Archives of Materials Science and Engineering

Volume 55
Issue 1
May 2012
Pages 37-44

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Informative technologies in the material products designing

L.A. Dobrzański, R. Honysz*

Division of Materials Processing Technology, Management, and Computer Techniques in Materials Science, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland

* Corresponding e-mail address: rafal.honysz@polsl.pl

Received 19.03.2012; published in revised form 01.05.2012

ABSTRACT

Purpose: The purpose of materials products designing is to optimize their functional properties in terms of technological, economic and ecological aspects.

Design/methodology/approach: Materials science is an example of a field, in which informative technologies used to understand and anticipate the construction of materials and their properties has a significant success.

Findings: Innovation and development of new informative technologies and the widespread use of modern materials will be essential for promoting economic development in the near future by application of entirely new, interdisciplinary field of science: computational materials science.

Practical implications: The use of informative technologies allows exploring in a short time and at low expense, many solutions for the design of the mechanical properties of materials and their simulation beyond the standardized range.

Originality/value: The most important benefit of material designing is the ability of suitable selection of material (or its manufacturing) for various applications with use of informative technologies.

Keywords: Analysis and modelling; Computational material science; Informative technologies; Material products designing

Reference to this paper should be given in the following way:

L.A. Dobrzański, R. Honysz, Informative technologies in the material products designing, Archives of Materials Science and Engineering 55/1 (2012) 37-44.

EDUCATION AND RESEARCH TRENDS IN MATERIALS SCIENCE AND ENGINEERING

1. Introduction

The purpose of engineering materials design is to optimize their functional properties in terms of technological, economic and ecological aspects. It generally applies to products made of these materials that meet very specific user requirements. Such designing, usually computer-aided, it must be based on a thorough knowledge of the relations (theoretical and empirical) between the chemical composition of the material, its structure and mechanical properties. The most important benefit of material designing is the ability of suitable selection of material (or its manufacture) for various applications [1-3].

Materials science is an example of a field, in which computer modelling techniques used to understand and anticipate the construction of materials and their properties has a significant success. Without a doubt, it is possible to speak about the creation of entirely new, interdisciplinary fields: computational materials science). According to the latest global trends, computational modelling is becoming an integral part of the material design. The use of computational models allows exploring in a short time and at low expense, many solutions for the design of the mechanical properties of materials and their simulation beyond the standardized range [3-5].

2. Models of engineering materials

The scientific literature presents many models characterized by varying degrees of complexity of the mathematical description and varying degrees of quality compliance with real, physical dependency. Models are understood as a reflection of the system using logical relationships between variables that describe them (Fig. 1.). Handling of these variables allows the analysis how the model behaves in certain conditions. Computational model is a simplified description of the relation between the mechanical properties of materials and the conditions of their production. It does not take into account some of the relation present in reality (as recognized by developing a model to be less important) [2,4-5].

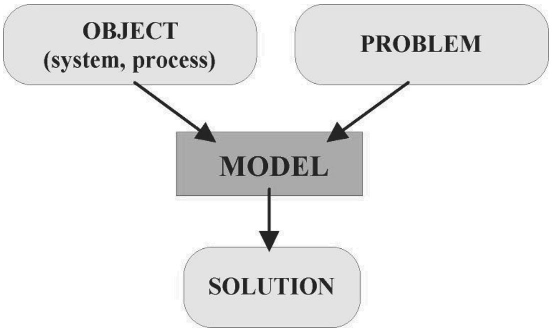


Fig. 1. The idea of modelling

Evaluation of the simulation results performed with use of developed model is based on comparison of all relevant variables model with measurement data. It is recommended, when developing the model, to obtain a comparable level of accuracy in representation of the majority of variables, than the unusually precision of single variable (although significant) and poor accuracy of the other variables [6,34-36].

Computational models are sets of information materials on their properties, expressed in the form of mathematical rules. Modelling is thus formalizing the description of these properties, limited to a set of properties exhibited by the physical model, using mathematical formulas and relationships. This means that the physical model determines the form of a mathematical model. The mathematical model should explicitly correspond with the physical model [2,7].

Innovation and development of new technologies and the widespread use of modern materials will be essential for promoting economic development in the near future. The increase in requirements for product quality and increasingly stringent of market criteria necessitates the search for new materials and efficient technologies for their production. This implies the need for accurate computer simulations, which require increasingly detailed and reliable dependency models of materials and manufacturing processes. Developed models can be divided into two groups:

- phenomenological models based on classical physical theories.
- empirical models, which involve process parameters with measurable quantities.

Both approaches have found many practical applications in the field of model research in the field of materials science.

The principal disadvantage associated with the construction of models is the process of their formulation. It requires a tedious, lengthy and expensive research, carried out both in laboratory conditions (stage of modelling) and as well as in industrial conditions (stage of model implementation). Approach that is becoming more widely used in studies of model processes is the use of artificial neural networks. The main advantage of this method is that the process of developing a model with use of artificial neural networks in most cases comes down to analyze a set of measurement data collected in databases, and to process parameters, which are usually physical quantities that can be laboratory-measured (Fig. 2.). Modelling with the use of artificial neural networks is used, when description of the relationship between the describing data and described data are not known, while a well-defined numerical values are given, collected from inputs and outputs of physical model. Artificial neural network can learn to recognize the analyzed problem, giving a quick response to changing conditions of the process [8-9].

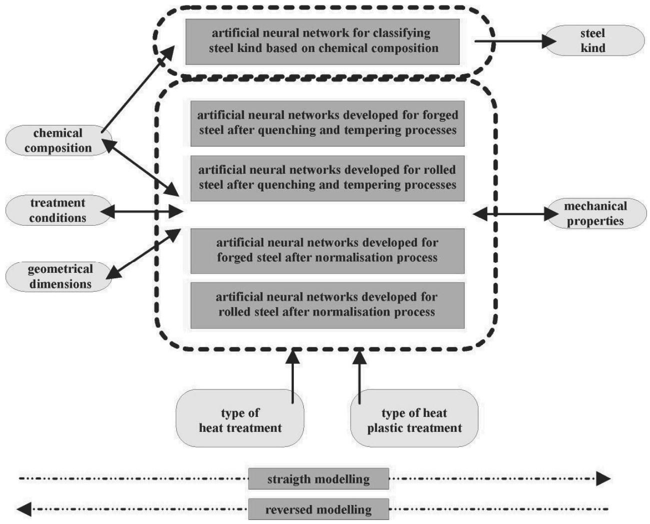


Fig. 2. Block diagram of dependence model in structural steels constructed by using the artificial neural networks binding together the concentration of chemical elements, conditions of plastic and heat treatment, geometry and mechanical properties of steel products [7,10-11]

2.1. Artificial neural networks

The neural network is described as, modelled on the basic mechanisms of action of the human brain, information processing system, in which the ability to learn and simultaneous processing of information and knowledge generalization was implemented. Often in the literature can be found a description of the neural network is a collection of interconnected elements called neurons. Most relevant and most frequently used in technical publications, is the definition, that the artificial neural network is the common name of mathematical algorithms and their software or hardware models, performing calculations or parallel processing of signals through the rows of elements, which are performing the basic operation of signal processing [12-14].

Artificial neural networks are very effective as a computational tool to solve such tasks with which other software cannot handle. This is because neural networks in comparison to other computing systems have two advantages. Firstly, calculations performed with use of artificial neural networks are performed parallel and so the speed of neural networks can significantly exceed the speed of sequential computation. The second advantage is the ability to obtain a solution without the step of constructing an algorithm (which in sequential computation is necessary in solving the problem). Neural network always operates as a whole and all its elements are contributing to the implementation of all actions that the neural network performs. One of the consequences of such action is its ability to function properly even after damaged a large part of its component elements. The current tendency for wider use of artificial neural networks leads to the formation of increasingly sophisticated and intelligent computer-aided engineering systems. Based on artificial intelligence software is increasingly applied in practice and a wealth of ideas for combining different methods is limited only to human ingenuity and computational powers of computers (Fig. 3.). This demonstrates the great interest of researchers and the further dynamic development of intelligent systems [14-15,37].

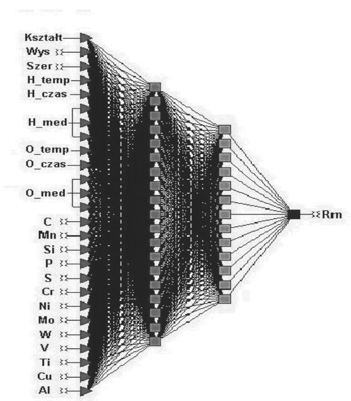


Fig. 3. Architecture of artificial neural network steel, four-layer perceptron 22:26-16-13-1:1 used for obtainment of tensile strength of quenched and tempered structural steel [11]

The development of neural networks is not everything. Construction of a model based on artificial neural networks also requires the development of the whole system, which will make full use of their capabilities. Thus developed the system should meet several conditions that cooperation with the user software ran smoothly. In particular, the system should be resistant to environmental influences and should be user-friendly. Therefore, the concept of building a computer system is inextricably linked to the concept of software engineering.

2.2. Software engineering

Software engineering is a field of engineering, which aims to build cost-effective computer systems. Software is abstract and elusive. There are no restrictions on materials, not subject to the laws of physics or industrial regimes. Software Engineering is the discipline of engineering, which covers all aspects of software development from the initial phase of the system specification to its care after the date of usage commencement. Software engineering covers not only the technical process of software development, but also activities such as programming project management, abstract thinking, developing tools, methods and theories supporting the creation and subsequent use of the software. Software engineers are involved in developing of software products, those products can be sold to customers and those tasks is to meet the relevant technical, economic or social needs [16-18].

Many people equate the concept of software with computer programs that are installed on the computers disks. In fact, it is too narrow look. The software is not only programs but also all the associated documentation, configuration data and additional data (metadata) that are necessary for the proper operation of these programs. The term software also includes scripts, networking systems installed on servers and providing services remotely via the Internet or local network. The computer system usually consists of several separate programs, configuration files, databases, and other elements related logically to each other and which working together serving to achieve a particular purpose (Fig. 4.). Cannot forget about system documentation, which describes the structure of the system, the user documentation that explains how to use this system as well as Web sites from which users can access the system online [16-19].

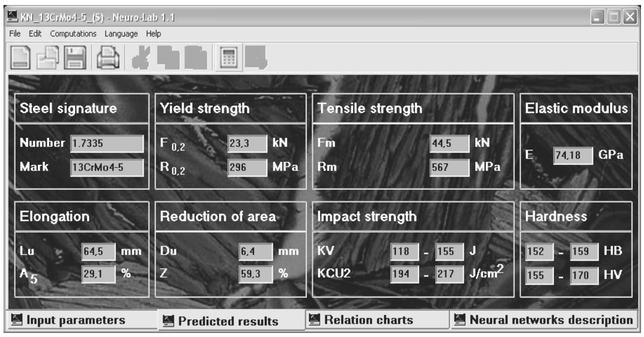


Fig. 4. Neuro-Lab - an intelligent system for predicting the mechanical properties of structural steels [19]

2.3. Cybernetics

Cybernetics in a special way contributed to the spread of abstract thinking in technology. Engineers, developers first build a theoretical model based on feedback and information flows between the elements of the scheme, and only then proceed to the experiments. More and more experiments are transferred from real environment to artificial environment, built by computer simulation.

In cybernetics, the method of abstraction is quite commonly used. This method is contrasted with the so-called logical-mathematical formalization. Using the method of abstraction consists in defining the system in a formal approach. Defined are artificial concepts and idealized objects, which are referred as abstracts. Because of these operations, isomorphic image of reality (of the analyzed problem) is created. Cybernetics allows organization examination of the specific system in three different ways:

- examines the impact of a single element onto another within the system,
- analyze the structure of event sets and check what are their relationship with the environment,
- defines the invariants of processes in the system.

Cybernetics understands the system as collection of interconnected elements interacting to achieve the objective. The information system in terms of cybernetic is an open system separate from the environment. It is a living system, which has the ability to exchange resources with the environment. In all cybernetically analyzed systems factors exists input and output processes that support the exchange with the environment. Any cybernetic system has two subsystems called the effector and the receptor.

Effector is responsible for the interaction of the system on the environment. As an example, it can be show the printer deriving data from the system to the environment in the form of printed report. Receptor is responsible for receiving signals from the environment, such as reading data from files loaded into the system or acquisition of data entered through various forms.

Environment interacts with the system corrupting his action. Through its action, environment leads to destruction of the system. Open system activates defence mechanisms against destructive action of the environment. A system that will defend themselves from attack and survive is in state of dynamic equilibrium. Achieving this state of existence is an objective for open system. With regard to software engineering, a system can be considered as being at steady state when the user (human or another system) as part of the environment through its action on the system, for example by working with the application will not be able to cause the malfunction or crash (destruction) of the system. Obtaining a steady state (operational stability) of software is crucial at the stage of its design. Software that is not at steady state is not able to cooperate correctly with the environment, and therefore is not able to function as intended [20-21].

2.4. User-friendly systems

A stable system is designed taking into account the assumptions and preferences of target users are defined as user-friendly systems. These systems for several years determine the direction of hardware and software development for mass-users. This results from the need to break down the barriers that prevent the use of computers for users in areas without knowledge and abilities in the field of software engineering (Fig. 5.). Abstract concepts are being replaced by computer graphic representations borrowed from classical office environment. These results from concept to refer to the natural predisposition humans and human experience gained from the traditional areas of activity. Especially important is to get the impression that the user controls the system and not vice versa. To ensure this several conditions must be fulfilled:

- commands issued by a user must invoke the desired and direct effect of system response, which allows to work in an intuitive and spontaneous, rather than mnemonic and learned way,
- the system should not in any way restrict the user. He should be able to use any of the available functions in an arbitrary time,
- the structure of the program should be protected from the destructive action of the user (intentional and unintentional). He should not feel that his inappropriate actions may cause any damage to the system,
- operations performed by the system should naturally arise from the current situation, the possibility of using the wrong tools should be eliminated,
- the creation of special modes, in which the user's functionality will be limited or extended in an unnatural way, should be avoided
- all operator activities should be performed in the same way. Operating the system should be possible both from the keyboard and from the mouse (depending on user preference) and should have the same functionality in both cases.

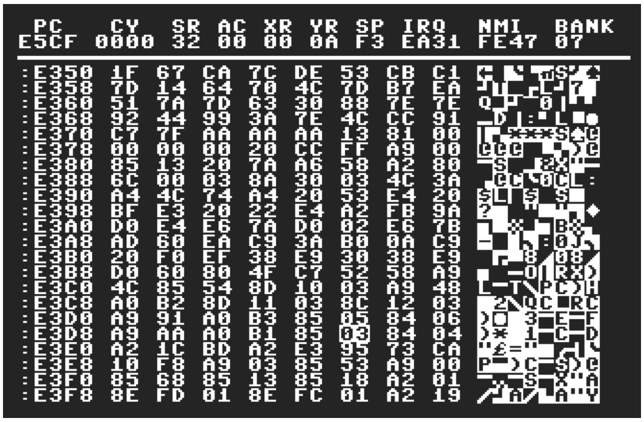


Fig. 5. Text interface of RAM memory monitor understandable only to advanced programmers

Operating systems with an integrated graphical user interface make it easy to build this type of software. To maximize the benefits of this combination integrated development environments were created. These are computer systems, which are supporting the software development at each of its level. The fact that these environments have been also designed as user-friendly creates new work possibilities even for users' unfamiliar with software engineering.

The production also simplifies development of high-level programming languages based on natural language. This has eliminated the use of obscure processor assembler codes. For several years, the leader is the C++ language. In this language most of the software available on the market is created. This language is easy to read and understand for humans, because it is based on the syntax of the English language. Programs written in that language can easily o under different operating systems [16-18, 22].

In the early sixties of last century, researches on increasing the efficiency of human intellectual activities were performed. One aspect of these studies was the human-machine interaction. The novel assumption was formulated, that since the purpose of human-computer interaction is to increase human capacity, the human, not a machine, should be the central point of the system.

This has resulted in innovation, without which the present work with information systems seems to be impossible. A mouse was constructed, so the dialogue is done by the operator by indicating the objects representing commands on the screen rather than by typing these commands from the keyboard.

In addition, the concept of modular operating systems was proposed, which has unified the basic input / output operations, which consolidated the way of communication with different programs and further simplify their creation. The first experimental computer system, for which the user-friendly software was designed, was Alto system produced in 1973 by Xerox (Fig. 6.). Although no one was planning the mass production, the system not to leave the assembly lines for the next decade.

a) b)

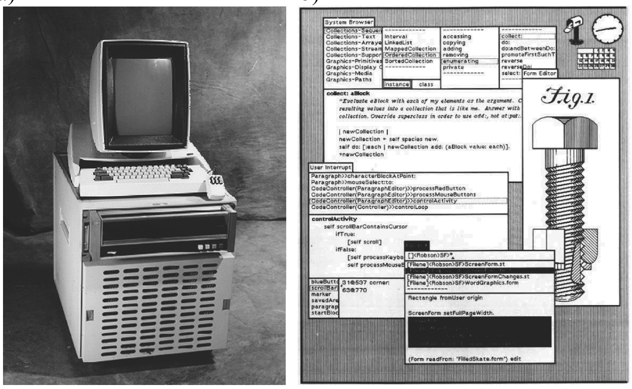


Fig. 6. Xerox Alto (1973), a) complete system, b) graphic user interface [38]

The spectacular success of this system led to no less dynamic development of the software. A number of packages, mainly for editing and formatting text, graphics creation and transmission of information over the network were created. At that time four key principles of user-friendly software, which are applicable to this day have established:

- selecting and pointing instead of remembering and writing
- graduation of information for the user by hiding the complexity of the system (shown only those options that are applicable at the moment)
- consistency and uniformity of service throughout the operation of the system (once someone understands the basic structure of the machine can work without looking to manuals)
- what the user sees on the screen is what the user gets in the final printed document. (can not be differences between the information presented in the system, and transferred outside the system) [22-23].

The project of a modern information system should include all aspects covered by the user-friendly software model. This inevitably affects on the utility value of the proposed system. All these elements are so important that absence a single of them can cause, that the system will be useless. This is particularly evident in the case of utility applications, where excellent tools are often rejected by users because of the complicated, unintuitive or overly extensive functionality resulting in confusion in the jungle of incomprehensible options [16,22].

Software Engineering also produces e-learning systems. These should primarily meet the conditions for user-friendliness, because poorly designed system supporting distance learning drastically reduces the effectiveness of teaching carried out by the use of the electronic media [24-25].

3. Models of engineering materials

E-learning is a new teaching technique independent of time and place, carried out using modern information technology and the communications using electronic media such as Internet, satellite broadcasts, audio/video recordings, CD-ROMs and electronic books. E-learning most often takes the form of teaching with use of computer in which is no physical contact between students and the teacher. Therefore, this form of learning is also known as distance learning. E-learning is an example of computer-aided teaching processes. For the implementation, only a personal computer with an Internet connection is required. That allows the study without the need of personal presence in classroom at university.

E-learning is the opposite of the traditional learning, which is known from academic everyday life, and which consists in the skills on communication and relationships between students and teacher, on clarity in content transfer, but also on monitoring of the individual work of students. Traditional teaching can be a process, which takes place in a particular place at a particular time with the applicable rules in classrooms of the university that realizes this course. E-learning, in comparison with traditional teaching, may be regarded as a supplement to traditional learning methods, extending it with new content or as a substitute for all or parts of courses performed traditionally (Fig. 7.).

E-learning can be implemented in many different ways. Due to the time classes can be perform in synchronous mode via appropriate messaging system, which allows real-time contact between the teacher and the other students (teaching online), and in asynchronous mode, with the use of audio-visual recordings, e-books, etc (teaching offline) [25-27].

Fig. 7. Futuristic vision of computerised student activities

3.1. E-learning platform

Distance learning is possible to implement due to a complex, though usually friendly to the user, an information system and called e-learning platform. Distance learning platform is a virtual work environment, enabling the distribution and management of e-courses and their users. To meet the growing interest in distance education at the Institute of Engineering Materials and Biomaterials, Silesian University of Technology, launched in October 2004 E-learning platform based on Moodle project (Fig. 8.) [39]. It offers to university students and staff the access to electronic teaching materials, which supports classes in the traditional manner. It is also a basis for e-learning courses in the field of materials science engineering carried out in the institute [26-27].

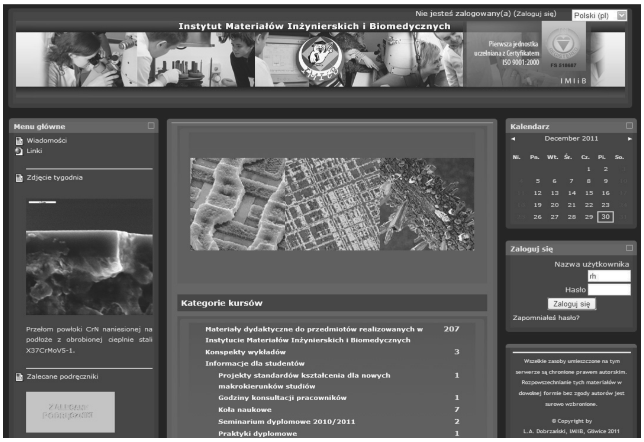


Fig. 8. E-learning platform of the Institute of Engineering Materials and Biomaterials [27,39]

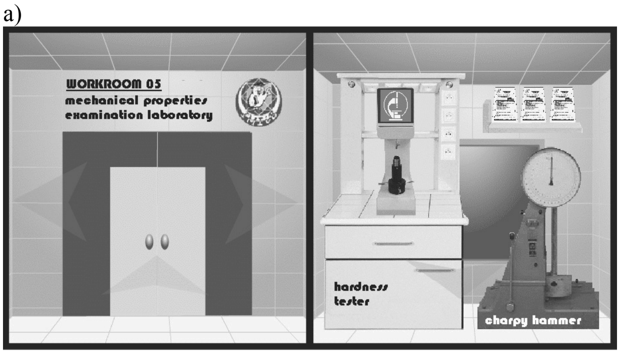
3.2. Virtual laboratory

Virtual Laboratory is located in virtual reality collection of simulators and trainers, whose main objective is to simulate the real work of research equipment placed in real research laboratories. Apart from these, user will find instructions for operating real and virtual investigative equipment, descriptions of training experiments possible to execute and many other education materials supporting the cognitive processes of research methodology. Virtual laboratory is among others a training environment for young staff and students, which are just starting to work with the given device type. They can acquire basic skills and routines to operate the device without fear of damage to expensive equipment or causing danger to life or health of their own and other users present in the laboratory. Improper handling of simulated device ends only with the simulated malfunction or damage visible only on the monitor screen. Then the user simply resets the simulation to the initial state and repeats the experiment with the introduced appropriate parameters [28-31].

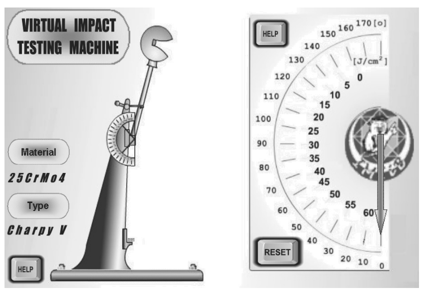
Very important is the economic aspect. Virtual laboratory is extremely cheap to maintain and operate. Beyond launch costs, which are the preparation of necessary computer system simulation and implementation of virtual machines with the necessary materials to support them, the only costs are the costs of system maintenance during operation. There is no need to have any samples of prepared material or other supplies, sometimes very expensive, technical inspection of simulated equipment are not necessary, any damage can be eliminated by resetting the simulation to its initial state. According to results of researches conducted in academic scientific centres possibility of performing the experiment at home without lecturer have a positive effect on the student. He does not feel helpless in the laboratory practise and does not make as many mistakes as a student familiar only with theoretical descriptions of machines and having a first contact with the device only in the classroom under the guidance of the instructor [31-33].

These problems are also related with the scientific work undertaken in the Department of Materials Processing Technology, Management and Computer Techniques in Materials of the Institute of Engineering Materials and Biomaterials. In the year 2009 a Materials science virtual laboratory was opened for institute's staff and students (Fig. 9.) [40]. its primary aim is results visualisation of investigations, simulations and predictions made by utilisation of materials numerical models in virtual environment only. Laboratory's secondary aim is to acquaint students and young scientific staff with investigation methodology in wide range of material science. In virtual workrooms simulations of investigative equipment, such as light and electron microscope, hardness tester or Charpy hammer, is placed. The main concept of virtual laboratory is to replace real machines with their virtual simulations. To access the laboratory, a PC class computer with connection to internet is required. Materials science virtual laboratory runs under control of operational system with graphic user interface, such as Windows or Linux in internet browser with Adobe Flash plug-in [25,27-28,31-33,39-40].

a)



b)



c)

Fig. 9. Material science virtual laboratory [28,40], a) mechanical properties examination laboratory, b) virtual impact testing machine, c) virtual hardness tester

4. Summary

The rapid development of information technology has caused, that computers capable of many ways to process huge amounts of data have become the devices of general application, not only in technical sciences. Currently it is hard to imagine functioning of agencies, offices and institutions without computers. Design and development workshops are full of computers used to design machines, buildings, vehicles, etc. Specialized software helps id design and the selection of materials from which surrounding us products are made.

Computers thanks to information technology are armed in appropriate educational software is one of the most interesting teaching aids, which give great opportunities. With the participation of computers, information platforms are created and published. This enables the instant access to all information. No other teaching device allows the user to view the content of the scientific analysis of physical phenomena, exercise and work in virtual space, and many other activities in such a dimension and time as the computer. Thanks to this new generation of engineers are better educated and better prepared to deals with, waiting for them, occupation problems.

References

[1] L.A. Dobrzański, Engineering Materials and materials design. Fundamentals of materials science and physical metallurgy, WNT, Warsaw-Gliwice, 2006 (in Polish).

[2] L.A. Dobrzański. Fundamentals of material design methodology, Silesian University of Technology Publishing, Gliwice, 2009 (in Polish).

[3] L.A. Dobrzański, Introduction to material science, Silesian University of Technology Publishing, Gliwice, 2007 (in Polish).

[4] J. Adamczyk, Theoretical metallurgy Part.1, Structure of metals and alloys, Silesian University of Technology Publishing, Gliwice, 1997 (in Polish).

[5] M.W. Grabski, The essence of engineering materials, Warsaw University of Technology Publishing, Warsaw, 2006 (in Polish).

[6] M.F. Ashby, Materials selection in engineering design, WNT, Warsaw, 1998.

[7] L.A. Dobrzański, R. Honysz, Artificial intelligence and virtual environment application for materials design methodology, Archives of Materials Science and Engineering 45/2 (2010) 69-94.

[8] N. Roberts (Ed.), Introduction to computer simulation: a system dynamics modelling approach, Prentice Hall PTR, 1996.

[9] S. Robinson, Simulation: the practice of model development and use, John Wiley & Sons, Chichester, 2004.

[10] L.A. Dobrzański, R. Honysz, Application of artificial neural networks in modelling of normalised structural steels mechanical properties, Journal of Achievements in Materials and Manufacturing Engineering 32/1 (2009) 37-45.

[11] L.A. Dobrzański, R. Honysz, Application of artificial neural networks in modelling of quenched and tempered structural steels mechanical properties, Journal of Achievements in Materials and Manufacturing Engineering 40/1 (2010) 50-57.

[12] T. Masters, Neural networks in practice, PWN, Warsaw, 1996.

[13] D. Rutkowska, M. Pilinski, L. Rutkowski, Neural networks, genetic algorithms and fuzzy systems, PWN, Warsaw, 1996 (in Polish).

[14] S. Haykin (Ed.), New directions in statistical signal processing: from systems to brain, The MIT Press, Cambridge, 2007.

[15] R. Tadeusiewicz, Elementary introduction to neural network techniques with examples programs, Academic Publishing House PLJ, Warsaw, 1998 (in Polish).

[16] B.D. Paul, Information Systems Engineering, WNT, Warsaw, 2004.

[17] I. Sommerville, Software Engineering, WNT, Warsaw, 2003.

[18] S. Szejko, Methods for software development, Mikom, Warsaw, 2002.

[19] L.A. Dobrzański, R. Honysz, Computer modelling system of the chemical composition and treatment parameters influence on mechanical properties of structural steels, Journal of Achievements in Materials and Manufacturing Engineering 35/2 (2009) 138-145.

[20] N. Wiener, Cybernetics, which is control and communication in the animal and the machine, PWN, Warsaw, 1971.

[21] N. Wiener, Cybernetics and Society, KIW, Warsaw, 1960.

[22] X. Almán Rodlán (Ed.), C++ visual programming, Multimedia Ediciones, Warsaw, 2000.

[23] G.J. Myers, Design of reliable software, WNT, Warsaw, 1990.

[24] B. Siemieniecki, The computer in education, Fundamental problems of in information technology, Adam Marszałek Publishing, Toruń, 2002.

[25] L.A. Dobrzański, R. Honysz, The significance of multimedia didactic aids in the informative society, Archives of Materials Science and Engineering 32/2 (2008) 117-120.

[26] D. Barraya, P. Burnett, G. Boulton-Levis, J. Campbell, Classroom learning environments and students' approaches to learning, Learning Environments Research 2/2 (1999) 137-156.

[27] L.A. Dobrzański, R. Honysz, Z. Brytan, Application of interactive course management system in distance learning of material science, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 429-432.

[28] R. Honysz, Materials design methodology with use of materials science virtual laboratory, PhD thesis, Institute of Engineering Materials and Biomaterials, Silesian University of Technology 2010 (in Polish).

[29] L.A. Dobrzański, M. Kowalski, J. Madejski, Methodology of the mechanical properties prediction for the metallurgical products from the engineering steels using the artificial intelligence methods, Journal of Materials Processing Technology 164-165 (2005) 1500-1509.

[30] L.A. Dobrzański, R. Honysz, Building methodology of virtual laboratory posts for materials science virtual laboratory purposes, Archives of Materials Science and Engineering 28/1 (2007) 695-700.

[31] J. GutenbaumMathematical systems' modelling, Exit, Gliwice 2003 (in Polish).

[32] K. Stec, Computer simulation as an aid tool in the theoretical electrical engineering laboratory, Computer Application in Electrical Engineering, Poznań-Kiekrz, 1996, 398-399.

[33] W.B. Lee, C.F. Cheung, J.G. Li, Applications of virtual manufacturing in materials processing, Journal of Materials Processing Technology 113, 416-423, 2001.
[34] http://www.issb.co.uk/ - Iron and Steel Statistics Bureau.
[35] http://www.steel.keytometals.com/ - The world's most comprehensive knowledge base of steel.
[36] http://www.worldsteel.org - World Steel Association.
[37] http://www.neuralnets.eu/ - Polish vortal of artificial intelligence.
[38] http://www.britannica.com/ - Encyclopedia Britannica.
[39] http://www.platforma.imiib.polsl.pl/ - E-learning platform of Institute of Engineering Materials And Biomaterials.
[40] http://www.vlab.imiib.polsl.pl/ - Materials Science Virtual Laboratory of Institute of Engineering Materials And Biomaterials.