version, a new option was worked out and proposed for the users. It is the

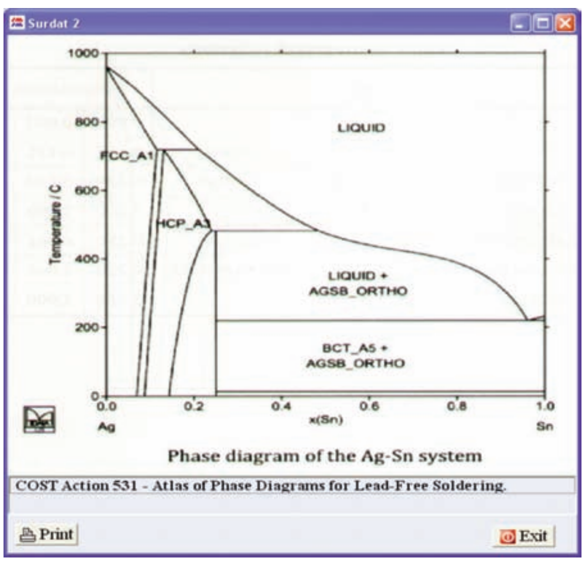
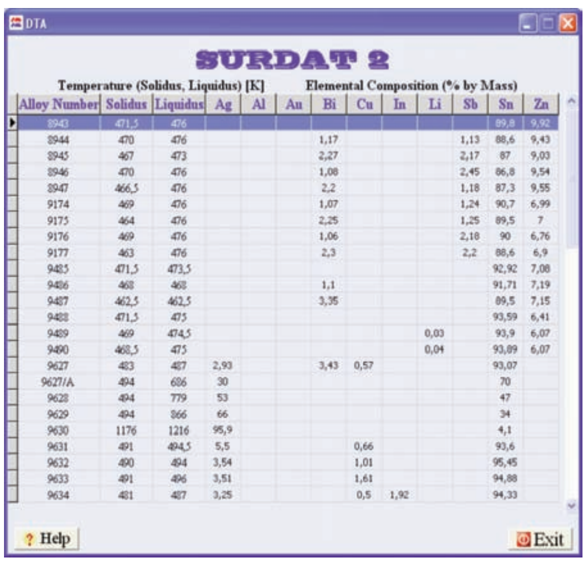


Figure 3. *Phase diagram of the Ag-Sn system [9].*



SURDAT 2

Alloy Number	Solidus	Liquidus	Ag	Al	Au	Bi	Cu	In	Li	Sb	Sn	Zn
	Temperature (Solidus, Liquidus) [K]		Elemental Composition (% by Mass)									
8943	471,5	476									89,8	9,92
8944	470	476				1,17				1,13	88,6	9,43
8945	467	473				2,27				2,17	87	9,03
8946	470	476				1,08				2,45	86,8	9,54
8947	466,5	476				2,2				1,18	87,3	9,55
9174	469	476				1,07				1,24	90,7	6,99
9175	464	476				2,25				1,25	89,5	7
9176	469	476				1,06				2,18	90	6,76
9177	463	476				2,3				2,2	88,6	6,9
9485	471,5	473,5									92,92	7,08
9486	468	468				1,1					91,71	7,19
9487	462,5	462,5				3,35					89,5	7,15
9488	471,5	475									93,59	6,41
9489	469	474,5							0,03		93,9	6,07
9490	468,5	475							0,04		93,89	6,07
9627	483	487	2,93			3,43	0,57				93,07	
9627/A	494	686	30								70	
9628	494	779	53								47	
9629	494	866	66								34	
9630	1176	1216	95,9								4,1	
9631	491	494,5	5,5				0,66				93,6	
9632	490	494	3,54				1,01				95,45	
9633	491	496	3,51				1,61				94,88	
9634	481	487	3,25				0,5	1,92			94,33	

Figure 4. *DTA investigation results.*

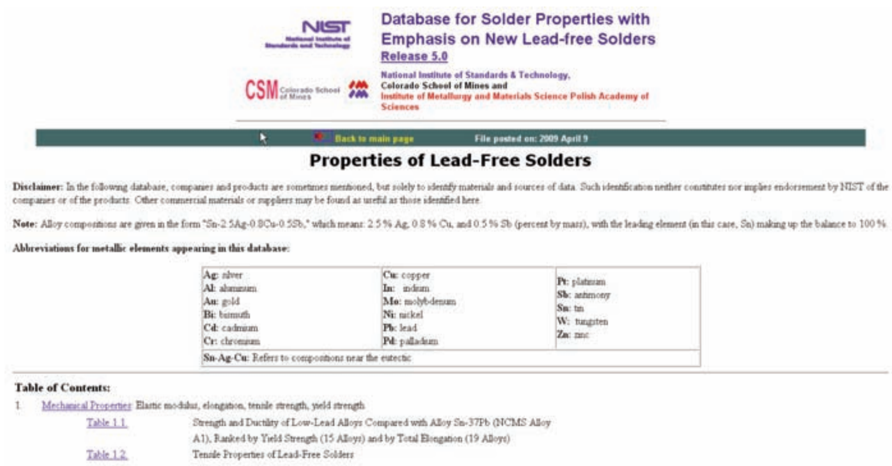


Figure 5*. First page of NIST database implemented to SURDAT 2.*

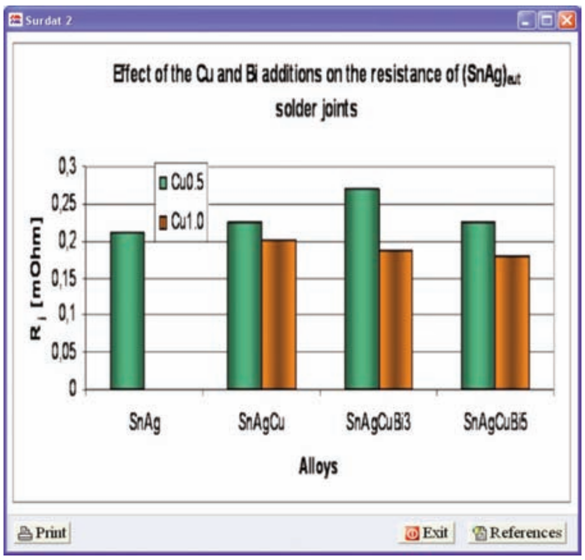


Figure 6. *Influence of Cu and Bi additions at the resistivity of $(SnAg)_{eut}$ lead-free solders.*

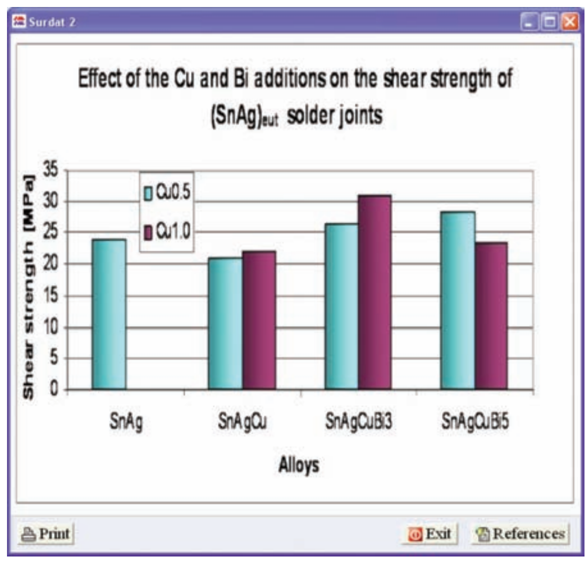


Figure 7. *Influence of Cu and Bi additions the $(SnAg)_{eut}$ lead-free solders.*

possibility to present any data (experimental, calculated from any models, etc.) together with the values gathered or calculated by SURDAT. A sample of such idea is presented in Fig. 8, where the viscosity isotherms of a hypothetical author XYZ are shown together with the experimental values obtained by [10] and calculated from the models of the authors cited in Fig. 8.

New software was created for the modelling of the surface tension and viscosity of multicomponent alloys in various configurations. Currently, there are options such as: the calculation of the temperature dependence for the given concentrations, the calculation of the isothermal runs and the third option is called isolines (isosurface tension or isoviscosity), which are the concentrations for which the surface tension has the same determined value. This option

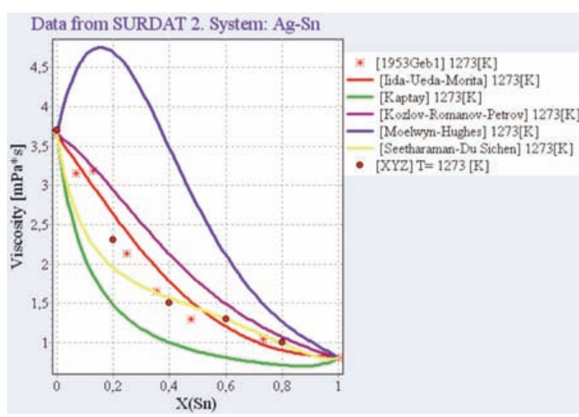


Figure 8. *Isotherms of viscosity calculated by different models compared with the experimental data of Gebhardt et al. [10] [1953Geb1] together with the hypothetic XYZ data at 1273 K.*

only applies to multi-component alloys, i.e. where the number of metals equals at least three. A presentation sample of the isolines of the surface tension in the Ag-Cu-Sn system is shown in Fig. 9.

In the upcoming years, the authors intend to upgrade the base of the component concentration in the monoatomic surface layer and the physicochemical properties of the systems being in the base, available in the literature.

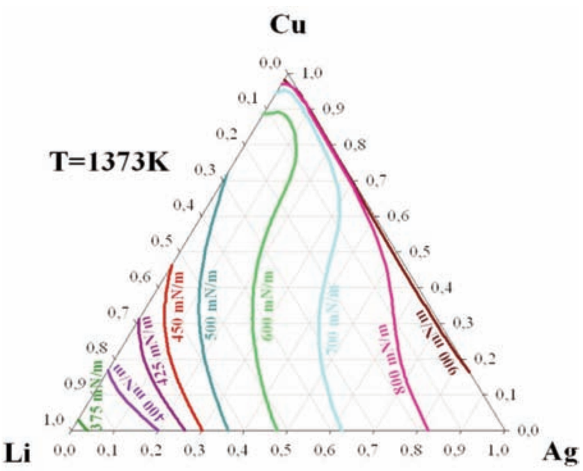


Figure 9. *Isolines of the surface tension in Ag-Cu-Li system at 1373K.*

3. Summary

The rich experimental materials compiled at IMIM PAN on lead-free solders based on the own data and that resulted from the cooperation, were used to develop an electronic database of lead-free solders, named SURDAT, which was published in 2007. In order for it to contain both the wetting properties (contact angle, wetting time, wetting force, interfacial tension) and the electrical and mechanical characteristics of solders and solder joints, a collaboration was initiated with the national industrial institutes, which allowed broadening the scope of the study of lead-free solders.

A description of the SURDAT database was published in 2007 in the form of monographs, as well as in the electronic form, and is generally available with the software base at the SURDAT website: www.imim.pl.

A new version of the database, named SURDAT 2, beside the earlier data, also contains the NIST database (National Institute of Standards and Technology in Boulder, Colorado, USA) [11], as well as the results of different research programs, such as: COST 531, an international network of ELFNET and Associated Phase Diagram and Thermodynamics Committee, COST MP0602 - HISOLD - Advanced solder materials for high temperature applications, and also the results of the research projects granted by the Polish Ministry of Science and High Education.

The work on the modification of the base was continued for two years and resulted in a new book and the electronic version at the beginning of 2011 (in Polish). It constituted a new option for the users of the base which allows adding the data of the surface tension or the viscosity measured or calculated by any author, into the graph. Also, the results of the modelling of the surface tension and the viscosity of multicomponent systems are possible to obtain in the form of isolines, temperature dependences and isotherms for the given concentrations.

In the future, the SURDAT 2 database will be expanded by the lacking data for all the systems being in this base and the concentration of the monoatomic surface layer, first, for the binary - and next, for the higher order systems. The English version of SURDAT 2 is being currently prepared.

Acknowledgment

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