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Integration of the NIST and SURDAT Databases on Physical Properties of Lead-Free Solder Alloys

W. Gąsior · Z. Moser · A. Dębski · T. Siewert

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Abstract The electronic SURDAT database published in 2007 (available freely from the website www.imim.pl/english) is being integrated with the NIST database (available freely from www.boulder.nist.gov/div853/lead_free/solders.html) to provide a single source for data on lead-free (Pb-free) soldering alloys. The NIST database was developed to support circuit board designers, and so it is focused primarily on mechanical properties. In contrast, the SURDAT database is focused primarily on thermophysical properties. Together, they will form a much more complete source for the properties of Pb-free solder alloys.

Keywords Database · Mechanical properties · Pb-free solders · Thermophysical properties

1 Introduction

The drive to replace traditional tin–lead (Sn–Pb) solders with Pb-free materials has propelled a search for data on the key properties of candidate alloy systems. These include physical, chemical, mechanical, and electrical properties, as well as cost and

W. Gąsior (✉) · Z. Moser · A. Dębski
Institute of Metallurgy and Materials Science, Polish Academy of Sciences, 25, Reymonta St., 30-059 Kraków, Poland
e-mail: nmgasior@imim-pan.krakow.pl

A. Dębski
e-mail: nmdebski@imim-pan.krakow.pl

T. Siewert
Materials Reliability Division, National Institute of Standards & Technology, Boulder, CO 80305, USA

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manufacturability. Among these, the physical properties, such as surface tension, interfacial tension, with copper as the base metal and contact angles, are important because of their direct correlation with the wettability of the substrate by solder. Systematic studies of the surface tension and density of pure metals, binary and multicomponent systems, including modeling of physical properties, were initiated at the Institute of Metallurgy and Materials Science, Kraków, Poland, in 1998. These studies were used to create the SURDAT database, which is an important step in the search for Pb-free soldering materials.

Data in the literature were scarce, and so the development of the SURDAT database on low melting alloys began with the production of surface tension and density data. This was mainly undertaken at the Institute of Metallurgy and Materials Science (IMMS) in Kraków, Poland using the maximum bubble-pressure method and the dilatometric technique. Substitution of Pb in Sn–Pb solders with Bi, Cu, Sb, In, and Ag was examined. In the last few years, the industry has focused on two eutectics: Sn–Ag (m.p. 221 °C) and Sn–Ag–Cu (m.p., 217 °C to 219 °C), and so these were added to the 2007 version of SURDAT [1]. Simultaneously, in 2006, interest was growing in Pb-free solders based on the Sn–Zn eutectic. Then in 2008, the idea of merging SURDAT (the version published in 2007) with the NIST database was first discussed. This article summarizes these preliminary steps in 2009 [2] and presents the future possibility of preparation of the second version, SURDAT 2, including new data such as both experimental and modeled viscosity, as well as the data of the partners participating in collecting data for the NIST database.

Detailed information about various programs initiated all over the world on Pb-free solders, on their properties, patents, and various producers is discussed in details in Ref. [3].

The NIST database grew out of a multi-year effort when NIST staff (especially Carol Handwerker and Tom Siewert) worked with a NEMI committee in the late 1990s to collect data that would allow circuit board manufacturers to move away from the traditional Sn–Pb solders. As the volume of data grew, it was vetted and edited by David Smith at NIST. Later, Carlos Madeni and Stephen Liu of the Colorado School of Mines joined our team, and developed versions that resided on the NIST and CSM websites. In a parallel effort, NIST developed a Recommended Practice Guide (NIST Special Publication 960-8) that gives guidance on how to develop solder data in a standardized and consistent format [4].

2 SURDAT Database

The SURDAT database was released at the beginning of 2007 in the form of a monograph with the installation software [1]. Also, it could be copied free of charge from the website www.imim.pl/english. The experimental data of metals and alloys measured at IMMS PAS and provided from the literature contained in SURDAT are presented in Table 1. Different possibilities of data presentation are shown schematically in Fig. 1.

On opening of the SURDAT computer database, the first window that appears on the screen (Fig. 2) identifies the organization and allows selection of the system. To proceed, select the appropriate system in the “SYSTEM SELECTION” section.

Table 1 Metals and Pb-free alloys in SURDAT database

Metals	Binary systems	Ternary systems	Quaternary systems
Pb	Pb–Sn		
Sn	Ag–Sn		
In	Ag–In		
Ag	Bi–Sn		
Bi	In–Sn	$(Sn–Ag)_{eut} + In$	
Sb	Ag–Bi	$(Sn–Ag)_{eut} + Bi$	$(Sn–Ag)_{eut} + Cu + Sb$
Cu	Sb–Sn	$(Sn–Ag)_{eut} + Cu$	$(Sn–Ag)_{eut} + Cu + Bi$
Zn	Sn–Zn	$(Sn–Ag)_{eut} + Sb$	
Al	Ag–Sb		
Au	Cu–Sn		
	Cu–Sb		

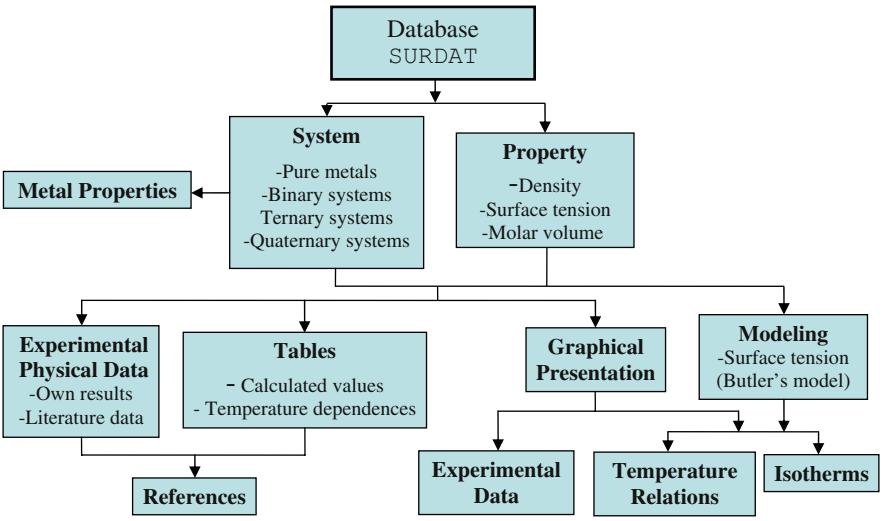

Fig. 1 Structure of the SURDAT database

After selecting the "Pure metals" option and pressing the "OK" button, you proceed to the next window of the program (Fig. 3). Here, you can select both the metal and the system (if you did not select the "Pure metals" option in the previous window), as well as the physical properties ("SELECT PROPERTIES").

The "Fig" option makes it possible to browse the temperature dependencies and isotherms determined and presented in publications. For pure metals, only temperature dependencies are available. When you select the property "Surface tension" in the "SELECT PROPERTIES" window, and additionally "temperature dependence," the program will show the diagram of the surface tension dependence on temperature as measured by various authors (Fig. 4). Further, on pressing the "References" button, you open the window with the list of publications used as sources of the data.

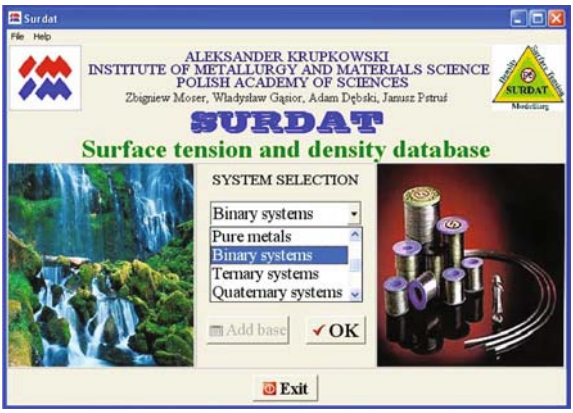

Fig. 2 First window of the SURDAT database: selection of the system type

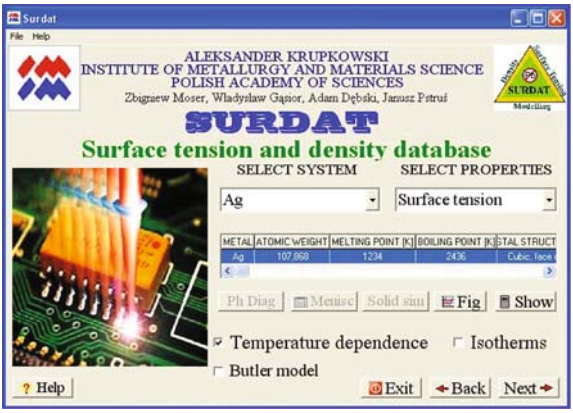

Fig. 3 Second step in SURDAT enables the selection of the suitable system and the desired property

Entry to the appropriate group of systems begins in the first window (Fig. 2) with the option choice "Select systems." In the selected window (Fig. 3), the user chooses the system and the property of interest. Data are available on the density, surface tension, and molar volume, which can be presented in the form of isotherms or temperature dependencies. An additional option in the SURDAT database concerns the modeling of the surface tension from Butler's relation [6]. There are two ways to present the data, depending on the selected option: "Isotherms" or "Temperature dependencies." In the "Isotherms" option, the experimental isotherms (as points) can be compared with the modeled values (line). In the case of the "Temperature dependencies" option, the modeled values of the surface tension can be combined with some or all of the experimental data or selected concentrations of any system in SURDAT (Fig. 5). In addition to density and surface tension, it is possible to calculate and show the values of the molar volume at a fixed temperature(s). Additional information such as references, temperature, or compositions of alloys are available at any stage of the functioning of SURDAT, in supplementary windows (see Fig. 5).

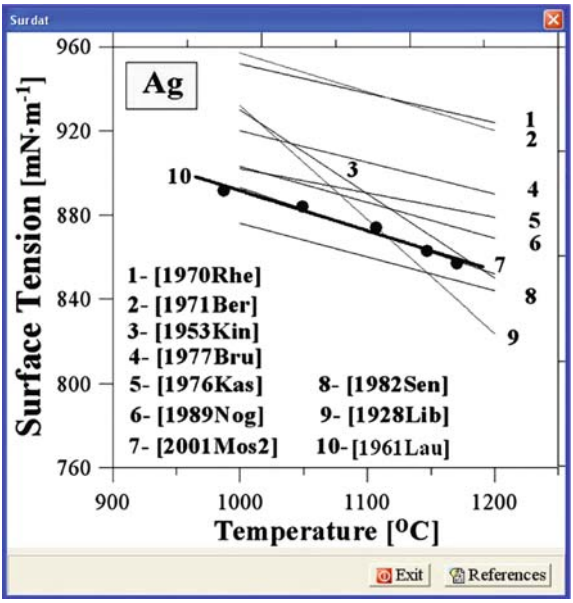

Fig. 4 Comparison of the temperature dependencies of the surface tension of liquid silver available in the literature with new experimental data by the dilatometric method [1]

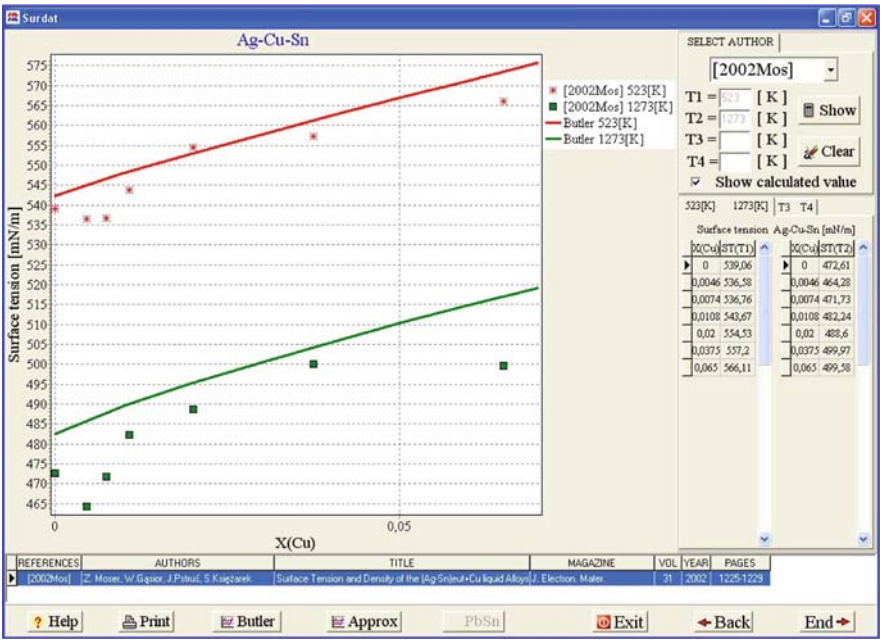

Fig. 5 Isotherms of $(Ag–Cu)_{eut} + Sn$ alloys calculated from the Butler model together with the experimental data (*symbols*) at 523 K and 1273 K. Supplementary windows show the reference (*bottom window*), and temperature and the experimental data of the surface tension (*windows on the right side*)

Table 2 New systems in the SURDAT 2 database

Binary alloys (*11*/13)		Ternary alloys (*4*/14)		Quaternary and quinary alloys (*2*/5)
Ag–Cu	Al–In	Ag–Cu–In	Ag–In–Sb	Ag–Cu–In–Sn
Al–Sn	Al–Zn	Ag–Bi–In	Ag–Sn–Zn	Bi–In–Sn–Zn
Au–Cu	Au–In	Al–Sn–Zn	Au–In–Sn	Bi–Cu–Sn–Zn
Au–Sn	Bi–In	Bi–Cu–Sn	Bi–In–Sn	Bi–Sb–Sn–Zn
Cu–In	Cu–Ti	Bi–Sb–Sn	Bi–Sn–Zn	$(Sn–Ag)_{eut} + Cu + Bi + Sb$
In–Sb	In–Zn	Cu–Sn–Ti	Cu–Sn–Zn	
Sn–Ti		In–Sb–Sn	In–Sn–Zn	

The second version of SURDAT (SURDAT 2) is being prepared. When it is complete, the physicochemical data of the new systems cited in Table 2 will be available together with those from the earlier edition.

3 NIST Database

The NIST Pb-free solder website, www.boulder.nist.gov/div853/lead_free/solders.html, currently uses version 4.0 of the database. It has more of a flat file database structure, with most of the data and links available via a single click from the home page, as shown in Fig. 6. The data are available in either HTML format (for direct viewing on the screen) or in Microsoft Word format (for downloading into spreadsheets or equations). About once a month, NIST receives requests for information that is not included in the database. These data may have been generated at one of the solder research centers around the world; so we have included links to the various Pb-free solder research centers, as well as universities who have at least some project on Pb-free solder.

There are also some related links, such as one to the National Science Foundation's program on New Technology for the Environment, so that interested visitors to the site can learn about other programs that are driving the development of Pb-free solder data.

4 Preliminary Version of SURDAT + NIST Database

The initial discussion on the integration of the SURDAT and NIST–CSM databases (Database for Solder Properties with Emphasis on New Lead-free Solders Release 4.0 published in 2002) occurred during the 16th Symposium on Thermophysical Properties in Boulder, Colorado, USA in 2006. The plan moved ahead more rapidly in 2008 when preparations to issue a new enlarged version SURDAT 2 in 2010 comprising results of the wettability of Bi and Sb with Sn–Ag, Sn–Ag–Cu, and Sn–Zn eutectic alloys began at IMMS in Krakow. The SURDAT + NIST database (Database for Solder Properties with Emphasis on New Lead-free Solders Release 5.0) was announced

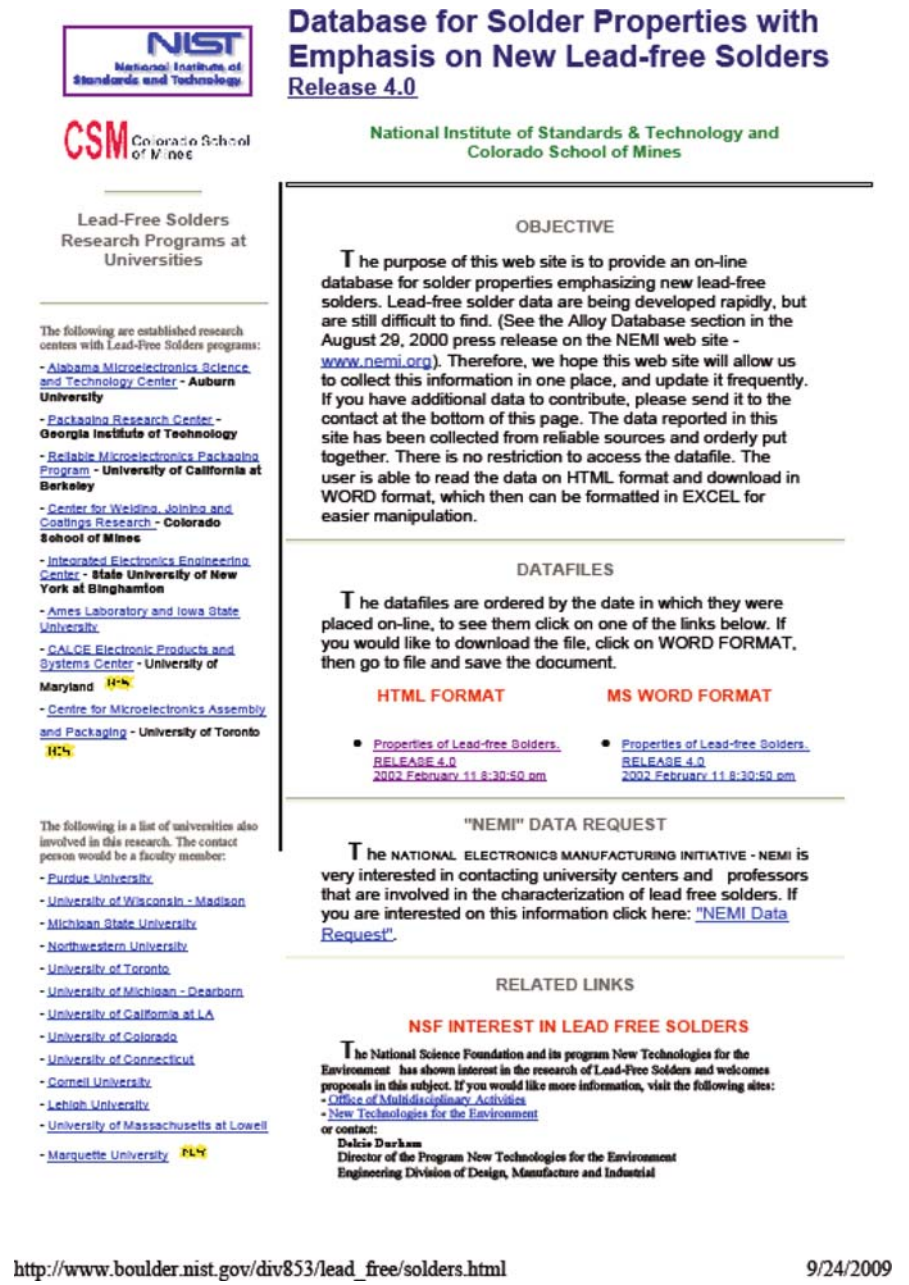

Fig. 6 Homepage of the NIST solder database showing hotlinks to the data files and related links

Fig. 7 First page of new database for solder properties by NIST, CSM, and IMIM PAN

during the 17th Symposium on Thermophysical Properties (Boulder, Colorado, June 21–26, 2009). The first page (starting window) is presented in Fig. 7.

The integrated SURDAT–NIST–CSM database will combine the data previously available in SURDAT, with the isothermal properties from the NIST–CSM database, as organized into the following sections:

1. Properties of Pure Elements used in Pb-free Solder Materials
2. Isothermal Properties of Binary Systems Pb-free Solder Materials
3. Properties of Binary Systems as a Function of Temperature Pb-free Solder Materials
4. Isothermal Properties of Ternary Systems Pb-free Solder Materials
5. Properties of Ternary Systems as a Function of Temperature Pb-free Solder Materials
6. Isothermal Properties of Quaternary Systems Pb-free Solder Materials
7. Properties of Quaternary Systems as a Function of Temperature Pb-free Solder Materials.

As in the SURDAT database, it will be possible to select alloy systems, from pure metals to quaternary systems. The presentation of physical properties (density, surface tension, or molar volume) can be obtained in the form of isotherms or temperature dependencies. The temperature dependence of the surface tension of Sn is shown as an example in Fig. 8, which is available from the section "Properties of Pure Elements Pb-free Solder Materials."

Other new data in the SURDAT 2 database are the meniscographic properties, including interfacial tension, measurements of wetting force and wetting time, as well as the calculation of wetting angle. These are obtained by activating the "Meniscographic Studies" selection window, followed by selecting the system. The values of cited properties are presented in the database in the form of diagrams or tables (following the format of the data in the literature). The set of the meniscographic properties for five-component alloys in the matrix of the $(Sn–Ag)_{eut} + Cu + Bi + Sb$ near eutectic alloys is shown as an example in Fig. 9. Information on the citations from which the mentioned properties have been taken is given under the diagrams or tables.

The completion of the new version of the SURDAT electronic database is planned for 2010. A supplemental goal of this publication is to invite other centers working in the field of Pb-free solders to join the preparations of the new version of SURDAT by sharing their experimental results with the authors for inclusion in the SURDAT electronic database.

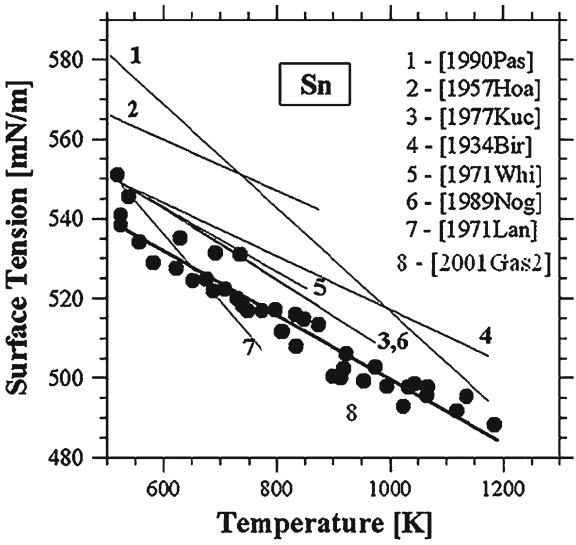

Fig. 8 Temperature dependences of the surface tension for Sn in the preliminary version of the SURDAT + NIST database

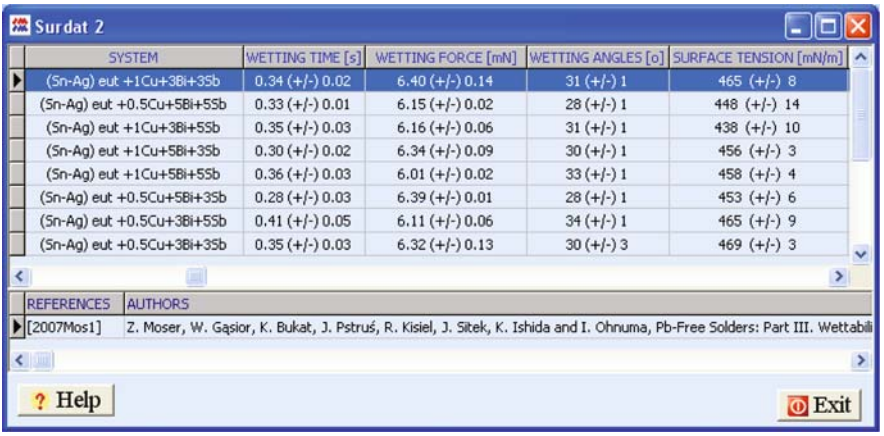

Fig. 9 Results of meniscographic investigations of $(Sn–Ag)_{eut} + Cu + Bi + Sb$ solders [5]

5 Summary

The experimental studies of new Pb-free solders at IMMS PAS allow compilation of the significant experimental results of their physicochemical properties, which were used for the creation of the electronic SURDAT database of Pb-free solders. Use of the software allows calculation of the surface tension and the viscosity from the thermodynamic properties and the physical properties of metals. In addition, there were collaborations with Tohoku University as well as industrial institutes in Poland. This collaboration resulted in developing the research programs on the wettability properties such as contact angle, wettability force, and wettability time, interfacial tension, and mechanical and electrical properties of Pb-free solders and solder joints.

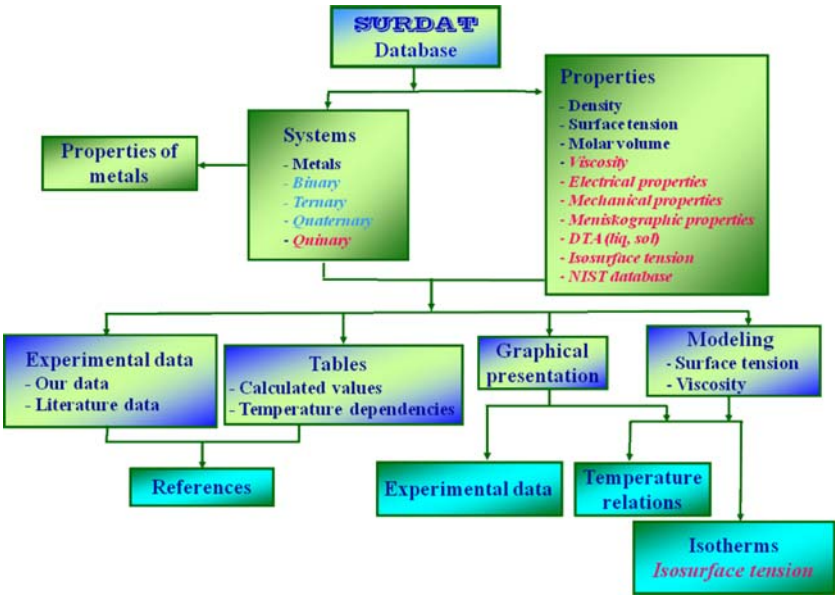

Fig. 10 Structure of the SURDAT 2 database

Four years ago, the authors began the construction of the SURDAT database, which includes at present the experimental and modeled values of the surface tension, density, and molar volume for over a dozen binary and higher-order systems. The SURDAT database was publicly released in 2007 in the form of a monograph and software. It is available free of charge from the www.imim.pl website. The experimental values of the density, molar volume, and the surface tension used in the SURDAT database were obtained during the COST Action 531 program (2002–2006), the international Pb-free solder web ELFNET, and the cooperation between members of the Associated Phase Diagram and Thermodynamic Committee.

The SURDAT database continues to grow through the addition of new data, new systems, and new physicochemical properties. The incorporation of physicochemical properties of metals and alloys is underway, and should be released at the beginning of 2010 year as SURDAT 2. The new system, properties, and the way of presentation are detailed by italics in the operation scheme shown in Fig. 10.

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