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AN INFORMATION MODEL BASED WELD SCHEDULE DATABASE¹

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ABSTRACT

As part of a computerized system (SmartWeld) (Ref. 1) developed at Sandia National Laboratories to facilitate agile manufacturing of welded assemblies, a weld schedule database (WSDB) was also developed. SmartWeld's overall goals are to shorten the design-to-product time frame and to promote right-the-first-time weldment design and manufacture by providing welding process selection guidance to component designers. The associated WSDB evolved into a substantial subproject by itself. At first, it was thought that the database would store perhaps 50 parameters about a weld schedule. This was a woeful underestimate: the current WSDB has over 500 parameters defined in 73 tables. This includes data about the weld, the piece parts involved, the piece part geometry, and great detail about the schedule and intervals involved in performing the weld.

This complex database was built using information modeling techniques. Information modeling is a process that creates a model of objects and their roles (i.e. data & relations) for a given domain (i.e. welding). The Natural-Language Information Analysis Methodology (NIAM) (Ref. 2) technique was used, which is characterized by: 1) elementary facts being stated in natural language by the welding expert, 2) determinism (the resulting model is provably repeatable, i.e. it gives the same answer every time), and 3) extensibility (the model can be added to without changing existing structure). The information model produced a highly normalized relational schema that was translated to Oracle™ Relational Database Management Systems for implementation.

INTRODUCTION

This database system has two primary purposes. The first purpose is to provide a compatible database for the SmartWeld Advisor (Ref. 3) to search for plausible weld schedules. The second purpose is to provide a mechanism for storage and recovery of historical information about weld schedules used in the Department of Energy complex. Previously, such weld schedules were recorded on paper and stored in file cabinets or engineering notebooks. Developmental schedules in particular were notoriously difficult to retrieve. Both production and developmental weld schedules are intended to be recorded.

MASTER

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The WSDB can be accessed directly, for entering data or browsing by welding engineers, or in an intelligent, automated fashion through the knowledge-based SmartWeld Advisor. The WSDB is designed to store weld schedules for a number of welding processes including: 1) arc (GTAW, PAW, GMAW), 2) electron beam (both high and low voltage), 3) laser (cw CO₂ and pulsed Nd:YAG), 4) friction (continuous drive and inertia), 5) upset and pinch solid state resistance welds, and 5) spot and seam fusion resistance welds.

The WSDB provides a user-friendly, systematic, and comprehensive interface for weld schedule data storage and retrieval. The graphical user interface consists of hierarchical layers of screens. These begin at the part description level, and then follow a natural progression in developing the information storage. For example, after the part has been identified, the weld process is identified, followed by characteristics of the weld itself (and the weld preparation), followed in turn by the process parameters needed to achieve it (power, travel speed, equipment, etc.). Other types of information are also included at logical points, such as required heat treatments, pre-weld cleaning, post-weld inspection, and specifications. Finally, catch-all comment fields are provided at every level to capture any information which is not explicitly noted.

In this paper, we will: 1) show the hierarchy of screens which are encountered for a typical database entry, 2) describe the logical structure of the database, 3) describe the many types of search procedures which may be conducted and 4) discuss how the database fits into the overall SmartWeld system.

AN OVERVIEW OF THE WSDB

After the user starts the weld schedule database tool (if not started from within SmartWeld), a login dialog window appears to authenticate the user. After completing this preliminary step, the first screen appears, giving the user the option to enter data for a weld schedule. There are five initial sections where the user can enter data, as depicted by the five buttons along the top of the screen in Figure 1.

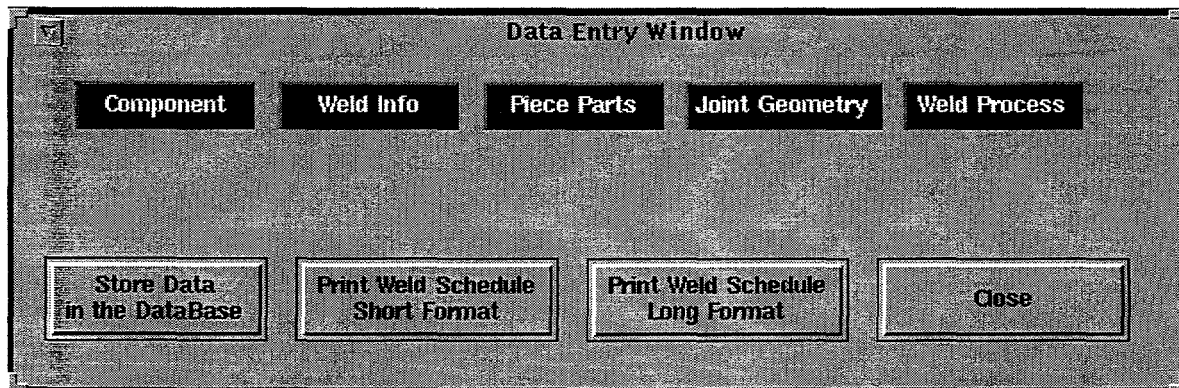


Figure 1. Initial data entry screen.

The buttons along the bottom store the data to the ORACLE database, print the weld schedule in short or long format (see details below), or close the application.

By clicking on the "Component" button, entry fields appear for information about the component being welded as well as information about the subassembly it is contained in (Figure 2.)

Data Entry Window

Component **Weld Info** **Piece Parts** **Joint Geometry** **Weld Process**

Top Level Assembly:

Name: GTS1

Drawing NBR:

Top Level Assembly Comment:

Existing TLA's

Battery
Development
GTS 2
GTS1
Sram

Delete TLA

Component Level Assembly:

Name: GTS1

Assembly NBR (MC):

Drawing NBR:

Family: Gas Transfer System

Component Comment:

Existing Components

Battery
CAP1 CAP2
D
GTS1
HF

Delete Component

Store Data in the DataBase Print Weld Schedule Short Format Print Weld Schedule Long Format Close

Figure 2. Database entry screen for component and subassembly information.

To enter or obtain information about the weld, one clicks on the “Weld Info” button and the screen in Figure 3 appears.

Data Entry Window

Component **Weld Info** **Piece Parts** **Joint Geometry** **Weld Process**

Weld Name	Cap1 Assy	Primary Weld Function	Structural
Weld Filename	GTS-1 Root-fl	Secondary Weld Function	Attachment
Equipment Location	SNLCA	Joint Location	Girth
Equipment NBR		Number of Passes	4
Production Rate Per Day	4.0	Data Source	HICKEN
Weld Penetration	7.96999 mm	Weld Length	169.018 mm
Status	Established	Weld Width	mm
Weld Comment			

Store Data in the DataBase **Print Weld Schedule Short Format** **Print Weld Schedule Long Format** **Close**

Figure 3. Weld Information.

For piece part information, one clicks on “Piece Parts” and obtains the screen illustrated in Figure 4.

Data Entry Window

Component
Weld Info
Piece Parts
Joint Geometry
Weld Process

Side 1

Piece Part Name

Material Model

Drawing NBR

Comment

Side 2

Piece Part Name

Material Model

Drawing NBR

Comment

Select Geometry

Extended Hemisphere

Cylindrical Length	<input type="text" value="1.54446"/>	<input type="text" value="mm"/>
Inner Diameter	<input type="text" value="54.3083"/>	<input type="text" value="mm"/>
Outer Diameter	<input type="text" value="70.399"/>	<input type="text" value="mm"/>

Extended Hemisphere

Cylindrical Length	<input type="text" value="1.54446"/>	<input type="text" value="mm"/>
Inner Diameter	<input type="text" value="54.3083"/>	<input type="text" value="mm"/>
Outer Diameter	<input type="text" value="70.399"/>	<input type="text" value="mm"/>

Store Data
in the DataBase

Print Weld Schedule
Short Format

Print Weld Schedule
Long Format

Close

Figure 4. Piece part information.

Note that information for both piece parts is entered as well as material chemistry information (by clicking on the "Material Model" button.) Figure 5 shows the joint geometry screen. In this case it is a U-groove butt weld with reinforced shoulders.

Data Entry Window

Component Weld Info Piece Parts **Joint Geometry** Weld Process

U GrooveButtWithReinforcedShoulders

Geometry Type ...

Shoulder	
Shoulder Height	3.23023 mm
Shoulder Width	3.53306 mm

UGroove	
Land Thickness	1.2921 mm
Radius	1.2921 mm
Angle	15.0 deg
Land Width	1.2921 mm

Store Data
in the DataBase

Print Weld Schedule
Short Format

Print Weld Schedule
Long Format

Close

Figure 5. Joint geometry information.

Finally, by clicking on "Weld Process", the hierarchy of weld processes is presented and the user is led through a series of screens particular to the process chosen. For GTAW, the series starts with the most general Fusion information (Figures 6, 7), then Arc specific information (Figure 8), followed by Non-consumable electrode information until we end with the most specific information pertaining only to GTA welds. Fusion information includes data about the weld fusion zone, such as its top and bottom surface contours, size and shape, associated shrinkage and distortion, cleaning and inspection data, temperature (thermocouple data), filler

(Figure 7), travel speed, and heatsink information. The Arc data includes voltage and current information (Figure 8) and the Non-consumable screen includes data about the electrode and torch. Current, voltage, filler, and speed are entered as interval data, that is, for a given interval number beginning at time t_1 and ending at time t_2 , the current went from Amps₁ to Amps₂.

Weld Process Window

Top Surface Height MIN <input type="text"/> mm	Under Bead Height MIN <input type="text"/> mm
Top Surface Height MAX <input type="text"/> mm	Under Bead Height MAX <input type="text"/> mm
Top Surface Contour Rating <input type="text"/> ▼	Under Bead Contour Rating <input type="text"/> ▼
Top Surface Contour <input type="text"/> ▼	Under Bead Contour <input type="text"/> ▼
Weld Shrinkage <input type="text"/> mm	Joint Position Flat <input type="text"/> ▼
Melting Efficiency <input type="text"/> %	Spec Penetration MIN <input type="text"/> mm
Distortion <input type="text"/> ▼	Spec Penetration MAX <input type="text"/> mm
Process Efficiency <input type="text"/> %	Cross Sectional Area <input type="text"/> sq mm
Cleaning Spec NBR <input type="text"/>	

Fusion Comment

	Time Beg sec	Time End sec	Speed Beg rpm	Speed End rpm	Speed History Filename
1	0.0	3.0	0.0	0.0	
2	3.0	109.6	0.43	0.43	

Comment

Figure 6. Fusion zone information screen showing general fusion information and the Speed interval values.

Speed ... Temperature ... Filler ... HeatSink ...

	Time Beg sec	Time End sec	Rate Beg mmps	Rate End mmps
1	0.0	3.0	0.0	0.0
2	3.0	105.5	17.0933	17.0933
3	105.5	105.5	17.0933	0.0

Feed Rate: Pulsed:

History Filename:

Wire Spec: Wire Size: mm Wire Alloy:

Existing Wires:

Add One Row Delete Wire

Figure 7. Filler interval information including wire specifications.

Weld Process Window

Weld Process Fusion Arc NonConsumable Electrode GTAW

Polarity: Pre Purge Time: sec

Stickout: mm Post Purge Time: sec

Shielding Gas: Arc Gap History Filename:

Shielding Gas Flow Rate: scfh

Arc Comment:

Currents ... Volts ... Deflections...

Current History Filename: Current Type:

Comment:

	Time Beg cycles	Time End sec	Peak Current Beg A	Peak Current End A	Backgr. Current Beg A	Backgr. Current End A	Current Form	Peak Time min	Backgr. Time sec	Freq. cps
1	0.0	3.0	75.0	175.0						
2	180.0	26.6	175.0	175.0	96.0	96.0	Square	0.75	0.25	1.0
3	1596.0	29.1	175.0	150.0	96.0	82.5	Square	0.75	0.25	1.0
4	1746.0	43.4	150.0	140.0						
5	2604.0	54.9	140.0	140.0						
6	3294.0	105.8	120.0	120.0						
7	6348.0	109.0	100.0	30.0						

Done

Figure 8. Arc information including Current interval information.

Due to the logical structure followed, by the time the user reaches the last screen (in this case labeled GTAW) all the salient information needed has already been filled in; thus, only a comment field is included (not shown for reasons of brevity).

When all the information available is typed in, the user simply clicks the insert button on the first screen to insert the weld schedule into the database. The WSDB does not expect all slots to be filled.

DATABASE UTILITIES

Search

Anyone with access can search the database since this function only requires read access to the data. The user is presented with a search criteria screen where material, a thickness range, welding process, joint geometry, data source, and weld process expert can be specified as shown in Figure 9. Once this is done a search is performed and the resulting abbreviated weld schedule are presented in a table. The user can now select a particular schedule from the table of search results to examine in more detail.

Search Window

Select Joint Geometry: From (mm) To (mm)

Select Weld Process: Enter Thickness Interval:

Select Part Type: Clear

Select Location: SNLCA Select Assembly:

Select Weld Process Expert: Do Search

Select Material: 304L

	Assembly Name	Component Name	Weld Name	Part Type	Weld Process	Joint Geom
1	Development	Small Acorn	Acorn	Gas Transfer System	GTAW	U_GrooveButtWithReir
2	Development	Large Acorn	Acorn	Gas Transfer System	GTAW	U_GrooveButtWithReir
3	W87	W87BL	AFTCAP	Gas Transfer System	Upset	SquareButtJoint
4	GTS1	GTS1	Cap1 Assy	Gas Transfer System	GTAW	U_GrooveButtWithReir
5	GTS 2	CAP1 CAP2	CAP ASSY	Gas Transfer System	GTAW	U_GrooveButtWithReir
7	Sram	HF	2	Gas Transfer System	HighVoltageEB	SquareButtWithAlignm
8	Sram	HF	3 Final	Gas Transfer System	HighVoltageEB	SquareButtWithAlignm
9	Sram	D	1	Gas Transfer System	HighVoltageEB	SquareButtWithAlignm
10	Sram	D	6 Final	Gas Transfer System	HighVoltageEB	SquareButtWithAlignm
11						

Show Detailed Weld Schedule Show Copy of Schedule Delete Selected Record Close

Figure 9. The results of a search for welds done at SNLCA using 304L stainless steel.

Update

Requiring more extensive access privileges, this feature works much the same as search, except that once the user is examining a weld schedule in detail, an update or change of the data is allowed. Also, the user can make a copy of a weld schedule. This is useful if one weld schedule is very similar to another with only a few modifications. Instead of entering a hundred parameters that are almost the same as an existing weld schedule entry, the user just copies the existing schedule under a new name, and then changes the few values that are different.

Printing

On the top level data entry screen, the user can select a weld schedule for printing. Two choices are given: 1) Print the schedule in short format, which only prints the parameters that have values, 2) Print in long format, which prints all parameters whether or not data exists. The blank fields are helpful to manually record information for subsequent data updates. Once the printing is invoked, a dialog screen will appear asking the user which printer to use. The schedule is printed in landscape format and usually takes three or four pages.

STRUCTURE OF DATABASE

The database was designed using the NIAM methodology which uses atomic facts, i.e. data and relations, about the domain to produce an information model. This model was developed using Asymetrix's InfoModeler™ on a personal computer. The model maps directly to a relational schema that was implemented in the ORACLE relational database management system. The four types of relationships between data objects used in NIAM are shown below in Figure 10.



Figure 10. The fundamental relationships in information modelling.

An overview of the information structure using these relations is shown in Figure 11. The weld itself is the heart of the structure and a unique internal identifier gets assigned to the weld by the system (WeldID). A component can have one or more welds (one-to-many) but each weld is uniquely identified. This overview diagram also shows that a weld can be performed by one or more welding processes (one-to-many). That is, a root pass can be done with an arc process and the remaining passes with a low voltage electron beam. The weld has a one-to-one relationship with its PieceParts, i.e. a weld has one set of PieceParts and a set of PieceParts belongs to a single weld (likewise with its JointGeometry). The other relationships are one-to-many; for example, the equipment number (EquipmentNBR) that identifies a piece a equipment can be used for many welds.

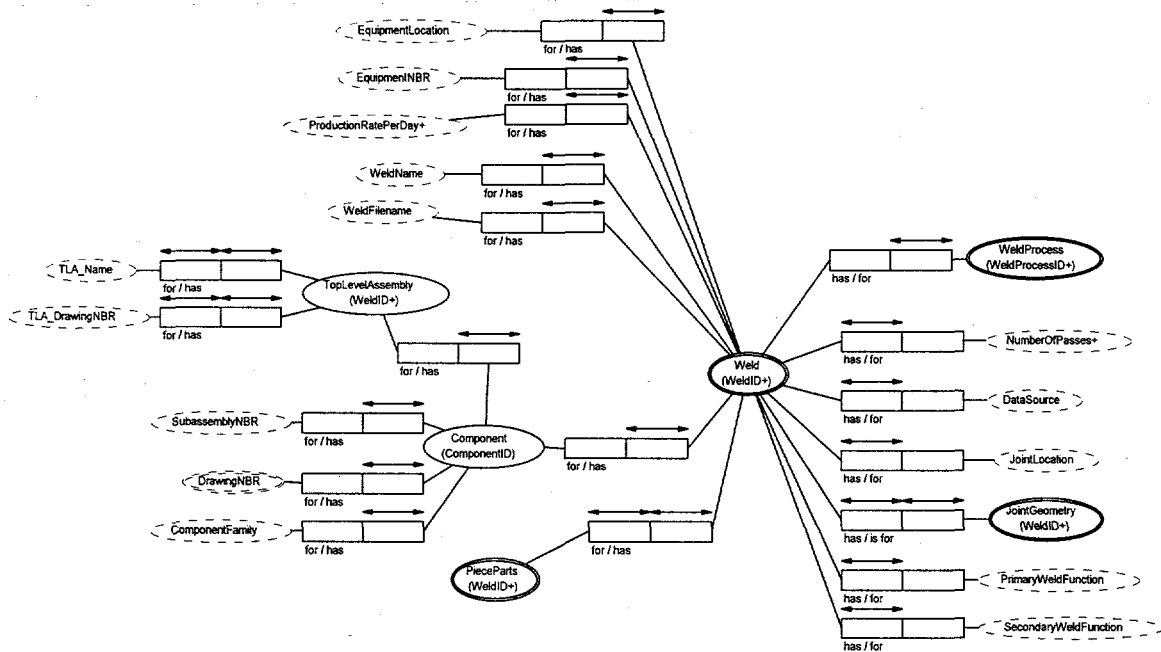


Figure 11. Overview of the information model for weld schedules.

The Welding Process object shown in the top right hand corner of Figure 11, with a double oval, shows that another entire information structure for welding processes exist. Each welding process has a set of parameters that are common to all welds regardless of process and a set of data specific to that welding process. A hierarchical information structure of the welding processes is shown in Figure 12. Items near the top are more general and represent information for all the welding process below them. The information increases in detail and specificity as you traverse the tree depthwise. The dashed ovals represent actual data for the weld schedule and for this information amounts to more than 500 elements that span 50 pages of the information modeling diagrams.

This information model maps directly to a highly normalized relational schema (the information cannot be expressed in fewer tables without loss of information or introduction of redundant data). Once you have the information modeled, the implementation to a relational database is

trivial and actually amounts to selecting the type of database management system (Oracle, Ingres, Sybase, Informix, etc) and pushing a button in the information modeling tool. The code that gets generated is called SQL (a database definition and query language) and it captures the data and relations defined in the model and ultimately is used to create the database to store the information.

The rest of the implementation is done using a database product and a third party tool for the Graphical User Interface (GUI) implementation. For the weld schedule database, we used Oracle's version of SQL to implement the data and relations and Kappa, an object-oriented toolkit, to implement the graphical user interface for data entry, browsing, and update. For a database of this magnitude, the GUI development turned out to be a sizable project. There are commercial tools that make this implementation easier than using Kappa, but we chose Kappa because the underlying object representation that is used for the GUI can also be used for manipulating the weld schedule information in the Advisor, which is also written in Kappa.

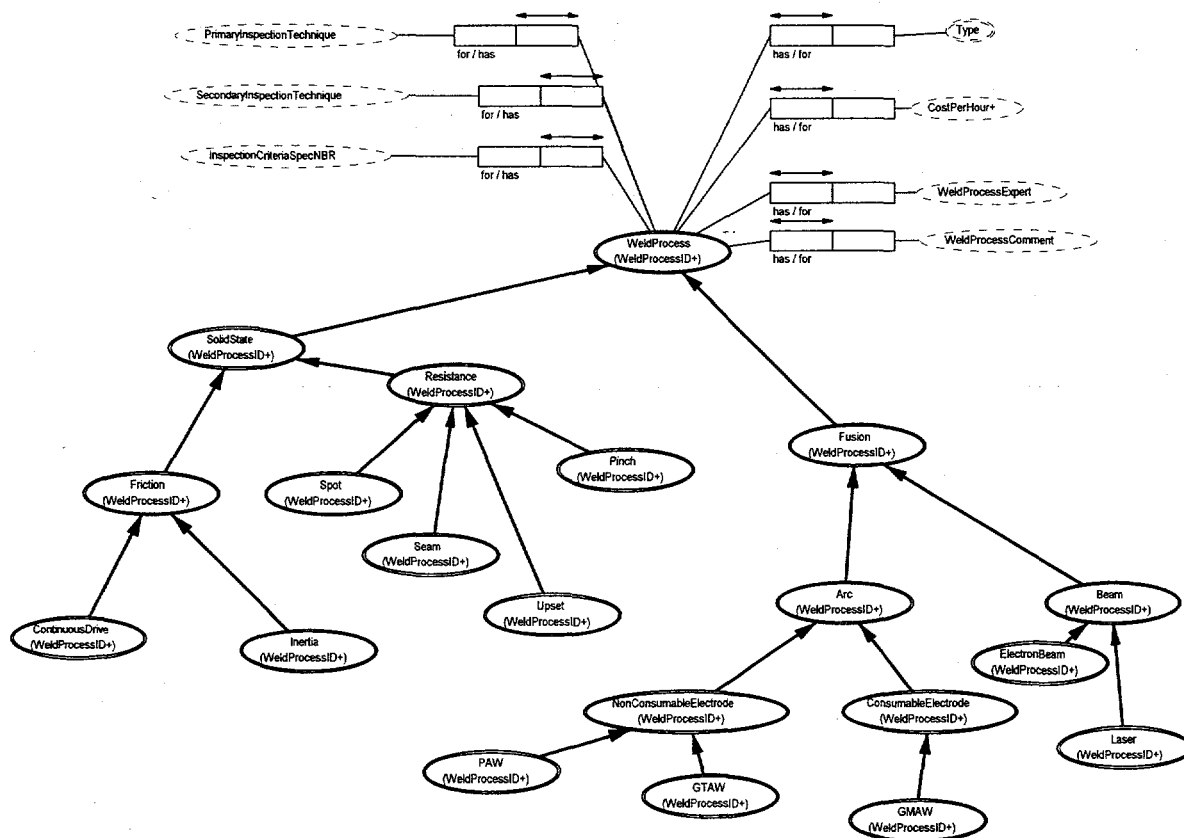


Figure 12. A hierarchical representation of welding processes.

The mapping from relational tables to Kappa objects is an automated procedure provided by Kappa. The tool is called DataAccess and maps any subset of a relational table to an object. The advantage of using objects is that now the data from the database is in objects and we can attach methods directly to each object to perform operations on the data. For data manipulation this

becomes very attractive when using a relational database management system. Typically this is done with a programming language specific to the database provider which can be cumbersome.

INTEGRATION WITH SMARTWELD

SmartWeld, developed at Sandia National Laboratories, is a concurrent engineering system that integrates product design and processing decisions within an electronic desktop environment (Ref. 1). The WSDB can be accessed for search, browse, and update directly by selecting the "Weld Schedule DB" button from the toolbar at the bottom of the main SmartWeld screen, Figure 13. The WSDB is also seamlessly integrated into the information flow of the guided SmartWeld environment (the center buttons in Figure 13.) After defining the part to be welded (materials and dimensions) and selecting a weld process and joint geometry as suggested by the Weld Advisor, the next step is to determine a weld schedule. This can be done in SmartWeld by either running an optimization code, SOAR (Ref. 4), to derive the weld schedule parameters or by accessing the WSDB and searching for any similar weld configurations. In either case (SOAR or the WSDB), the pertinent information required to determine the schedule (material, penetration depth, weld process, joint geometry, etc) is passed by SmartWeld.

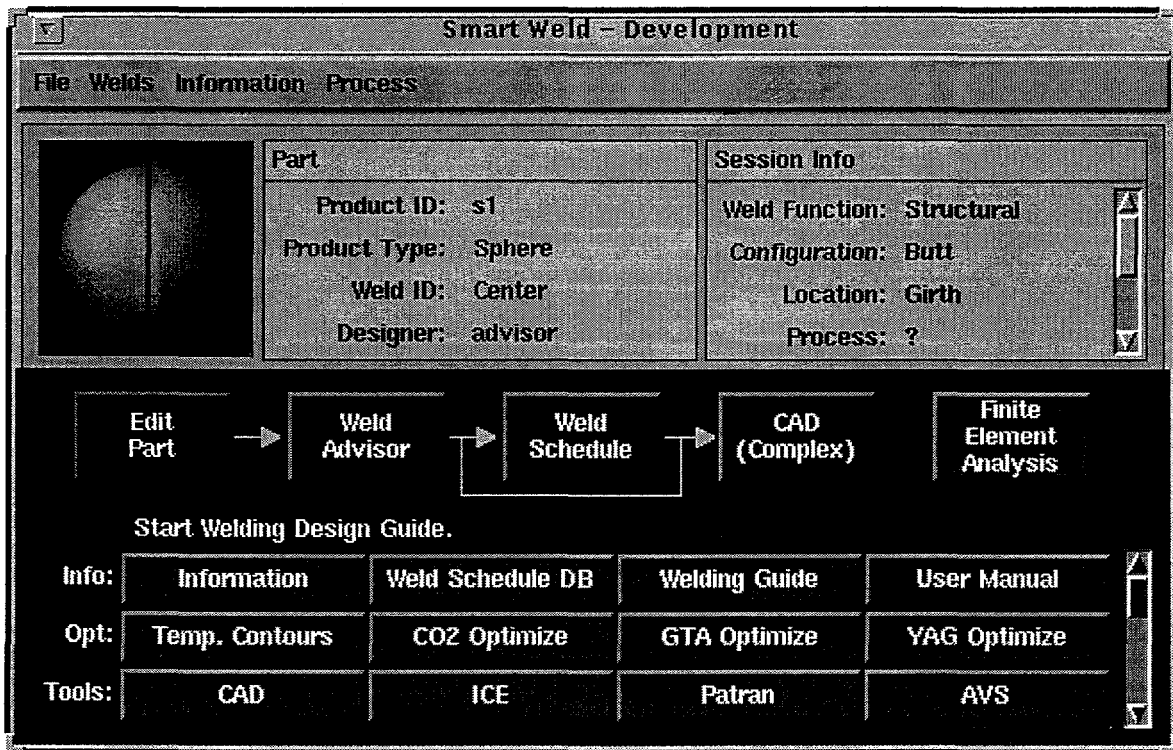


Figure 13. Top level SmartWeld screen.

Since SmartWeld and the WSDB are both written in Kappa, the same software is reused for searching the database and manipulating the data. Once a weld schedule is selected from the advisor, the data is extracted from either source and mapped into an object representation for use

downstream in the analysis codes that require the details of the weld schedule intervals including the settings of power, speed, voltage, current, and filler wire parameters to model the welding heat source.

SUMMARY

The WSDB described herein is complete and deployed for use at several DOE sites for manual weld schedule data entry and search. It is anticipated that historical weld schedules will be inserted into the WSDB on a gradual basis and current and newly developed schedules will be input regularly. Future work includes enabling intelligent welding machine controllers to transfer a major percentage of the weld schedule information to the WSDB with minimal human intervention. Likewise, once SmartWeld and the user concur on a schedule, it will be downloaded from the database to the machine controller.

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