NEW WELDING INFORMATION SYSTEM ON THE INTERNET(PREDICTION OF THE PROPERTIES OF WELD HEAT-AFFECTED ZONES) (http://inaba.nims.go.jp/Weld/)

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ABSTRACT

To promote continuous transfer and development of welding technology, a new system for predicting the microstructures and mechanical properties of welded joins has been built on the Internet. It combines a database system containing continuous cooling transformation diagrams (CCT diagrams) for welding and an expert system for computing weld thermal histories. In addition, this system employs a technique which was invented during the development of another distributed database system called "Data-Free-Way" , which was designed to contain information on advanced nuclear materials and materials obtained from other programs of welding research at NIMS in the past. This paper describes the current state of our new system for computing weld thermal histories to predict the properties of welded joints using the CCT diagrams database, which is now available on the Internet. Some problems encountered with the database used in such a system are also referred to.

Keyword: Welding, Online Simulator, CCT diagram, Database, Internet

1 INTRODUCTION

In recent years, rapid advances have been made in the field of information processing technology using networks and computers. This progress has enabled anyone to disseminate valuable information via the Internet and thus play an active role in his field. In the technical field of welding, the systematic organization of theories and past experiences into a database system and the availability of such a system to the public on the Internet can undoubtedly promote the continuous transfer and development of welding technology. Many theoretical and technical reports on simulating welding have appeared since the theory of heat conduction was proposed by Rosenthal (1941). Many international conferences (See for example Cerjak and Bhadeshia (2002)) are held today to discuss simulating welding. Welding research and commercial companies have also already distributed many software packages such as MAP (Bhadeshia, 2000) and Quick-Welder (RCCM, n.d) or SYSWELD (ESI, n.d). Moreover, other sites on virtual welding have been published on the Internet by Ohotani (1999), Babu (2000), and Yurioka (2001). However, breakthroughs on how to store and retrieve data and express results are necessary for the realization of this useful system. In the near future, the integration of these sites will be necessary.

The National Institute for Materials Science (NIMS) has been constructing a new system to predict the micro-structures and mechanical properties of weld heat-affected zones (HAZ) (Okada, Kasugai, & Hiraoka, 1988) which combines a database system of continuous cooling transformation diagrams (CCT diagrams) for welding (Kasugai & Fujita, 2000) and an expert system for computing weld thermal histories on the Internet (Fujita, 1997). In addition, this system employs a technique which was invented while developing another distributed database system called “Data-Free-Way” (Fujita, Kurihara, Shindo, Yokoyama, Tachi, & Iwata, 1997) for advanced nuclear materials and materials obtained from other past programs of welding research at NIMS.

This paper describes the current state of our new system for predicting the properties of weld HAZs, which is now available on the Internet. Some problems encountered with the database of such a system are also presented.

2 THE GENERAL CONCEPT BEHIND AN INFORMATION SYSTEM FOR WELDING PROCEDURES

Generally speaking, any welding procedure needs information about the following: the material to be welded (base metal), the geometry of the joint (how to prepare its edges), the welding process, welding consumables, and procedural parameters such as the weld heat input and conditions before and after the weld heat treatment.

In order to make sound welds, the following issues must be addressed as well: whether hydrogen caused cracks in the weld; the extent of the residual stresses and martensitic structures, and needless to say, the joints' performance, including the mechanical properties of the joint, must be predicted in advance.

Due to these special requirements of the welding procedure, any designed system should be able to answer as many of these questions as quickly and as accurately as possible. Such a system may be a combination of several sub-systems, i.e., a database containing the data on welding procedures, a knowledge base of past empirical data, and an expert system for calculating heat flows, and thermal experiences during welding.

Last, but not least, attention should be focused on the fact that, even though great advances in the field of database technology are expected in the near future, only a very limited amount of empirical information can be stored and retrieved. Thus, as referred to elsewhere and if possible, it would be desirable to prepare a function for conducting remote operations.

3 SYSTEM FOR PREDICTING THE PROPERTIES OF WELDED HAZ

3.1 Outline

Figure 1 shows a schematic representation of our distributed database system DFW for materials information on the Internet. A new sub-system for predicting weld HAZ properties was added to old DFW system.

The new system is a substantially updated version of the prototype by Okada *et al*. (1988), which was only operated on a personal computer and consisted mainly of two parts.

One component is the database, the majority of which is filled with factual information obtained at NRIM in the past, while the remainder contains bibliographic information collected from various places around the world. Not only does the database store information in the form of alpha-numeric data but it also stores information in the form of diagrams or photographs. Users can retrieve and print this information, and the hard copy differs little from that displayed on monitors at present. Nevertheless, because of the difficulties of representing all the steps of a welding procedure in a still photograph, it may be necessary to store this information in the form of moving pictures with audio in future. Such a sub-system, as well as the hardware for it, is currently being prepared by our group. Most of the stored information are CCT diagrams of welding steels, which show transformation diagrams, the temperature graphs and the metallographic changes of weld HAZs during cooling from 1623 K (just below the melting temperatures of steels) under different rates of cooling, as well as the resulting hardness and constitution of the micro-structures. The database stores all starting temperature transformation curves in numerical values as well. The advantage of storing data as numerical values is their efficient use and expression throughout the system. However, in the current system, the data in this CCT diagram database and the Weld thermal history simulator presented later are not linked directly yet. The best way of storing data may need further consideration.

The other component of the information system is an expert system for simulating the temperature distributions around the area being welded. Hereafter, this system is referred to as "Weld thermal history simulator".

Users who have to make a final decision on each procedural parameter often need more detailed and concrete information than that retrieved from the database. To meet such needs, these are some pre-prepared functions for carrying out remote experiments or remote maintenance in the current system.

The whole system can be used anywhere in the world whereever an Internet Browser (Netscape, Explorer, etc.) is available. Figure 2 outlines this system and provides a guide to accessing the CCT diagram database, the Weld thermal history simulator, and the animated tutorial program for beginners.

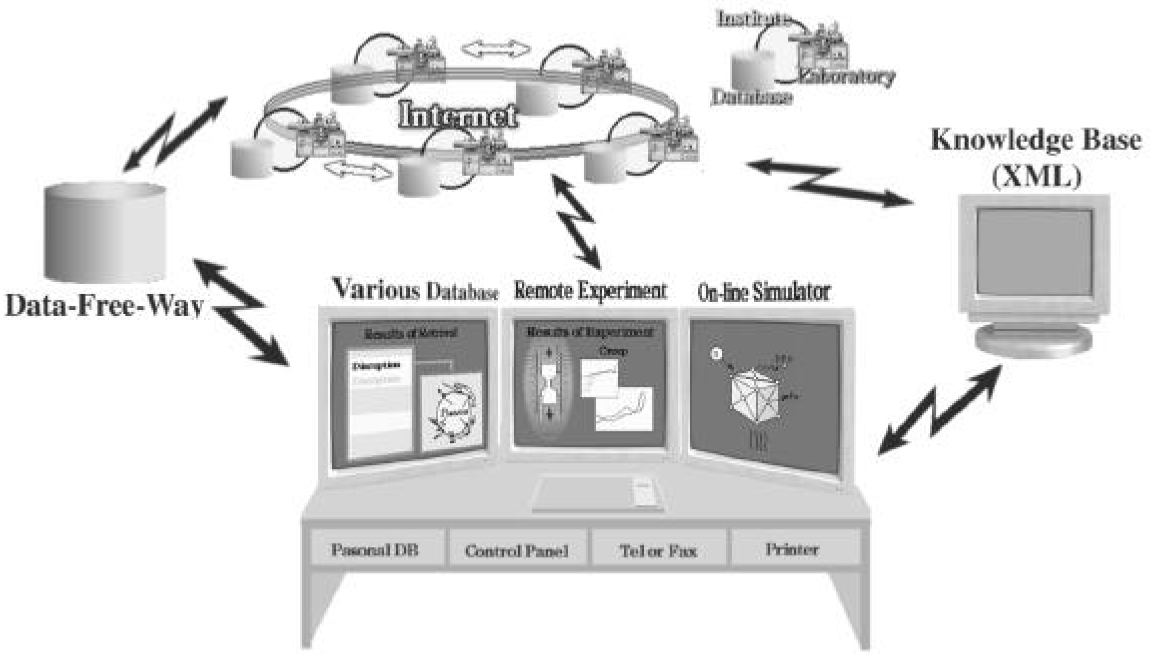


Figure 1. Schematic representation of a materials information system.

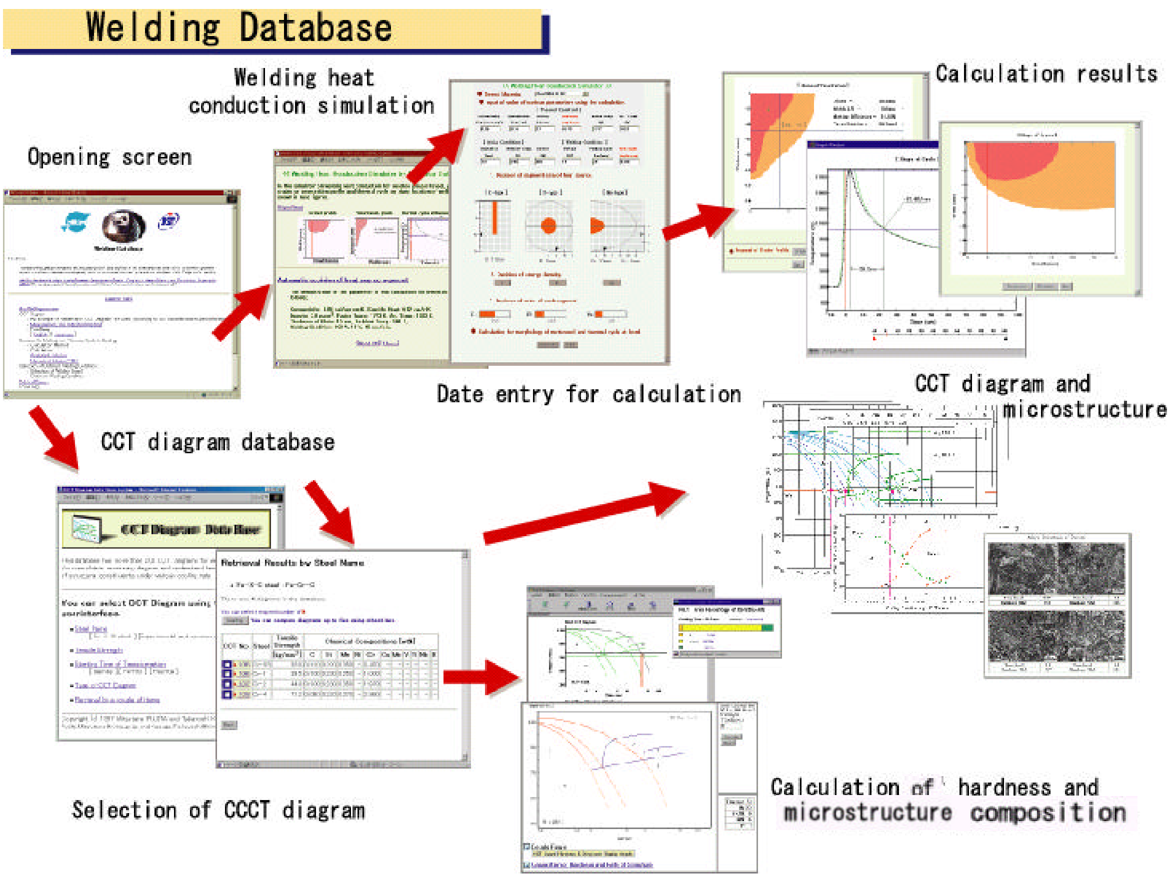


Figure 2. Outline of the heat-conduction simulation for determining the properties of welded HAZ.

3.2 THE CCT Diagram Database

3.2.1 Outline

To utilize the CCT diagrams via the Internet, ORACLE tools which allow the development of Web-enabled systems used to manage the data. They are retrieved by accessing the Web through an Internet browser. This operation is done by clicking the mouse or hitting digit keys. On screen instructions make this operation easy. One feature of the database is that it can link the stored data with image files or other programs outside the database such as the Weld thermal history simulator.

3.2.2 Stored data and their structures

The data stored includes the chemical composition and mechanical properties of the steel, its CCT diagram, which shows the change in the HAZ's hardness, changes in its micro-structural constitution with cooling time, photo-micrographs of the HAZ, data directly and indirectly associated with any CCT behavior of the steel, in the form of numerical values & characters.

Figure 3 explains these structures. The table for the forms of steels produced consists of the product ID, its proper, popular, or technical name, its name after processing, its chemical composition, and its mechanical properties. While the table for cooling time and HAZ hardness contains its product ID and the critical (shortest) cooling time values necessary for the steel's phase transformations. The database stores the CCT diagrams and the attached graphs that show the changes in the HAZ's hardness and microstructure with cooling time in two data forms, i.e., as graphical and numerical data. As mentioned before, experts in welding would be relatively familiar with these images. On the other hand, needless to say, numerical data are suitable for devising experimental formulas on the HAZ hardness or ratio of micro-structural constitutions versus cooling time. Thus, quantitative information about HAZ properties can be readily obtained in advance of the welding procedure by substituting the predicted cooling time into these formulas.

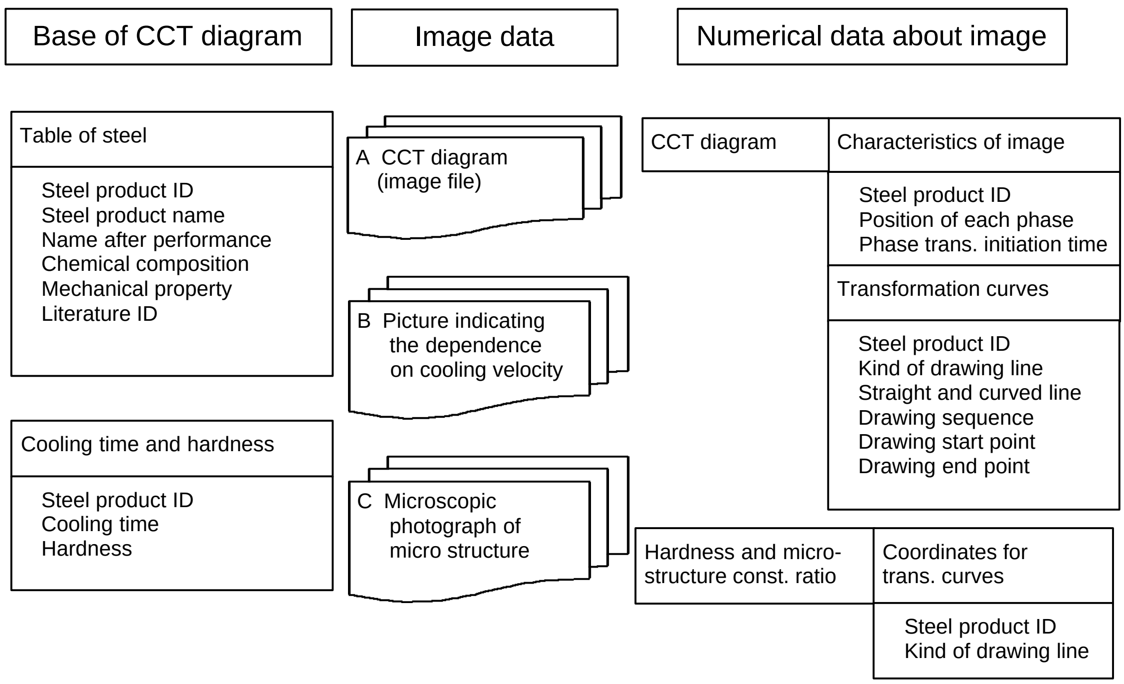


Figure 3. Data structure of a CCT diagram database

3.2.3 Retrieval representations

Parameters used for retrieving CCT diagrams can include the name of the steel to be retrieved, its properties, application, chemical composition, micro-structure, and, in some cases, the morphology of the phase transformation and its rate. Moreover, as a preliminary retrieval step in the current CCT diagram database, several CCT diagrams, which are presumed to meet the user's requirements, are listed by inputting some of these items, measures, or parameters. Here, the morphology of the transformation and its above-mentioned rate are substituted briefly by the type (shape) of the CCT diagram and the critical cooling time at which the transformations starts. Then, the user finally selects the most appropriate one to be displayed from those retrieved initially.

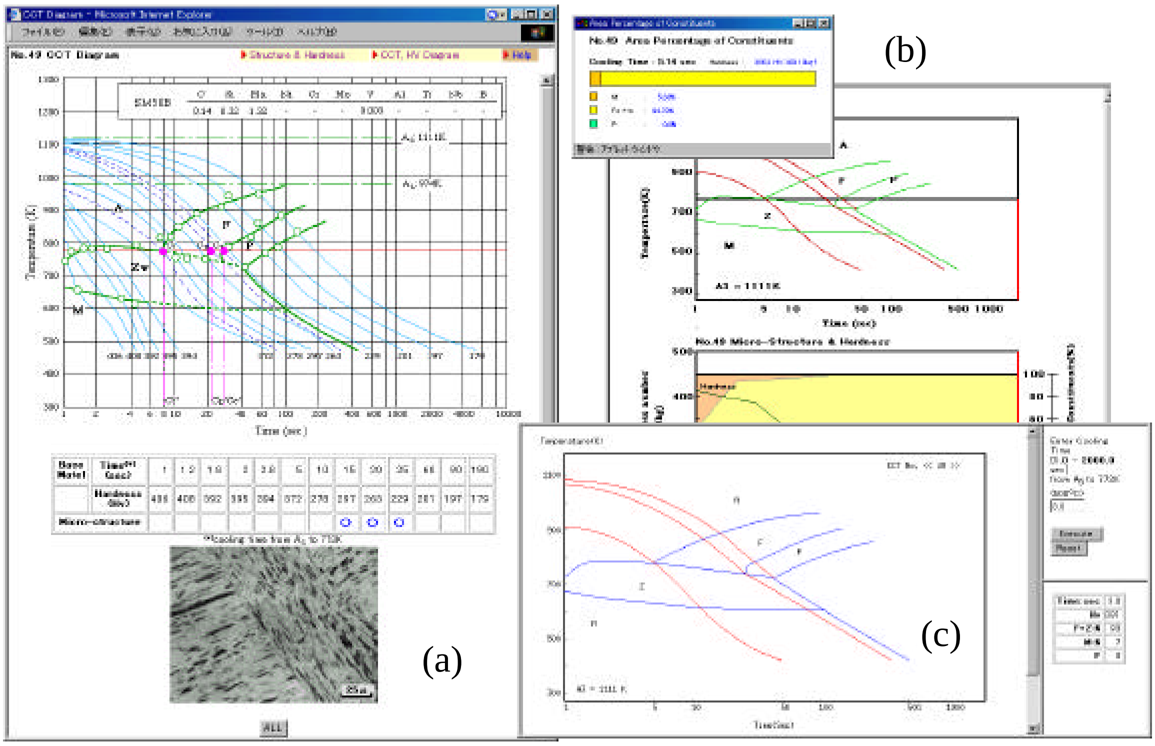


Figure 4. An example of the retrieval results from the CCT diagram database. (a) the original CCT diagram expressed as graphical data (b) the diagram recomposed interactively from numerical data and (c) another representation of the retrieved numerical data.

An example of CCT diagram retrieval results are shown in Figure 4. (a) is the original CCT diagram which graphically represent data for welding specialists with micro-photographs. (b) is the recomposed numerical data stored in the database. In order to express a CCT diagram more simply, only its essence is given here. Since such a re-composition only needs a limited amount of numerical data, this results in shortened retrieval times as well as reduced network loads. In addition, several CCT diagrams can be compared at the same time.Another attempt at representing the retrieval of numerical data was made using the JAVA language. An example of such a retrieval is shown in (c). This makes it possible to simultaneously express any numerical data such as the HAZ's hardness or micro-structural constitution for a specified rate of cooling. For HAZ micro-structures, the photographs can be displayed either singly or as a set.

3.3 Weld Thermal History Simulator

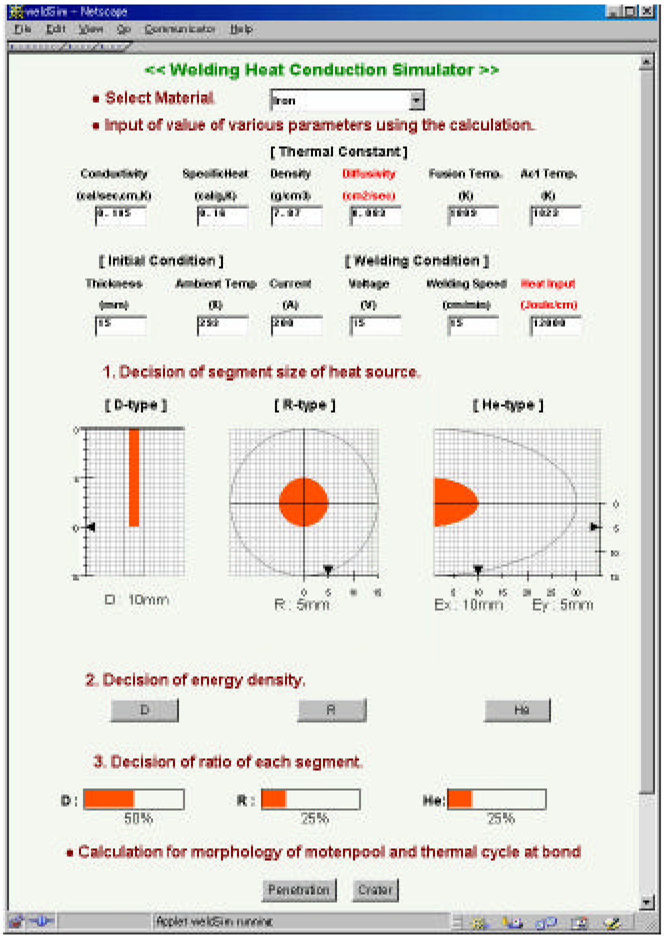
3.3.1 Inputting Data

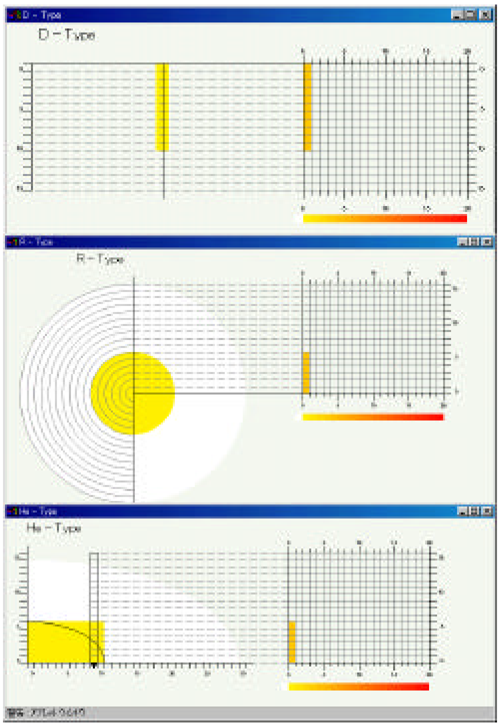
Computation of heat flows require data on thermal properties such as the thermal conductivity and the specific heat of materials. The melting temperatures and Ac1 transformation temperatures of steels are also necessary for computing the location of molten pools and weld HAZs, respectively. In addition, computations require welding procedure parameters such as the arc current, arc voltage, welding speed, preheat temperature, and thickness of the plate to be welded. Figure 5 shows the screen for inputting these data in to the current simulator. Most of the data are input by hitting keys. In addition, by operating his mouse, the user can select other information related to the heat source, such as its shape and energy density. Boxes that set the conditions and patterns that represent features of heat sources are laid out on screen for the easy input of data. However, the user of the system has to have some degree of expertise in welding to complete the inputting.

With a view to making a more usable database, especially for users who are not experts in welding, we are now collecting additional data on the heat sources applicable for different welding processes and welding conditions.

3.3.2 Computation Method

Numerical computations, necessary for simulating the transient or quasi-stationary distributions of





Screen to determine energy density of the heat source

Figure 5. Data input screen of the heat-conduction simulator with sample thermal properties of materials for a sample thermal cycle prediction.

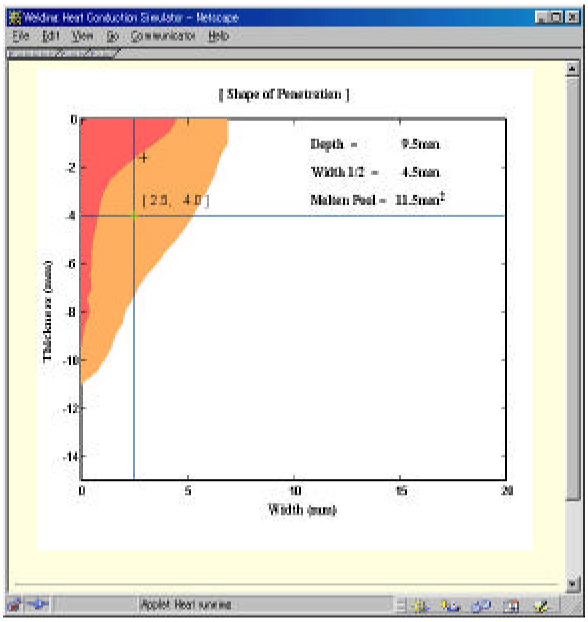


Figure 6. Shape of the molten pool and the HAZ.

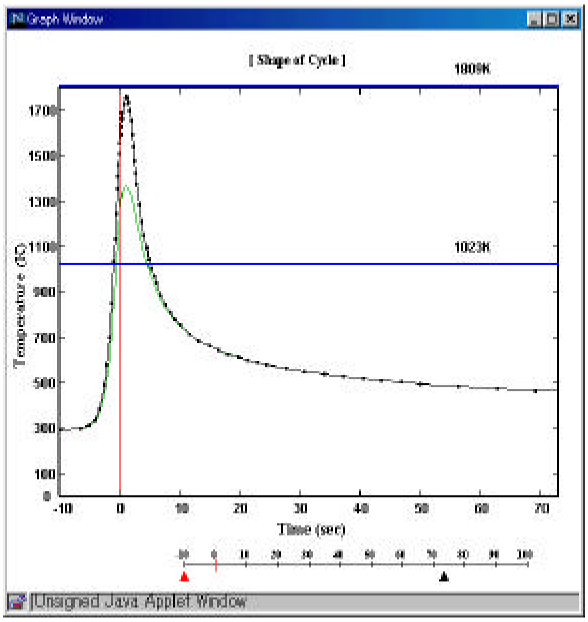


Figure 7. Thermal history curve at point + and at the crossed lines shown in Figure 6.

temperatures around the part being welded, start after the data described above has been inputted and after the button labelled "start computation" is pushed, using a program sent from the Web server. This program is written in the JAVA language. Thus, the computations are platform independent. They are executed by taking the most suitable values, or in some cases, by combining suitable ones from empirical equations reported in the past, from analytical solutions, or from an iterative finite difference method

3.3.3 Expression of computed results

The results of the computations are expressed as shown in Figures 6 and 7. Figure 6 shows the contour line of the melting temperature and that of the Ac1 temperature through a transverse (perpendicular to the weld centerline) cross-section of a weld, which gives the profile of a molten pool and HAZ, respectively. In Figure 7, the weld thermal history at point + in Figure 6 and at the point where two fine lines cross in the same figure are drawn as two curves in Figure 7. Inputting the coordinates of such points is achieved by pointing and clicking with the mouse. A slight but insignificant difference between the two is seen, especially around their peaks.

Needless to say, the HAZ's hardness and the micro-structures of a steel are a result of its thermal history during welding and its chemical composition. In practice, they depend on the time it takes to cool to 773K (500 ^{0}C) from the Ac3 transformation temperature. Every computed curve makes it possible to predict the HAZ's hardness and the micro-structures for each steel specified, as a matter of course. In brief, the CCT diagram database and Weld thermal history simulator makes it possible to predict the HAZ's hardness distribution for a given steel.

3.4 Prediction of Weld HAZ Properties

3.4.1 Flow of Prediction

The present system has a database subsystem in the computer to store data temporarily, according to the flow of calculation, as shown in Figure 8.

Selection of welding steel

↓

Input of welding conditions

↓

Calculation of cooling time from Ac1 to 773 K for every point at intervals of 1mm in the HAZ

↓

Retrieval of hardness corresponding to the time elapsed from the CCT diagram database

↓

Drawing the hardness map

Figure 8. Flow-chart for the prediction of weld HAZ properties.

First of all, we select a steel, whose chemical composition of which is the closest to that of the steel to be predicted. Then, we retrieve the CCT diagram of the selected steel. The retrieved CCT diagram and all the data associated with it are parsed that subsystem automatically. This data, includes a graph showing the changes in Vickers‘ hardness (load: 9.8 kN) and the change in the ratio of micro-structural constitutions (% area) with cooling time from the Ac3 transformation temperature to 773 K (500 ^{0}C). Figure 9 shows a typical example of such graphs. Experimental formulas for HAZ hardness and the ratio of micro-structural constitutions as a function of cooling time are also stored temporarily in that subsystem.

Secondly, the thermal properties of the selected steel and parameters of the welding procedure are input into the Weld thermal history simulator. Computations of cooling time are executed for the whole HAZ.

Finally, we get the contour lines of HAZ hardness by referring the computed cooling time at each point to the formula for HAZ hardness.

3.4.2 Hardness distribution map

Figure 10 shows an example of the contour lines of hardness through the transverse cross-section of a bead weld. In the figure, the white-washed and semi-elliptical zone is that of weld metal, with the HAZ outside it. Hardness is the highest just beside the weld’s bond line, and gradually reduces towards its base metal zone.

The reason for this is the nature of heat conduction, because the shorter the distance from the heat source the higher the peak temperature and the faster the cooling.

Thus, all the data retrieved here converges into a hardness distribution map. Usually, it takes a long time and much effort to produce such a map by processing measured data only. The present system of prediction, however, achieves the same purpose quickly and easily. In Figure 10, the map is divided into 1-mm squares. Smaller squares, which are available, allow for more detailed and precise information for predicting the geometry and properties of HAZs; this is helpful in checking for anything that’s been over looked and to make welded joints of higher quality. This subsystem for producing HAZ hardness distribution maps is a combination of the CCT diagram database subsystem and the Weld thermal history simulator. It is currently being updated to cater for a more diverse range of steel products and a more extensive range of welding procedure parameters. Before long, this third subsystem will be available to the public on the Internet. It is believed that the release of this system will contribute to the circulation of higher quality technical information. Another subsystem for producing HAZ micro-structural constituent distribution maps will also be available in the future.

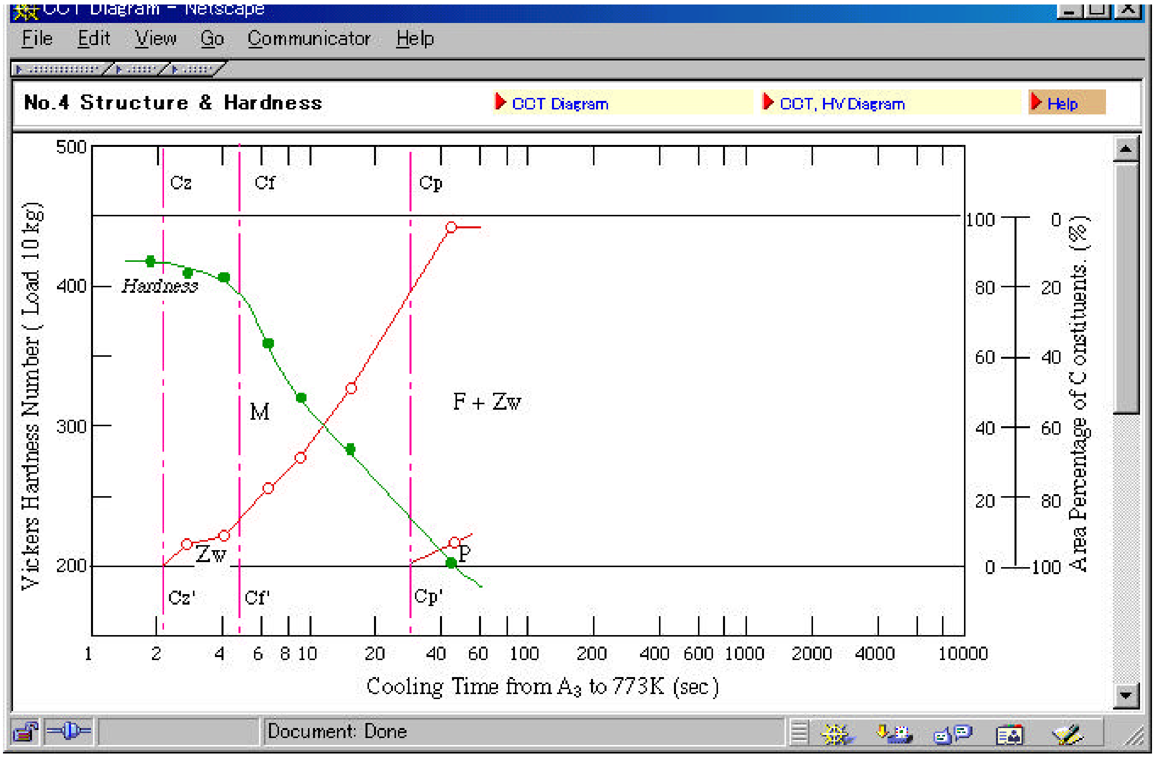


Figure 9. Changes in Vickers' hardness and the ratio of micro-structural constitutions with cooling time from the Ac_3 transformation temperature to 773 K.

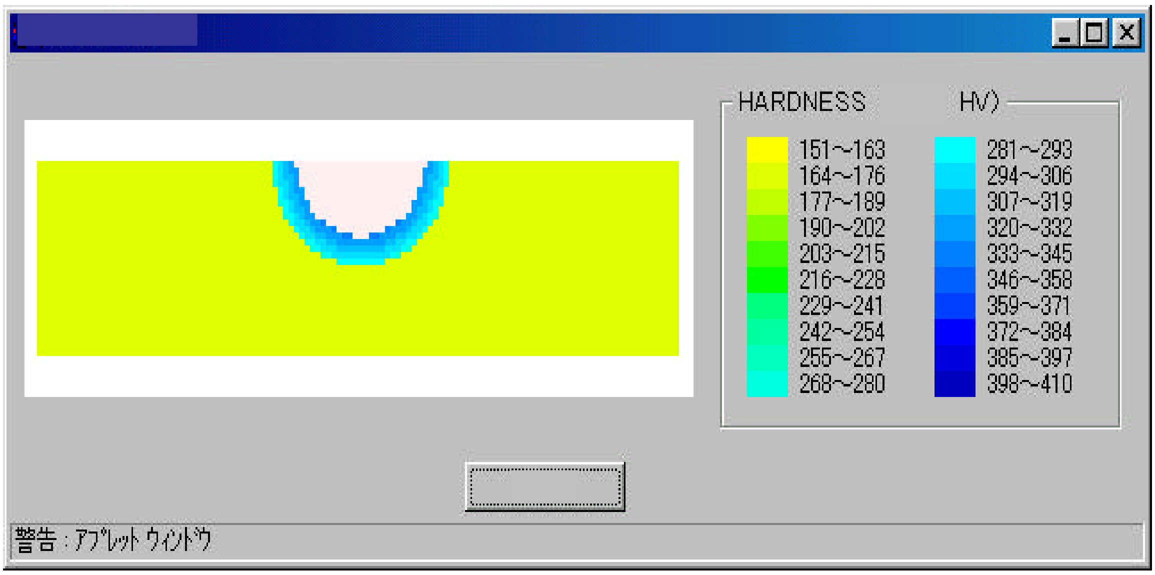


Figure 10. Contour lines of hardness through a cross-section of a weld.

4 CONCLUDING REMARKS

To achieve state-of-the-art welding, it is desirable to increase the mutual exchange of information between the fields of materials and welding. The new system presented in this paper represents such an effort. It combines a database system of continuous cooling transformation diagrams for welding and an expert system for computing weld thermal histories, both of which have been developed at the National Research Institute for Metals over several years.

5 ACKNOWLEGEMENTS

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6 REFERENCES

Bhadeshia, H. K. D. H., (1999) *Materials Algorithms Project Program & Data Library*, Retrieved June 7, 1999 from the Materials Algorithms Project Web site: http://www.msm.cam.ac.uk/map/data/data-index.html#weldprop

Babu, S. (2000) *Modeling of Weld Microstructure Development*, Retrieved June 7, 2000 from Modeling of Weld Microstructure Development Web site: http://engm01.ms.ornl.gov/index.html

Cerjak, H. & Bhadeshia, H. K. D. H., (Eds.), (2002) *Mathematical of Weld Phenomena 6*, London, UK: Maney Publishing

Fujita, M., Kurihara, Y., Shindo, M., Yokoyama, N., Tachi, Y., & Iwata, S., (1997) A Distributed Database System for Mutual Usage of Material Information (Data-Free-Way). In Nishijima S, & Iwata S., (Eds.), *Computerization and Networking of Materials Databases*: *ASTM STP1311* (Vol. 5, pp. 249-260) West Conshohocken, PA: ASTM.

Fujita, M., (1997) *Welding Database.* Retrived Oct 7, 1997 from the Data-free-way for Nuclear Materials Web site: http://inaba.nims.go.jp/Weld/

Kasugai, T. & Fujita, M., (Eds.) (1999), *Atlas of CCT Diagram for Welding (I)*, NRIM-special report No. 99-02, Tsukuba, JP, National Research Institute for Metals. Retrieved Oct. 10, 1997 from CCT Diagram Database Web site: http://inaba.nims.go.jp/Weld/cct/

Ohotani, S. (1999) *Consultation of Welding*, Retrieved June 7, 1999 from the Research Information Database (RIO-DB) Web site: http://www.aist.go.jp/RIODB/manufacturing/weld.html

Okada, A., Kasugai, T., & Hiraoka, K., (1988) Heat-Source Model in Arc Welding and Evaluation of Weld Heat-Affected Zone, *Trans. ISIJ*, *28*, 876-882.

Research Center of Computational Mechanics, Inc (n.d.) Quick-Welder. Retrieved Oct 7, 2000 from the *Research Center of Computational Mechanics, Inc.* Web site (in Japanese): http://www.rccm.co.jp/seihin/quickwelder/index.html

ESI Group (n.d.) SYSWELD. Retrieved June 7, 1999 from the *ESI Group* Web site: http://www.esi-group.com/Products/Welding/

Rosenthal, D. (1941) Mathematical Theory of Heat Distribution During Welding and Cutting, *Welding Journal*, *22*, 220s-234s.

Yurioka, N. (2001), *Welding Calculation* Retrieved September 8, 2001 from Nippon Steel Co. of Welding Calculation Web site: http://member.nifty.ne.jp/yurioka/